STUDY OF HIGH WATER TEMPERATURE EFFECTS ON AIR STRIPPING OF VOLATILE AND SLIGHTLY-VOLATILE ORGANICS FROM WATER

By

PAYOUNGSAK KITTIKUL

Bachelor of Science
Kasetsart University
Bangkok, Thailand
1975

Bachelor of Science in Engineering Technology
Oklahoma State University
Stillwater, Oklahoma
1979

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1981

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1987

STUDY OF HIGH WATER TEMPERATURE EFFECTS ON AIR STRIPPING OF VOLATILE AND SLIGHTLY-VOLATILE ORGANICS FROM WATER

Thesis Approval

John M. Veenstra
Thesis Adviser

William F. McTernan

Marvin Bates

D. L. Burks

Ena L. Glover

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. J. Veenstra, the author's thesis adviser, for his guidance and encouragement throughout the course of his study.

The author wishes to express his sincere gratitude to Drs. M. Bates, W.F. McTernan, E.L. Stover, and S.L. Burks, committee members, for their careful reading of this manuscript and giving the author honor of serving as committee members.

The author wishes to acknowledge the help of his wife and Mrs. L. Jones. Also, a special thanks to Ms. Sherl Holesko for carefully and accurately typing this thesis, and for offering help whenever needed.

Last, but not least, the author wishes to thank his parents for their financial support which made it possible for the author to further his education.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

LIST OF SYMBOLS

C_g = gas phase solute concentration (mole/m^3)

C_g^* = equilibrium concentration of the gas phase with the bulk gas concentration (mole/m^3)

C_l = solute concentration in the liquid phase (mole/m^3)

C_l^* = equilibrium concentration of the gas phase with the bulk liquid concentration (mole/m^3)

D_{AB} = diffusivity of solute A and solvent B (m^2/mole)

D_g = diffusivity of a solute in the gas phase (m^2/sec)

D_l = diffusivity of a solute in the liquid phase (m^2/sec)

D_w = diffusivity of a solute in water (m^2/sec)

E = fractional void volume in a dry packed bed dimensionless unit

F = diffusivity factor (°K sec^2/kg m)

F_r = Froude number dimensionless unit

G = gas flow rate (m^3/m^2-hr)

G_m = gas loading rate (kg/m^2·sec)

H = Henry's constant for the solute (m^3·atm/mole)

H_c = dimensionless Henry's constant

HTU = height of transfer unit (m)

J = molecular mass transfer flux of the solute (mole/m^2·sec)

K_g = overall mass transfer coefficient based on liquid phase concentration units (m/sec)

K_l = liquid flow rate (m^3/sec)

L = liquid flow rate (m^3/m^2-hr)

L_m = liquid mass loading rate (kg/m^2-sec)

M.W = molecular weight of substance (gm/mole)

M_1 = molecular weight of solute (gm/mole)

M_2 = molecular weight of solvent gas (gm/mole)

NTU = number of transfer unit

P = partial pressure of solute in gas phase (atm)

Q_g = volumetric gas flow rate (m^3/min)

Q_l = volumetric liquid flow rate (m^3/min)

R = universal gas constant = 8.2056×10^{-5} (m^3·atm/mole °K)
= 1.987 (k cal/k mole)

R_e = Reynold number dimensionless unit

R_g = gas phase resistance to mass transfer (sec or hr)

R_l = liquid phase resistance to mass transfer (sec or hr)

T = temperature (°K or °C)

T_g = temperature at which the volumetric gas flow (°K)

V = volume (m^3 or l)

V_a = molar volume of the solvent at its normal boiling point (cm^3/mole or m^3/mole)

V_b = molar volume of the solute at its normal boiling point (cm^3/mole or m^3/mole)

V_i = reactor liquid volume during the ith time interval (m^3)

Y = association factor for the solvent in the Wilke-Chang diffusivity correlation dimensionless unit

Z = total packed height of tower (m)

a = interfacial area per unit bulk volume of packing (m^2/m^3)

a_t = total dry packing area per unit bulk volume of packing (m^2/m^3)

a_w = wetted interfacial area per unit bed volume (m^2/m^3)

d_p = nominal diameter of a unit packing (m)

g = accerlation due to gravity = 9.81 (m/sec^2)

k = mass tranfer coefficient individual phase (m/sec)

k_g = gas phase mass transfer coefficient (m/sec)

k_l = liquid phase mass transfer coefficient (m/sec)

n = empirical constant for a particular packing dimensionless

r = the radius of spherical solute (°A)

t = time (hr, min or sec)

x_g = gas phase boundary layer thickness (m)

x_l = liquid phase boundary layer thickness (m)

ΔH = the standard entholpy of reaction for the dissolution of the component in water (k cal/k mole)

Δt_i = duration of the ith interval (min)

α = empirical constant specific to a particular packing dimensionless

μ_g = gas viscosity (kg/m.sec)

μ_l = liquid viscosity (kg/m.sec)

μ_w = viscosity of water (kg/m.sec)

ρ_g = gas density (kg/m^3)

ρ_l = liquid density (kg/m^3)

σ = surface tension of liquid (kg/sec^2)

σ_c = critical surface tension with respect to packing (kg/sec^2)

σ_{12} = Lennard-Jones characteristics collision diameter with respect to components 1 and 2 (°A)

$\Omega_{D,12}$ = collision integral dimensionless unit

CHAPTER I

INTRODUCTION

Significant pollution problems of drinking water supplies, primarily groundwater, have been of serious concern recently in the United States and throughout the world. More than 40% of the U.S. population depends on groundwater as the source of their drinking water supply (1). It is currently estimated that approximately 1% of the nation's groundwater is already contaminated (2). Dozens of wells serving several thousand people in California, Wisconsin, New York, Pennsylvania, Florida, New Jersey, Massachusetts, New Hampshire, and Connecticut have been found to be contaminated with organic compounds (3, 4, 5, 6, 7, 8, 9, 10). These compounds are not naturally occurring but are the result of accidental leaks and spills, improper disposal of hazardous and non-hazardous solid and liquid waste, septic systems, agriculture, and underground injection.

In general, there are five methods available for treating contaminated groundwater. Among the possible treatment alternatives are (11):

1. Reverse osmosis
2. Coagulation and clarification
3. Synthetic resin absorbents
4. Activated carbon adsorption
5. Air stripping

The first three are effective in treating particular organic compounds. Activated carbon adsorption has been found to be successful in removing a complex of organic compounds. However, most of the contaminants in groundwater fall into a group of liquids considered to be volatile organic compounds (VOCs). Because of their high volatility, air stripping can be used to partially or totally remove most of these organic compounds (11, 12, 13).

Stripping or desorption, as defined, by Treybal (14), is a "mass transfer operation due to direct contact of two immiscible phases." This mass transfer is a result of concentration differences between gas and liquid phases. Aeration, or air stripping in the case of removing volatile organic compounds from water, can be represented as the transfer of volatile organic compounds from the water phase into the gas phase owing to intimate contact of water and air (11). There are several means of promoting air-water contact to enhance mass transfer of volatile organic compounds. Some examples are diffused aeration, mechanical surface aeration, spray tower aeration, and countercurrent packed tower. Previous studies have shown that countercurrent contacting in a packed tower is one of the most efficient in achieving mass transfer of volatile organic compounds; this is accomplished with less expenditure for energy than diffused aeration and mechanical surface aeration (15, 16, 17, 18, 19, 20). However, spray tower aeration, which has been shown to be an effective method for removing volatile organic compounds, are likely to have higher energy costs than a countercurrent packed tower (15, 20, 21).

A countercurrent packed tower provides a continuous intimate contact of water and air. The tower is a vertical column that has been filled

with packing material or devices possessing a large surface area (raching ring, bearl saddle, intalox/metal, intalox saddle/ceramic, tellerette, and pall ring) so that the water distributed over the top of the packing trickles down the packing bed, displaying a large surface area to contact the air that is forced upward (11).

Currently, air stripping is used to remove the highly volatile contaminants such as toluene, trichloroethylene, ethylbenzene, and tetrachloroethylene. Pakanati (11), at Oklahoma State University, found that the water temperature had a greater effect on removing a slightly-volatile organic compound (nitrobenzene) than the air temperature. Gosset (12) stated that future studies of stripping technology should involve groundwater containing both volatile and slightly-volatile organic compounds.

The purpose of this study was to determine the effects of water temperature on air stripping of volatile and slightly-volatile organic compounds from water. Fifteen different volatile and slightly-volatile organic compounds all classified as priority pollutants by the United States Environmental Protection Agency (USEPA) were used in this study. The objectives of this research were as follows:

1. Evaluate the removal of organic substances by air stripping at the variable experimental conditions of gas-to-liquid ratio, packing depth, water temperature, and air temperature.

2. Measure the Henry's Law constant of substances by using batch air stripping at water temperatures of 10, 25, 35, and 55°C.

3. Compare the Henry's Law constants measured in this study with the values obtained using Goldstein's predictive equations, solubility

and vapor pressure data as well as with values available in the literature.

4. Estimate the overall mass transfer coefficient for the substances at the experimental variables of gas-to-liquid ratios, packing depth, water temperature, and air temperature.

5. Compare the estimated overall mass transfer coefficient for the substances used in this study to various empirical equations and the reference compound method.

Application of Research

High water temperature air stripping removes not only the volatile organic compounds but also some of the slightly-volatile organic compounds, which to date are removed only by more expensive treatment techniques such as activated carbon absorption. The application of this treatment technology to the field of groundwater contamination is relatively new and needs more work to evaluate its ability to remove organic compounds that are not removed by normal stripping. This technology offers the potential for a reasonable cost treatment method that can remove both volatile and slightly-volatile organic compounds from contaminated water. This same unit process could be used rather than resorting to the use of multiple treatment processes (i.e., air stripping followed by activated carbon adsorption).

CHAPTER II

LITERATURE REVIEW

Once an aquifer has become contaminated there are two basic methods that can be used for restoration of an aquifer -- in-situ treatment or withdrawal and treatment by physical and biological techniques. A review of the current in-situ treatment technologies has been done by Knox et al. (22). These authors also state that enhancement of the native microbial population and withdrawal and treatment are the most effective methods of aquifer restoration. The enhancement technique has been mainly used to reclaim aquifers contaminated by gasoline, but it has also been fairly effective in treating organic solvents that have contaminated a groundwater. The disadvantage of this method is that the alternative source of oxygen, i.e., ozone or hydrogen peroxide, can be toxic and are largely yet unproven.

Technologies available to separate organic compounds from water that has been removed from an aquifer are listed in Table I (23). Many times a physical unit such as air stripping is coupled with a biological unit to treat a contaminated groundwater that has been pumped to the surface.

One of the oldest processes of purifying water is air stripping. Although its use to remove specific organic contaminants is relatively new, air stripping has been effectively employed to remove carbon dioxide, ammonia, hydrogen sulfide, and other taste and odor causing

TABLE I

COMMON PROCESSES FOR THE SEPARATION OF ORGANICS FROM WATER (23)

Process	Required Characteristic of Organic	Recovery of Organics Achieved	Primary Cost Dependence*
Biochemical Aerobic Anaerobic	Biodegradable	No. Organics are destroyed	Concentration of organics
Solvent extraction	More soluble in solvent than in water	Yes, by fractionating the solvent	Water throughput
Membrane Ultra-filtration, Reverse Osmosis	High molecular weight (ionizable)	Concentrated aqueous stream recovered	Water throughput
Adsorption Carbon, Resin	Absorbs on selected adsorbent	Not with carbon; possible with resins	Concentration of organics
Stripping	Volatile	Not usually with air; possible with steam stripping	Water throughput

*In addition to removal efficiency.

compounds from drinking water. Air stripping is recognized as an effective and inexpensive treatment method to purify water. Hazen (24) stated, "...the simplest, cheapest, and most generally applicable method of removing tastes and odors is by aeration."

The USEPA in the past had considered regulations for the control of organic chemicals in drinking water (25, 26, 27). Recently the USEPA established recommended maximum contaminant levels for eight VOCs (28). At the same time, the USEPA proposed recommended maximum contaminant levels for eight additional synthetic organic chemicals (28). This had led over the past decade to widespread research on the removal of organic compounds from water. Therefore, additional applications of aeration have been developed. It has been established that air stripping has the potential to treat groundwater as well as wastewater when volatile organic contaminants are present.

Weinstein (29), discussing the ability of air stripping to treat groundwater contaminated with halogeneted organic solvents, pointed out that it is a potential method for decontamination of aquifers. He also suggested that air stripping can be applied to other wastewaters with similar contaminants, either alone or in combination with some other process.

Engelbrech et al. (30) confirmed the importance of air stripping as a simultaneous removal method in the activated sludge process for petrochemical waste treatment. In cases where the waste consists primarily of volatile compounds, air stripping might totally suffice as a treatment method.

The ability of air stripping to remove trace organic contaminants is no longer subject to question. McCarty (31), evaluating the full-

scale stripping tower at Water Factory 21, a facility operated by the Orange County water district in southern California, concluded that an 80% removal could be achieved for more than a third of the organic compounds on EPA's list of priority pollutants. However, it should be noted that only when contaminants are highly volatile is air stripping an effective process.

When contaminants other than the volatile compounds are present air stripping should be used in combination with other treatment methods (32). McKinnon (32) reported a 30 to 50% reduction in the operating cost of a 2 million gallon per day water treatment plant by installing a 9 foot diameter, 25 foot height packed air stripping tower ahead of the granular activated carbon contactors, at Rockaway Township, New Jersey.

The design of packed towers for stripping volatile organic compounds from water depends on the type of contaminant, the desired removal, and the air and/or water temperature. Gaudy et al. (33) studied the factors affecting the stripping of the organic compounds. Batch-stripping experiments using diffused aeration were employed to study the effect of temperature, air flow rate, and tank dimensions. They concluded that temperature has a significant effect on the mass transfer coefficient, K_1a. The tank dimensions also had an effect on stripping. An increase in the cross section to volume ratio increased the stripping, suggesting a large influence of surface are accessibility on mass transfer. Air flow rates also had similar effects.

Dyksen (34) presented data from a pilot scale packed tower that was 1 foot in diameter and 12 feet tall. Results of air stripping tests, conducted at several locations in the northeast, showed a strong influence of Henry's law constant (H) and the gas/liquid ratios on the

removal efficiency. Experiments conducted at various water temperatures, ranging from 4°C to 24°C, showed a need for an increase in packing depth at lower temperatures to obtain equal removal efficiency. To illustrate the effect of air temperature, a heat balance between air and water for a gas/liquid of 20:1 was evaluated. Since the water temperature changed by less than 1°C, Dyksen concluded that the temperature of the air has little or not effect on the removal efficiency. However, it should be noted that the temperature of the air could show a significant effect when the gas/liquid ratios are high (200:1 or more), the difference in the temperatures of the influent air and water is large, and the contaminants have a low H. Dyksen (34) looked at the effect water temperature had on the removal of trichloroethylene by air stripping. Trichloroethylene removal was about 6% greater at 26°C as opposed to 12°C. This increase in removal held true at both high and low trichloroethylene levels. Pakanati (11) stated that, for any given liquid loading rate, the mass transfer coefficient for the 22°C water was about 50% greater than for the 15°C water.

Gosset (35) examined the effects of water temperature between 10°C to 30°C, ionic strength, and the presence of additional organics on the aqueous solution/gas equilibria of six chlorinated organic compounds. In this work Gosset noted that the Air Force routinely use trichloroethylene and other chlorinated compounds as cleaning solvents during the maintenance of aircraft and that trichloroethylene contamination of groundwater has been found in the vicinity of several Air Force bases. Gosset also noted that since the Air Force uses and disposed of a variety of chlorinated and aromatic solvents, it is likely that future

applications of stripping technology may involve groundwater containing organics other than trichloroethylene.

In order to increase the removal efficiency of compounds removed by stripping technology some investigators have used steam to elevate the temperature of the influent air. Stover et al. (36) used steam stripping, since many of the organics in the groundwater they examined had Henry's law constants less than 10^{-3} to 10^{-4} atm.m^3/mole. Volatile organic compounds with Henry's law constants of 10^{-2} to 10^{-3} atm.m^3/mole are good candidates for air stripping (11). Steam stripping at temperatures around 60°C showed better removal of the volatile organic compounds than conventional air stripping. Steam stripping also reduced the concentration of many of the more non-volatile, extractable organic compounds (36).

Pakanati (11) investigated the effects of both air and water temperature on the removal of both volatile and a slightly-volatile (nitrobenzene) compounds. He found the temperature of the influent air ranging from 5 - 35°C had no effect on the removal of highly volatile compounds. As the air temperature increased, the removal of the slightly-volatile compound increased. While the temperature of the influent water did affect the removal efficiency of all the compounds, lower removals were obtained at lower water temperatures. The effects were greater at higher gas-to-liquid ratios (175:1) than at the smaller ratios (46:1).

Lamarre et al. (37) reported on the use of high water temperature (54 - 178°F) air stripping of organics, from a groundwater contaminated by a hazardous waste site. Most of the compounds contaminating the groundwater of this site were very soluble which made their removal at ambient-temperature (54°F) by air stripping difficult. Their results

indicated the following methylethyl ketone (MEK) removal:

Temperature	G/L	% Removal
54°F	490	43
90°F	513	92
136°F	469	99

Their results showed removal efficiency increased dramatically with temperature and less sharply with gas-to-liquid ratio. Acetone, one of the most difficult compounds to strip out of the groundwater, was used as an indicator compound. Ninety percent removal of acetone was achieved at an operating temperature between 160 - 170°F and gas-to-liquid ratio between 50 - 100.

Sullivan et al. (38) used water heated to 140°F and a gas-to-liquid ratio of 200:1 to achieve a 99.995% reduction in MEK. This was the first full scale (100 gpm) application of this new air stripping tower that was designed to function at ambient air temperatures as low as 10°F.

The ability to predict performance due to the variations in the temperature of the water and the air is required for proper design of stripping towers. Because the gas/liquid partition coefficient (H) is an important factor in the design of stripping towers, it is useful to estimate the effects of temperatures on it. Very little can be found in the literature concerning the temperature effect on H. Kavanaugh and Trussell (39) gave a Van't Hoff-type equation to model the relationship of Henry's law constant with temperature. Gosset (35) experimentally evaluated Henry's law constant, over a temperature range 10°C to 30°C, for six organic compounds. He obtained equations for the dependence of H upon the temperature by linear regression of the data.

The stripping ability of a compound cannot be based only on H. Although trichloroethylene has a higher H value than dichloroethane, Signley et al. (40) found that at 25°C dichloroethane is more easily removed. Therefore it is necessary to evaluate the mass transfer coefficient and their dependence upon temperature for a proper design of a stripping tower. Kavanaugh and Trussell (39) reported that, with decreasing temperature, both the Henry's law constant (H) and mass transfer coefficient (K_1a) decreased. In a 1981 (41) paper by the same authors, they reported a 50% decrease in H and 10% decrease in K_1a for chloroform as the temperature dropped from 20° to 10°C. Gosset et al. (12) found a 50% decrease in H and 48% decrease in K_1a for chloroform as the temperature dropped from 20° to 10°C. They also reported a 54% decrease in the Henry's constant for 1,2-dichlorobenzene as the temperature dropped from 20° to 10°C.

Theoretical Consideration

Gas-Liquid Equilibrium

When two phases such as air and water are placed into contact in order to permit transfer of constituent substances between them, the transfer of the substances present in excess take place until equilibrium is reached. The equilibrium accomplished is dynamic with the molecules continuing to transfer simultaneously from one phase to the other, resulting in a zero net transfer. After the equilibrium is reached, the concentration within each phase does not change. The equilibrium situation in nonideal dilute solutions, such as water and/or wastewater, is defined by Henry's law. In 1803, William Henry noticed that the volume of a gas that will dissolve in a given volume of water

is independent of pressure. Similarity, the mass of gas that dissolves in a given volume of water is directly proportional to its vapor pressure. The constant of proportionality between equilibrium gas partial pressure and liquid concentration is now known as Henry's law constant, which can be shown mathematically a number of ways. The various methods used to express Henry's law constant along with the interconversion of this form was recently summarized by Roberts and Munz (42). Two that are commonly used in the environmental engineering literature are:

$$H = \frac{P}{C_l} \tag{2.1}$$

where: H = Henry's law constant of the solute, m^3.atm/mole
P = partial pressure of the solute, atm
C_l = equilibrium liquid phase solute concentration, mole/m^3

and:

$$H_c = \frac{C_g}{C_l} \tag{2.2}$$

where: H_c = Henry's constant in dimensionless units
C_g = gas phase solute concentration, mole/m^3

Henry's law is most closely followed at low-solute concentrations (the mole fraction of the solute is not greater than 0.02) (42), and is applicable only if the solute does not associate, dissociate, or undergo chemical reaction with the solvent. At high concentration, the equilibrium gas phase partial pressure of the solute is greater than Henry's law predicts (35). Kavanaugh and Trussell (41) reported that the concentration at which deviations from Henry's law constant begin to occur depends upon the chemicals in the system. For example, in the water/ammonia system, a plot of equilibrium partial pressure versus

aqueous concentration shows that a deviation occurs when the liquid ammonia concentration is greater than 2.780 gm/1. They also state that research is urgently needed to obtain values of Henry's constant for low-contaminant concentrations typical of trace organic levels found in water supplies. A knowledge of Henry's law constant (H_c) is necessary to calculate both the direction of the mass transfer coefficient and the distribution of resistance to mass transfer between the air and the water. The larger the Henry's law constant of a compound, the greater will be the concentration of the substance in air, at equilibrium, and, therefore, it should be more easily removed by air stripping than a compound with a lower Henry's constant.

One of the factors affecting Henry's law constant is temperature. Kavanaugh and Trussell (42) pointed that the temperature dependencies of equilibrium constants are generally modelled using a Van't Hoff-type equation, which can be mathematically stated as:

$$\ln H = \frac{-\Delta H}{RT} + K \qquad (2.3)$$

where: ΔH = the standard enthalpy of reaction for the dissolution of the component in water, kcal/kmole
T = absolute temperature, °K
K = an empirical constant
R = the ideal gas constant, 1.987 kcal/kmole °K

Equation 2.3 assumes that the enthalpy change caused by the dissolution of the contaminant in water is independent of the temperature, because of the small temperature range of water that is normally encountered in the field.

If H and H_1 are Henry's law constants at any two temperatures of T and T_1 respectively, then the equation can be expressed by the following equation:

$$\ln H - \ln H_1 = \frac{-\Delta H}{R} \left(\frac{1}{T} - \frac{1}{T_1}\right) \tag{2.4}$$

Since $\ln H - \ln H_1 = \ln H/H_1$, the above equation can be written as:

$$\ln \frac{H}{H_1} = \frac{-\Delta H}{R} \left(\frac{1}{T} - \frac{1}{T_1}\right) \tag{2.5}$$

Since the enthalpies tend to be constant over short temperature ranges, a regression of ln H versus 1/T should be linear and permit the calculation of the Henry's law constant at any temperature if its value at one temperature is known. The value of $\Delta H/R$ can be calculated from vapor pressure and solubility data.

Principle of Mass Transfer Coefficients

Mass transfer occurs at the boundary between water and air. According to the Lewis-Whitman (43) two film theory, mass transfer across a gas/liquid interface takes place by molecular diffusion through a thin film at the phase boundary. This theory assumed that equilibrium conditions exist at the interface, the thin film exists on each side of the interface, and the bulk of each phase is completely mixed. Under these assumptions one conclusion is that the rate of mass transfer is controlled by molecular diffusion through each stagnant film or boundary layer. This can be described by Fick's first law that says the total flux is a function of the concentration gradient in each phase.

$$J = -D_{AB} \frac{\delta c}{\delta x} \tag{2.6}$$

where: J = the molecular mass transfer flux of the solute, mole/m^2.sec
D_{AB} = diffusion coefficient (diffusivity) of a solute A into solvent B, m^2/sec
$\frac{\delta c}{\delta x}$ = concentration gradient, mole/m^4

Figure 1 shows the two-layer model of gas-liquid interface. If the concentration gradient is considered to be linear over the distance of x, then equation 2.6 can then be written for the liquid phase as follows:

$$J = \frac{D_1}{x_1}(C_1 - C_{1i}) = k_1(C_1 - C_{1i}) \qquad (2.7)$$

where: $k_1 = \frac{D_1}{x_1}$ = local liquid phase mass transfer coefficient, m/sec

x_1 = liquid phase boundary layer thickness, m
C_1 = liquid phase bulk solute concentration, mole/m^3
C_{1i} = liquid phase solute concentration at the interface, mole/m^3
D_1 = diffusivity of solute concentration in liquid phase, m^2/sec

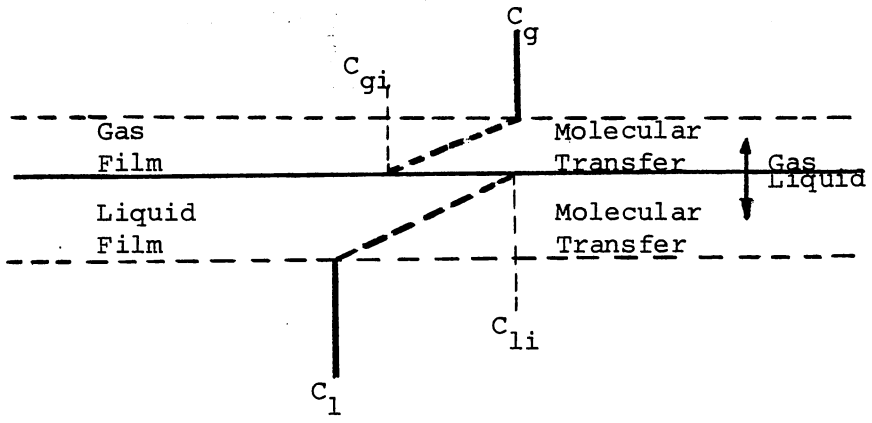


Figure 1. Two-Layer Model of Gas-Liquid Interface

The concentration (C_{1i}) in Equation 2.7 is that presumed to exist at the air-liquid interface. A similar analysis is made for the air

phase. Since the mass leaving the liquid phase must be equal to the mass entering the air phase, the expressions for flux can be mathematically stated as:

$$J = \frac{D_g}{x_g} (C_{gi} - C_g) = k_g (C_{gi} - C_g) \tag{2.8}$$

where: $k_g = \frac{D_g}{x_g}$ = local gas phase mass transfer coefficient, m/sec
x_g = gas phase boundary layer thickness, m
C_g = gas phase bulk solute concentration, mole/m^3
C_{gi} = gas phase solute concentration at the interface, mole/m^3
D_g = diffusivity of solute in gas phase, m^2/sec

The Lewis-Whitman model essentially assumes steady state diffusion, in forms such as $(C_1 - C_{1i})x_1$, to replace the gradients $(\delta c/\delta x)$ at the interface. Since the concentrations at the interface cannot be measured, the overall mass transfer coefficients of gas and liquid phases are defined based on the difference between the bulk concentration in one phase and the concentration that would be in equilibrium with the bulk concentration in the other phase:

$$J = K_1 (C_1 - C^*_1) \tag{2.9}$$

and

$$J = K_g (C_g - C^*_g) \tag{2.10}$$

where: K_1 = overall mass transfer coefficient based on liquid phase concentration, m/sec
K_g = overall mass transfer coefficient based on gas phase concentration, m/sec
C^*_1 = equilibrium concentration of the liquid phase with the bulk gas concentration, mole/m^3
C^*_g = equilibrium concentration of the gas phase with the bulk liquid concentration, mole/m^3

Expanding Equation 2.9 to include the interfacial liquid phase solute concentrations yields:

$$J = K_l[(C_l - C_{li}) + (C_{li} - C^*_l)] \tag{2.11}$$

Since equilibrium is assumed at the interface, applying Henry's law and substituting,

$$C_{li} = \frac{C_{gi}}{H_c}$$

and

$$C^*_l = \frac{C_g}{H_c}$$

into Equation 2.11 results in:

$$J = K_l[(C_l - C_{li}) + (C_{gi} - C_g)/H_c] \tag{2.12}$$

Substitute the right hand portion of Equation 2.7 and 2.8 to Equation 2.12. Therefore,

$$J = K_l \left(\frac{J}{k_l} + \frac{J}{H_c k_g}\right) \tag{2.13}$$

This can be rearranged to yield:

$$\frac{1}{K_l} = \frac{1}{k_l} + \frac{1}{H_c k_g} \tag{2.14}$$

Expanding Equation 2.10 to include the interfacial gas phase solute concentration yields:

$$J = K_g[(C^*_g - C_{gi}) + (C_{gi} - C_g)] \tag{2.15}$$

Applying Henry's law and substituting

$$C_{gi} = C_{li} \cdot H_c$$

and

$$C^*_g = H_c \cdot C_l$$

into Equation 2.15 results in:

$$J = K_g[H_c(C_l - C_{li}) + (C_{gi} - C_g)] \tag{2.16}$$

Substitute the right hand portion of Equations 2.7 and 2.8 to Equation 2.15. Therefore,

$$J = K_g \left[\frac{H_c J}{k_1} + \frac{J}{k_g}\right] \tag{2.17}$$

This can be rearranged to yield:

$$\frac{1}{K_g} = \frac{H_c}{k_1} + \frac{1}{k_g} \tag{2.18}$$

Therefore, overall mass transfer coefficients of liquid and gas phases can be defined in terms of the individual film coefficients of gas and liquid phases and Henry's constant. K_1 and K_g are overall mass transfer coefficients, and $1/K_1$ and $1/K_g$ are overall resistance to mass transfer. Included in the right hand term of Equations 2.14 and 2.18 are the individual liquid and gas phase resistances respectively. Therefore, the total resistance to mass transfer can be written as:

$$R_t = R_1 + R_g \tag{2.19}$$

where: R_t = the total resistance to mass transfer either considering a liquid phase or a gas phase, sec/m
R_1 = the liquid phase resistance, sec/m
R_g = the gas phase resistance, sec/m

In modeling the behavior of packed towers for the removal of volatile organic compounds, two phases of resistance, shown in the above equations, have been used (12, 13). For example, the mass transfer of oxygen is considered liquid phase limited, so Equation 2.14 becomes,

$$\frac{1}{K_1} = \frac{1}{k_1} \tag{2.20}$$

or

$$R_t = R_1 \tag{2.21}$$

For water, resistance lies in the gas phase, the transfer is said to be a gas phase controlled transfer, so Equation 2.18 reduces to

$$\frac{1}{K_g} = \frac{1}{k_g} \tag{2.22}$$

or

$$R_t = R_g \tag{2.23}$$

Mass Transfer Models

Gosset et al. (12) pointed out that the area across which diffusion occurs and the overall mass transfer coefficient cannot be determined independently, in case of packed tower application, the two terms are usually referred to as the volumetric mass transfer coefficient, $K_l a$ or $K_g a$. This $K_l a$ represents the two quantities combined: K_l, the overall mass transfer coefficient based on liquid phase concentration; and "a" referring to the effective area of the contact between two phases per unit bed volume (12).

Reference Models

Mumford and Schnoor (44) suggested that the mass transfer coefficients could be found to be directly proportional to the diffusion coefficient raised to some power n. The two-layer (film) theory, under the highly turbulent and steady state conditions in packed towers, admits a dependence on diffusivity to the 1.0 power (43). Dobbins (45), Tamir and Merchuk (46) and Smith et al. (47) reported that the penetration and surface renewal theories do not occur in turbulent systems, such as the interfaces in packed towers, and the value of n lies between 0.5 and 1.0. The penetration and surface-renewal theories are two other

mass transfer models that have been proposed by Higbie (48) and Dancwerts (49). If diffusion is considered to be similar to effusion, then the proportional effusion rate of two substances is the same as the proportional diffusion rate of the same substances between two phases. Effusion, as defined by Atkin (50), is the

> flow of material from one region to another is an example of a transport property. For example, if a gas is confined to a container but open to a low-pressure region through a small hole, the gas will flow through the hole until the pressures are equal on both sides (this process is called effusion).

This idea has been used with some success, since the diffusion coefficient is mainly a function of solvent properties. The diffusion coefficient is considered to be inversely proportional to the square root of molecular weight of its subatance. This concept is based on Graham's law of effusion, and can be calculated as (44):

$$D\alpha\ (M.W)^{-0.5} \tag{2.24}$$

where: D = diffusion coefficient, m^2/sec
M.W = molecular weight of substance, gm/mole

As mentioned previously, the mass transfer coefficient is directly proportional to the diffusion coefficient

$$k\alpha\ (D)^{n} \tag{2.25}$$

where: k = mass transfer coefficient individual phase, m/sec
n = 1.0 in the two film theory

Substituting this for n = 1.0 and combining with Equation 2.24

$$k = (M.W)^{-0.5} \tag{2.26}$$

This equation can be used to calculate the individual phase mass transfer coefficient by using a reference compound. For liquid phase mass transfer coefficient of compound c

$$(k_1)_c = (k_1)_{H_2O} \frac{(M.W)_{H_2O}}{(M.W)_c}^{0.5} \tag{2.27}$$

where: $(k_1)_c$ = mass transfer coefficient of liquid compound interest, m/sec

$(k_1)_{H_2O}$ = mass transfer of reference liquid water, m/sec

$(M.W)_{H_2O}$ = molecular weight of water, gm/mole

$(M.W)_c$ = molecular weight of compound interest, gm/mole

Similarly, for the gas phase mass transfer coefficient:

$$(k_g)_c = (k_g)_{O_2} \frac{(M.W)_{O_2}}{(M.W)_c}^{0.5} \tag{2.28}$$

where: $(k_g)_c$ = mass transfer coefficient of gas compound interest, m/sec

$(k_g)_{O_2}$ = mass transfer coefficient of reference gas, oxygen, m/sec

$(M.W)_{O_2}$ = molecular weight of oxygen, gm/mole

Tamir and Merchuk (46) reported that in the penetration and surface renewal theories the mass transfer coefficient is directly proportional to the 0.638 power of the diffusion coefficient. However, Smith et al. (47) found that the mass transfer coefficient is proportional to the 0.61 power of diffusivity. Therefore, the average power of the diffusion coefficient was chosen for use in this study. Substituting this value (0.624) for n in Equation 2.25 and combining with Equation 2.24.

$$k \propto (M.W)^{-0.312} \tag{2.29}$$

The above equation can be used to estimate the individual phase mass transfer coefficient by using a reference compound. For the liquid phase mass transfer coefficient of compound c:

$$(k_l)_c = (k_l)_{H_2O} \frac{(M.W)_{H_2O}}{(M.W)_c}^{0.312} \tag{2.30}$$

For the gas phase mass transfer coefficient of compound c:

$$(k_g)_c = (k_g)_{O_2} \frac{(M.W)_{O_2}}{(M.W)_c}^{0.312} \tag{2.31}$$

Liss and Slater (51) established, using field data measurements of total resistance for transfer from sea to air, that a value of k_l or $(k_l)_{H_2O}$ = 0.00333 m/min for oxygen and k_g or $(k_g)_{O_2}$ = 0.50 m/min for water. These values were obtained by considering that the entire resistance to the transfer of water across the interface occurs in the gas phase while for the oxygen, all the resistance is in the liquid phase. Therefore, oxygen and water serve as the reference compounds. Knowing the individual phase mass transfer coefficients (k_l and k_g), the overall mass transfer coefficients (K_l and K_g) can be calculated using Equations 2.14 and 2.18. The $K_l a$, overall mass transfer coefficient K_l times the specific interfacial area (a) of the packing material, of any compound can be calculated, if the $K_l a$ of reference compound is known, using the following expression (44).

$$(K_l a)_c = (K_l a)_r \frac{(K_l)_c}{(K_l)_r} \tag{2.32}$$

where: $(K_l a)_c$ = volumetric mass transfer coefficient of compound of interest, 1/sec
$(K_l a)_r$ = volumetric mass transfer coefficient of reference, 1/sec
$(K_l)_c$ = overall mass transfer coefficient of compound of interest, m/sec
$(K_l)_r$ = overall mass transfer coefficient of reference, m/sec

Sherwood-Holloway Model

In 1940, Sherwood and Holloway (52) studied the desorption of hydrogen, oxygen, and carbon dioxide from water in a countercurrent packed tower using air in columns filled with Raschig rings and Berl saddles packed. Water temperature varied from 5 to 40°C, water mass loadings from 0.2712 to 43.39 kg/sec.m^2 (200 to 32000 lb/hr.ft^2), and mass loadings from 0.0407 to 1.763 kg/sec.m^2 (30 to 1300 lb/hr.ft^2). The experimental results showed little variation in the volumetric liquid mass transfer coefficient with size and type of packing, liquid and gas mass loading rates, packing height, and solute concentration. From this work, Sherwood and Holloway developed a model to estimate k_1a, assuming gas phase resistance was negligible. The Sherwood and Holloway model can be written as:

$$\frac{(k_1)a}{D_1} = 10.764\alpha \left[\frac{0.3048\ L_m}{\mu_1}\right]^{1-n} \left[\frac{\mu_1}{\rho_1 D_1}\right]^{0.5} \qquad (2.33)$$

where: $(k_1)a$ = volumetric liquid mass transfer coefficient, 1/sec
D_1 = solute liquid diffusivity, m^2/sec
L_m = liquid mass loading rate, kg/sec.m^2
μ_1 = liquid viscosity, kg/sec.m
ρ_1 = liquid density, kg/m^3
α,n = constants which are a function of packing type and size

Values of α and n were measured for 0.5, 1.0, 1.5, and 2.0 in. Raschig rings and 0.5, 1.0, and 1.5 in. Berl saddles (52). However, it should be noted that the Sherwood-Holloway model may not be suitable for moderately volatile compounds such as THMs, due to a significant gas-phase resistance.

Shulman Model

The Sherwood-Holloway model is limited to determining the mass transfer coefficients, where the gas phase resistance is negligible and the packing constant (α and n) are available for the packing type used. Thus, to overcome these limitations, Shulman et al. (53) developed two resistance models where both liquid and gas phase resistance are considered. They separated the estimation of individual phase mass transfer coefficient and the effective interfacial area. The following expressions were developed by Shulman for both liquid and gas phase mass transfer coefficients:

$$\frac{k_l d_s}{D_l} = 25.1 \left[\frac{d_s L_m}{\mu_l}\right]^{0.45} \left[\frac{\mu_l}{\rho_l D_l}\right]^{0.5} \tag{2.34}$$

$$\frac{k_g d_s}{D_g} = 1.195\ (1 - E)^{0.36} \left[\frac{d_s G_m}{\mu_g}\right]^{0.64} \left[\frac{\mu_g}{D_g \rho_g}\right]^{0.333} \tag{2.35}$$

where: μ_g = gas viscosity, kg/sec.m
ρ_g = gas density, kg/m^3
D_g = solute gas diffusivity, m^2/sec
L_g = gas mass loading rate, kg/sec.m^2
d_s = diameter of a sphere having the same surface area as a unit of packing, m
E = fractional void volume in a dry packed bed, volume void/volume bed, dimensionless

The liquid phase expression, Equation 2.34, is valid for liquid mass loading from 0.65 to 9.7 kg/sec.m^2 (500 to 7500 lb/hr.ft^2). Equation 2.35, the gas phase expression, is limited to air mass loadings ranging from 0.26 to 1.4 kg/sec.m^2 (200 to 1000 lb/hr.ft^2) with volumetric gas to liquid ratios of 1 to 100 (53). Shulman defined the effective interfacial area, a_e, as a function of gas and liquid loading and packed typed, and this value is smaller than the value of the wetted

interfacial area of the packing. For Raschig rings and Berl saddles, the effective areas are given in an extensive series of graphs in the original works (53, 54).

Onda Model

Laboratory studies by Robert et al. (19) and Riojas et al. (55) have shown the Onda correlations (56). To better estimate the mass transfer coefficient of organic solutes in a countercurrent packed column as compared to the estimate of other empirical models, Onda et al. (56) assumed that the effective interfacial area equals the wetted interfacial area. They estimated the gas and liquid mass transfer coefficient (k_l and k_g) by using correlated values with various dimensionless groups of operational variables. The Onda correlations (55) expressions for both liquid and gas phase mass transfer coefficients are:

$$k_l \left(\frac{\rho_l}{\mu_l g}\right)^{1/3} = 0.0051 \left[\frac{L_m}{a_w \mu_l}\right]^{2/3} \left[\frac{\mu_l}{\rho_l D_l}\right]^{-0.5} (a_t d_p)^{0.4} \qquad (2.36)$$

$$\frac{k_g}{a_t D_g} = 5.23 \left[\frac{G_m}{a_t \mu_g}\right]^{0.7} \left[\frac{g}{\rho_g D_g}\right]^{1/3} (a_t d_p)^{-2} \qquad (2.37)$$

where: g = acceleration due to gravity = 9.81 m/sec^2
a_w = wetted interfacial area per unit bed volume, m^2/m^3
a_t = total dry packing area per unit bed volume, m^2/m^3
d_p = nominal diameter of a piece of packing, m

Onda defined the wetted surface area, a_w, as a function of the liquid mass loading rate, physical properties of the liquid and packing, the surface tension of liquid, and the critical surface tension with respect to the packing (56):

$$\frac{a_w}{a_t} = 1 - \exp\left[-1.45\left[\frac{\sigma_c}{\sigma}\right]^{0.75} (Re)^{0.1}\ (Fr)^{-0.05}\ (We)^{0.2}\right] \quad (2.38)$$

where: σ_c = critical surface tension with respect to the packing material, kg/sec^2

σ = surface tension of liquid, N/m

Re = Reynold number, $L_m/a_t\mu_l$

Fr = Froude number, $L_m^2.a_t/\rho_l^2.g$

We = Weber number, $L_m^2/\rho_l.\sigma.a_t$

Equation 2.36, the liquid phase expression, is valid for liquid mass loading from 1.0 to 15.0 $kg/sec.m^2$ (700 to 11000 $lb/hr.ft^2$). Equation 2.37, the gas phase expression, is valid for air mass loading ranging from 0.02 to 1.7 $kg/sec.m^2$ (15 to 1250 $lb/hr.ft^2$).

In addition to Onda's expression for wetted interfacial area, a_w, there are two more generally adaptable expressions for a_w. Yoshida and Koyangi (57) presented the following equation for wetted interfacial area:

$$\frac{a_w}{a_t} = 0.079\left[L_m\left[\frac{\sigma}{20}\right]^{3q}\right]^{1/3} \quad (2.39)$$

where: $q = -0.74\ (d_p)^{-0.70}$ (2.40)

Meda et al. (58) developed the following expression for interfacial area:

$$a = \frac{0.34}{d_p}\ (Fr)^{-1/2}\ (We)^{2/3} \quad (2.41)$$

Estimation of Liquid Phase Diffusivities

Owing to the difficulties of experimental measurements and some confusion in the experimental results, empirical correlations for predicted liquid phase diffusivities have been established by Wilke and

Chang (59), Scheibel (60), Othmer and Thaker (61), and Hayduk and Laudie (62). These correlations assume an infinitely dilute solution and no solute-solvent interaction in a mixture of solutions.

Based on hydrodynamic theory (63, 64), the Stokes-Einstein equation states:

$$D_1 = \frac{RT}{6\pi\mu_1 r_A} \tag{2.42}$$

where: r_A = the radius of spherical solute, °A
μ_1 = solvent viscosity, cp

The $D_1\mu_1/T$ has been stated to be relatively constant for many solutes and an accurate method for making temperature corrections to diffusion coefficients (65). Thus, many investigators have used the form $D_1\mu_1/T$ as a starting point in developing correlations when the solute and solvent are of an unknown molecular radius.

Wilke-Chang Correlation

In 1955, Wilke and Chang (59) developed an empirical modification of the Stokes-Einstein equation. They used available data on the Stokes-Einstein to support their analysis. The resulting expression was:

$$F = \frac{T}{D_1\mu_1} \tag{2.43}$$

where: F = diffusion factor

Wilke and Chang (59) demonstrated that F was a smooth function of the molar volume of the solute and molecular weight of the solvent. The resulting correlation was:

$$D_1 = \frac{7.48 \times 10^{-8} (M.W.Y)^{0.5} T}{\mu_1 V_b^{0.6}} \tag{2.44}$$

where: V_b = molar volume of the solute at its normal boiling point, $cm^3/mole$
M.W = solvent molecular weight, gm/gm.mole
Y = association factor of the solvent

Wilke and Chang (59) recommended that Y be chosen as 2.6 if the solvent is water.

Scheibel Correlation

In 1954, Scheibel (60) developed an equation similar to the Wilke and Chang expression by eliminating the association factor for the solvent (Y). The resulting correlation was:

$$D_1 = \frac{KT}{(\mu_1 V_b)^{\frac{1}{3}}} \tag{2.45}$$

where: $K = (8.2 \times 10^{-8}) \left[1 + \left(\frac{3V_a}{V_b}\right)^{2/3}\right]$

When water is the solvent and $V_b < V_a$, use $K = 25.2 \times 10^{-8}$.
V_a = solvent molar volume at its normal boiling point.

Othmer-Thaker Correlation

In 1953, Othmer and Thaker (61) found that the rate of diffusion in dilute aqueous solutions could be established by using the solvent viscosity for temperature correction and solute's molar volume to the 0.6 power. Othmer-Thaker retained $V_b^{0.6}$ as in the original Wilke-Chang correlation, resulting in the following equation:

$$D_w = \frac{14.0 \times 10^{-5}}{(\mu_w)^{1.1} (V_b)^{0.6}} \tag{2.46}$$

where: D_w = diffusivity in an aqueous solution, cm^2/sec
μ_w = viscosity of water, cp

This expression was created primarily for estimating diffusion in water.

Hayduk-Laudie Correlation

In 1974, Hayduk and Laudie (62) re-evaluated the aqueous diffusivity data obtained by the Wilke-Chang and the Othmer-Thaker correlations. They found the average error of the Wilke-Chang correlation could be reduced by decreasing the association parameter for water from 2.6 to 2.26. They also proposed an expression of diffusion very similar to Othmer and Thaker (61). The resulting correlation was:

$$D_w = \frac{13.26 \times 10^{-5}}{\mu_w^{1.4} V_b^{0.586}} \tag{2.47}$$

Estimation of Gas-Phase Diffusivities

In 1951, Chapman and Enskog (66) independently derived the formula for viscosity and thermal conductivity. The results produced the corresponding formula of diffusion coefficients for binary gas systems at low pressure. The resulting correlation was:

$$D_g = 0.0018583 \sqrt{\frac{T^3 \left(\frac{1}{M_1} + \frac{1}{M_2}\right)}{P\sigma_{12}^2 \Omega_{D,12} 10^4}} \tag{2.48}$$

where: D_g = gas phase solute diffusivity, m^2/sec
T^g = absolute temperature, °K
M_1 = molecular weight of solute, gm/mole
M_2 = molecular weight of solvent gas (air = 28.97 gm/mole)
P = absolute pressure, atm
σ_{12} = Lennard-Jones characteristic collision diameter with respect to components 1 and 21, °A
$\Omega_{D,12}$ = collision integral, dimensionless

For nonpolar, nonreacting, molecular pairs, σ_{12} can be estimated by combining the Lennard-Jones parameters of species 1 and 2 empirically:

$$\sigma_{12} = \tfrac{1}{2}(\sigma_1 + \sigma_2) \tag{2.49}$$

Values of σ_1 and σ_2 are tabulated in Bird et al. (67) or may be estimated as:

$$\sigma = 1.83\ V_b^{1/3} \tag{2.50}$$

where: V_b = molar volume of the solute at its normal boiling point, $cm^3/mole$

The collision integral, $\Omega_{D,12}$, is a function of the dimensionless parameter of Tk/E_{12}, where k = Boltzman constant = 1.38×10^{-6} erg °K, and E_{12} = energy of molecular interaction, in erg:

$$\frac{E_{12}}{k} = \left[\frac{(E_1)}{k} \times \frac{(E_2)}{k}\right]^{0.5} \tag{2.51}$$

Values of E_1 and E_2 are tabulated in Hirschfelder et al. (68), or can be estimated as:

$$\frac{E}{k} = 1.15\ T_b \tag{2.52}$$

where: T_b = temperature at normal boiling point, °K

Once the values of Tk/E_{12} are known, the values of $\Omega_{D,12}$ can be found as a function of Tk/E_{12} by using tables in Hirschfelder et al. (69)(page 205).

Over the temperature range of interest, the temperature variation of the $\Omega_{D,12}$ parameter are known, therefore, solute diffusivity in the gas phase can be estimated by using Equation 2.48.

The effects of temperature on gas and liquid densities, gas and liquid viscosities, gas and liquid diffusivity, gas and liquid viscosity, and liquid surface tension are presented in Appendix A.

Design Equations of Countercurrent Air Stripping Towers

Air stripping can be effectively performed in a packed tower in which air and water flows are countercurrent to one another, with the water flowing downward over the packing material as a film, while the air flows upward as the continuous phase. The design equations for air stripping have been developed in the field of chemical engineering and are given in standard texts on mass transfer, for example Treybal (14), Sherwood, Pigford, and Wilke (70), and Perry and Chilton (71). These design equations are more proper for handling concentrated solutions. However, lately, Singley et al. (40), Kavanaugh and Trussell (39), and Mumford and Schnoor (44) have developed equations for analyzing and designing countercurrent packed columns for water treatment, in which the liquid solution is dilute. The expressions developed below are a slight modification of those presented by Mumford and Schnoor (44). Figure 2 shows a countercurrent packed column having a cross-section area X. If "a" is the specific interfacial surface area of the packing material, then the interfacial surface area accessible for mass transfer in a differential depth dZ of the packing is given by:

$$dA = aX\ dZ \tag{2.53}$$

The molecular mass transfer flux of the solute in this volume element is

$$J = \frac{d(Q_1C_1)}{dA} = \frac{d(Q_1C_1)}{aX\ dZ} \tag{2.54}$$

where Q_1 is the volumetric flow rate of liquid (m^3/hr) and C_1 is the bulk concentration in the liquid ($mole/m^3$). Combining Equation 2.54

with Equation 2.9

$$J = \frac{d(Q_1 C_1)}{aX\ dZ} = K_1(C_1 - C_1^*) \tag{2.55}$$

For the dilute solutions of concerns, Q_1 can be considered constant, so Equation 2.55 can be rearranged as

$$\frac{Q_1}{X}\ (dC_1) = K_1 a\ (C_1 - C_1^*)\ dZ \tag{2.56}$$

It should be noted that $Q_1/X = L_m$, the liquid loading rate ($m^3/hr\text{-}m^2$), rearranged, and then integrate

$$\int_{C_1^1}^{C_1^2} \frac{dC_1}{C_1 - C_1^*} = \frac{K_1 a}{L_m} \int_1^2 dZ \tag{2.57}$$

where 1 refers to the bottom of the tower and 2 to the top. The left side of Equation 2.57 is defined as the number of overall liquid phase transfer unit (NTU). The integral term on the right is the column height per transfer unit (HTU). Hence, a general equation for the total height needed for the desired removal can be written as

$$Z = (HTU)(NTU) \tag{2.58}$$

The above equation which says that the number of transfer units times the height per transfer unit is equal to the total column height. The term $K_1 a/L_m$ in Equation 2.57 is equal to 1/HTU.

Equation 2.57 can not be integrated in its present for because it involves two variables, C_1 and C_1^*. However, C_1^* may be expressed in terms of C_1 using equilibrium relationship, and then Equation 2.57 can be integrated. Consider the packed column depicted in Figure 2. Over a

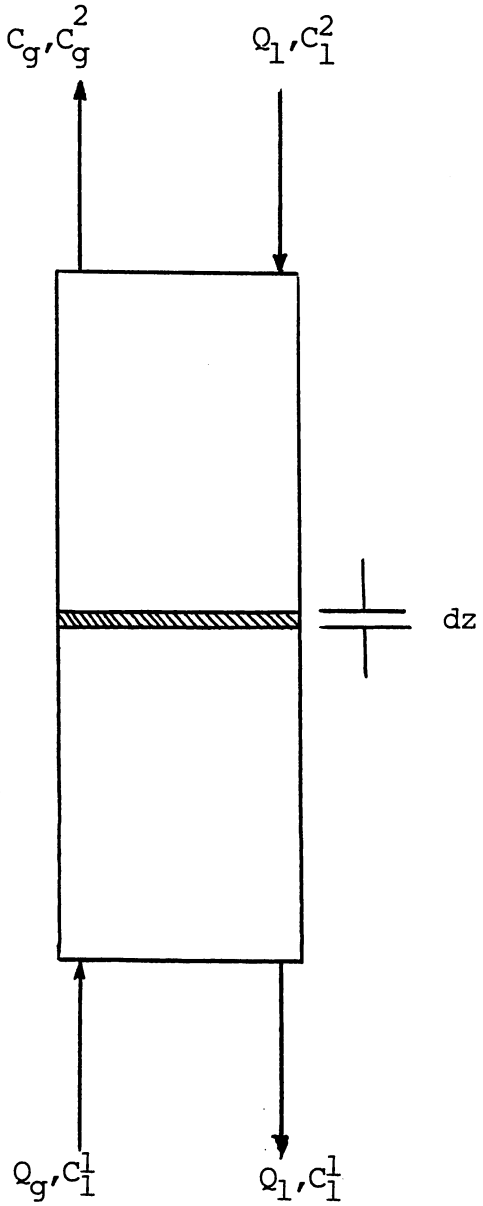


Figure 2. Counter Current Packed Tower

differential height dZ, the mass of solute leaving the liquid and entering the air must be the same.

$$dG_m\ C_g = dL_m\ C_l \tag{2.59}$$

In water treatment the solutions are dilute, the volume change due to solute leaving or entering the liquid or air stream is not significant, thus

$$G_m\ dC_g = L_m\ dC_l \tag{2.60}$$

rearranging,

$$\frac{dC_g}{dC_l} = \frac{L_m}{G_m} \tag{2.61}$$

The term dC_g/dC_l is the slope of the operating line, a plot of C_g versus C_l at each location in the column. The definition of Henry's law is the slope of the equilibrium line, a plot of C_g versus C_l^*, the liquid concentration in equilibrium with each C_g

$$H_c = \frac{dC_g}{dC_l^*} \tag{2.62}$$

dividing Equation 2.62 by Equation 2.61

$$\frac{dC_g}{dC_l^*} \Big/ \frac{dC_g}{dC_l} = H_c \Big/ \frac{L_m}{G_m} \tag{2.63}$$

rearranging,

$$\frac{dC_g}{dC_l^*} = \frac{H_c\ G_m}{L_m}\ \frac{dC_g}{dC_l} \tag{2.64}$$

The equilibrium concentration C_l^* is determined from Henry's law as

$$H_c = \frac{C_g}{C_l^*} \tag{2.65}$$

or

$$C_l^* = C_g/H_c \tag{2.66}$$

Substituting the equilibrium concentration of liquid, C_l^*, into Equation 2.64.

$$\frac{dC_g}{dC_g/H_c} = H_c \frac{G_m}{L_m} \frac{dC_g}{dC_l} \tag{2.67}$$

rearranging,

$$H_c \frac{dC_l}{dC_g} = H_c \frac{G_m}{L_m} \tag{2.68}$$

separating variables

$$H_c dC_l = H_c \frac{G_m}{L_m} dC_g \tag{2.69}$$

Integrating

$$H_c \int_1^2 dC_l = H_c \frac{G_m}{L_m} \int_1^2 dC_g \tag{2.70}$$

$$H_c C_l \Big|_1^2 = H_c \frac{G_m}{L_m} C_g \Big|_1^2 \tag{2.71}$$

$$H_c (C_l^2 - C_l^1) = H_c \frac{G_m}{L_m} (C_g^2 - C_g^1) \tag{2.72}$$

For clean air, $C_g^1 = 0$

$$H_c\ (C_1^2 - C_1^1) = H_c \frac{G_m}{L_m} C_g^2 \tag{2.73}$$

Equation 2.73 holds for any C_1^2 and C_g^2 so subscripts 2 are dropped

$$\frac{H_c}{C_g}\ (C_1 - C_1^1) = H_c \frac{G_m}{L_m} \tag{2.74}$$

rearranging Equation 2.65

$$\frac{H_c}{C_g} = \frac{1}{C_1^*} \tag{2.75}$$

Substituting this in Equation 2.74

$$\frac{C_1 - C_1^1}{C_1^*} = H_c \frac{G_m}{L_m} \tag{2.76}$$

rearranging,

$$C_1^* = \frac{L_m}{H_c G_m}\ (C_1 - C_1^1) \tag{2.77}$$

This can be substituted into the left side of Equation 2.57, the expression for NTU

$$NTU = \int_1^2 \frac{dC_1}{\frac{L_m}{H_c G_m}\ (C_1 - C_1^1) + C_1} \tag{2.78}$$

rearranging,

$$NTU = -\int_1^2 \frac{dC_1}{C_1 \frac{L_m}{H_c G_m} - C_1^1 \frac{L_m}{H_c G_m} - C_1} \tag{2.79}$$

or

$$NTU = -\int_{1}^{2} \frac{dC_1}{C_1\left(\frac{L_m}{H_c G_m} - 1\right) - C_1^1 - \frac{L_m}{H_c G_m}} \tag{2.80}$$

The integration gives

$$NTU = -\frac{1}{\frac{L_m}{H_c G_m} - 1} \ln\left[C_1\left(\frac{L_m}{H_c G_m} - 1\right) - C_1^1 \frac{L_m}{H_c G_m}\right]\Bigg|_1^2 \tag{2.81}$$

$$NTU = -\frac{1}{\frac{L_m}{H_c G_m} - 1} \ln\left[C_1^2\left(\frac{L_m}{H_c G_m} - 1\right) - C_1^1 \frac{L_m}{H_c G_m}\right] - \ln\left[C_1^1\left(\frac{L_m}{H_c G_m} - 1\right) - C_1^1 \frac{L_m}{H_c G_m}\right] \tag{2.82}$$

rearranging,

$$NTU = -\frac{1}{\frac{L_m}{H_c G_m} - 1} \ln\left[\frac{C_1^2\left(\frac{L_m}{H_c G_m} - 1\right) - C_1^1 \frac{L_m}{H_c G_m}}{-C_1^1}\right] \tag{2.83}$$

$$NTU = -\frac{1}{\frac{L_m}{H_c G_m} - 1} \ln\left[\frac{C_1^2}{C_1^1}\left(-\frac{L_m}{H_c G_m} + 1\right) + \frac{L_m}{H_c G_m}\right] \tag{2.84}$$

$$NTU = -\frac{1}{\frac{L_m}{H_c G_m} - 1} \ln\left[\frac{C_1^2}{C_1^1}\left(1 - \frac{L_m}{H_c G_m}\right) + \frac{L_m}{H_c G_m}\right] \tag{2.85}$$

Since the column height Z is known, HTU can be calculated by rearranging Equation 2.58

$$HTU = \frac{Z}{NTU} \tag{2.86}$$

from Equation 2.57

$$\frac{K_1 a}{L_m} = \frac{1}{HTU} \tag{2.87}$$

thus,

$$K_1 a = \frac{L_m}{HTU} \tag{2.88}$$

Noting that $H_c = H/RT$, substituting H_c to Equation 2.86

$$NTU = \frac{1}{1 - \frac{RTL_m}{HG_m}} \ln \left[\frac{C_1^2}{C_1^1} \left(1 - \frac{RTL_m}{HG_m}\right) + \frac{RTL_m}{HG_m} \right] \tag{2.89}$$

Previous Evaluation of Mass Transfer Correlations

Lately several researchers have worked out the different correlations, Reference, Sherwood and Holloway, Shulman and Onda, used in the design of countercurrent packed towers for stripping highly, moderate, and a few slightly volatile organic compounds. Most of these studies indicate that for moderate and slightly volatile organic compounds the two-resistance correlations of Shulman and Onda are much better predictors of the overall volumetric mass transfer coefficient, $K_1 a$, values than the single- and double-resistance correlations of Sherwood and Holloway and Reference Methods, respectively.

Using the Reference model expressions, Pakanati (11), in pilot plant studies of moderate and slightly volatile organic compounds, reported that the correlations of the Reference model does not agree with measured values of $K_1 a$. The results of this variation may be caused by the equations in the Reference model which rely only on the molecular weight of the substances.

Robert et al. (72) reported that by using the Sherwood and Holloway single-phase resistance correlation the agreement of K_1a values were within the 20% range between the predicted and measured values for highly volatile organic compounds. However, Sherwood and Holloway's correlation overestimated K_1a values for the moderate volatile organic compounds at low air mass loading rates.

Umphres et al. (73) measured K_1a values of trihalomethanes removed in a 30 cm diameter column packed with 2.54 cm Ceramic Intalox saddles. Liquid mass loadings ranged from 1.358 to 21.73 kg/sec.m^2 at gas-to-liquid ratios of 40, 90, and 100. These studies used the Sherwood and Holloway equation for comparison between measured and predicted K_1a values. They reported that there was agreement between measured and predicted K_1a values for highly volatile organic compounds, but poor agreement for less volatile organic compounds.

Singley and Billeo (74) measured K_1a values of highly and moderately volatile organic compounds in a 38 cm diameter column packed with 2.5 cm Berl saddles. The maximum mass gas loading rate was 680 kg/sec.m^2, the maximum mass liquid rate was 28.52 kg/sec.m^2, and gas-to-liquid ratios ranged from 7 to 30. The measured and predicted K_1a values from the Sherwood and Holloway correlation agreed except for the least volatile organic compounds.

Using the Sherwood and Holloway expression to evaluate pilot plant performance for air stripping of five volatile organic compounds, Ball et al. (75) reported agreement between measured and predicted K_1a values for highly volatile organic compounds except for bromoform which was overestimated by 50%. The author (75) concluded that the assumption of negligible gas phase resistance may be invalid for compounds of moderate

and less volatility and that two-phase resistance models of Shulman and Onda are needed. Both Shulman and Onda estimate overall mass transfer coefficients based on gas and liquid phase resistances (75).

Robert et al. (72) pointed out that K_1a values predicted from Shulman's correlations underestimated the actual measured values by 30%. The results of this variation may be caused by the effective area. However, they reported that the Onda correlations did agree closely with the actual measured K_1a values within ± 20%. The wetted surface area, a_w, may be the source of this accuracy. The author (72) concluded that the Onda correlations were the best of the four models evaluated. Tables II and III are summaries of the K_1a values of the organic compounds used in this study that have been reported by other investigators (11, 44).

TABLE II

SUMMARY OF SELECTED K_1a VALUES REPORTED BY PAKANATI (11)

Organic Compound	Water Temp. (°C)	Air Temp. (°C)	G/L	Packing Size (mm)	Packing Height (m)	Column Diameter (cm)	K_1a (hr^{-1})
Toluene	15	15	46	9.5	0.91	7.52	41.5
	15	15	108	9.5	0.91	7.52	23.7
	15	15	175	9.5	0.91	7.52	17.7
	22	22	46	9.5	0.91	7.52	53.6
	22	22	108	9.5	0.91	7.52	29.9
	22	22	175	9.5	0.91	7.52	21.6
Nitrobenzene	15	15	46	9.5	0.91	7.52	1.20
	15	15	108	9.5	0.91	7.52	1.10
	15	15	175	9.5	0.91	7.52	1.60
	22	22	46	9.5	0.91	7.52	2.00
	22	22	108	9.5	0.91	7.52	1.50
	22	22	175	9.5	0.91	7.52	2.70

Packing type: Ceramic Intalox Saddles

TABLE III

SUMMARY OF SELECTED K_1a VALUES REPORTED BY MUMFORD (44)

Organic Compound	Water Temp. (°C)	Air Temp. (°C)	G/L	Packing Size (mm)	Packing Height (m)	Column Diameter (cm)	K_1a (hr^{-1})
Toluene	10	10	5	6.4	1.81	10.16	24.9
	10	10	15	6.4	1.81	10.16	28.2
	10	10	30	6.4	1.81	10.16	30.6
Chlorobenzene	10	10	5	6.4	1.81	10.16	10.4
	10	10	15	6.4	1.81	10.16	22.5
	10	10	30	6.4	1.81	10.16	28.4
Ethylbenzene	10	10	5	6.4	1.81	10.16	29.8
	10	10	15	6.4	1.81	10.16	31.0
	10	10	30	6.4	1.81	10.16	31.0
m-Dichlorobenzene	10	10	15	6.4	1.81	10.16	14.1
	10	10	30	6.4	1.81	10.16	22.6
o-Dichlorobenzene	10	10	5	6.4	1.81	10.16	12.0
	10	10	15	6.4	1.81	10.16	12.1
	10	10	30	6.4	1.81	10.16	18.1
Naphthalene	10	10	15	6.4	1.81	10.16	8.1
	10	10	30	6.4	1.81	10.16	1.3

Packing type: Berl Saddles

CHAPTER III

MATERIALS AND METHODS

Program of Study

This research project was conducted in two separate phases that were mentioned in the objectives defined previously. The chemical compounds studied were: toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, 1-chloronapthalene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene.

Phase one of this study examined the effect of temperature on Henry's constant. The Henry's constant of a compound is an important parameter affecting the design and performance of an air-stripping tower. Its effects on the values of $K_l a$ and $K_g a$ (Equations 2.14 and 2.18), along with its appearance in Equation 2.85, are testimony to its impact. Thus, the water temperatures of 10°, 25°, 35°, and 55°C (each of 15 organic compounds in distilled water) were chosen to assess the effects of temperature on Henry's constant. The experimental results were compared to the results of other methods (equations) used to predict the Henry's constant dependence on temperature.

In a second major phase of this study, the overall volumetric mass transfer coefficients ($K_l a$) were measured for 15 volatile and slightly-volatile organic compounds. These $K_l a$ values were determined using

Ceramic Intalox saddles packing, while varying the temperature of water from 15° to 55°C, the temperature of air from 5° to 25°C, and the gas-to-liquid ratios from 30 to 150. These data were used to estimate the accuracy of the Reference Method (48) and the Onda correlations (56) for predicting K_1a values.

Gas Chromatography Analysis

Samples collected during both phases of this research were analyzed using a Tracor 565 Gas Chromatograph (GC) equipped with an FID and a 1.83 m by 6.4 mm o.d. glass column packed with 4% SE-30/6% SP-2301 on 100/120 mesh Supelcoport. The oven temperature was programmed from 40°C (isothermal, 4 minutes) to 250°C (isothermal, 5 minutes) at a rate of 9°C/minute. The helium carrier gas flow rate was 35 ml/minute. The injection temperature was 230°C and the FID temperature was 250°C.

Dilution Curve

Dilution curves (standard curves) were developed to show that the peak areas, for both volatile and slightly-volatile organic compounds used in this study, could be linearly related to the known mass. These dilution curves were made only to confirm that they were linear throughout the mass ranges used in this study.

In these experiments, the volatile and slightly-volatile organic compounds were dissolved in aqueous methanol. These dissolved compounds were injected into the gas chromatograph in quantities of 12.5, 25, 50, 75, 125, 175, 200, 250, 500, and 750 ng. The dilution series of the various compounds was tested for a correlation between the gas chromatograph peak areas and masses by linear correlation analyses. The results

showed that the gas chromatograph response for all the compounds used in this research were linear over the mass range of interest. Table IV shows the linear correlation coefficients of these experiments.

TABLE IV

DILUTION CURVE LINEAR REGRESSIONS
CONTAINING 12.5 - 750 NG OF
EACH COMPOUND

Compound	Correlation (r)
Toluene	0.9463
Chlorobenzene	0.9500
Ethylbenzene	0.9766
Tetrachloroethane	0.9217
1,3-Dichlorobenzene	0.9455
1,2-Dichlorobenzene	0.9977
Nitrobenzene	0.9442
Napthalene	0.9982
1-Chloronapthalene	0.9411
2,6-Dinitrotoluene	0.9947
Fluorene	0.9315
2,4-Dinitrotoluene	0.9923
Hexachlorobenzene	0.9919
Phenanthrene	0.9909
Fluoranthene	0.9406

Effect of Temperature on Henry's Constant

Gosset et al (12) determined Henry's constant for six organic compounds in batch air stripping over a limited temperature range of 10° to 30°C. In this study, the measurement of Henry's constant was conducted in a manner very similar to the procedure used by Gosset et

al. (12) and MacKay (76). The most noticeable differences were the temperature ranges and type of chemical compounds used.

Preparation of the Stock and Feed Solutions for the Effects of Temperature on Henry's Constant

Two stock solutions were prepared for use in determining the effects of temperature on Henry's constant. The first stock solution contained toluene, chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, and 1-chloronapthalene (organic-unsaturated stock solution). The concentration of each of these compounds in the stock solution was 4.0 mg/ml. This stock solution was made up in methanol. Only 1 ml of this solution was prepared and it was stored at 4°C in a 1 ml glass vial, to minimize available head space, with a Teflon lined cap. The second stock solution was composed of 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene (organic-saturated stock solution). Each of these compounds are solid and are only slightly soluble in water. The concentration of each of these compounds in the stock solution was 4.0 mg/ml. This stock solution was also made up in methanol. Only 1 ml of this solution was prepared and it was stored at 4°C in a 1 ml glass vial.

The feed solution was prepared by combining and diluting the two stock solutions. The second stock solution (1 ml) was added to 1600 ml of distilled water in a 2000 ml volumetric flask. The flask was capped, shaken vigorously for 10 minutes, and allowed to stand undistributed for 1 hour. This solution consisted of a layer of saturated water floating over a layer of undissolved organic compounds. In order to obtain a composite (feed) solution that contained all 15 compounds, 1 ml of the

first stock solution was introduced into the 2 liter volumetric flask containing the second stock solution. The flask was capped tightly and shaken for a few minutes. Only 1 liter of this composite solution was withdrawn from the center (top layer) of the 1 liter flask and placed into a 1 liter volumetric flask. This flask was capped tightly and stored at 4°C.

The Stock Solution

It is felt that a short word of explanation about the stock solution is in order. The first stock solution contained toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, and 1-chloronapthalene at a concentration of 2.5 mg/l. Due to the relatively high solubility of these compounds in water (Table VI), this concentration is easily achievable.

The second stock solution contained 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene. Each of these compounds are only slightly soluble in water. In fact, the exact water solubility of some of these compounds has not been determined (Table VI). This posed a potential problem. In order to avoid this problem, organic-saturated stock solutions were prepared. This technique of using organic-saturated stock solutions for hydrophobic compounds was also used by Gosset et al. (12) in their work on stripping towers.

To prepare the organic-saturated stock solution, 4.0 mg of each of the six compounds (second stock solution) was placed in a 2000 ml volumetric flask containing 1600 ml of distilled water. The flask was

shaken vigorously for 10 minutes then allowed to set undistributed for 1 hour. Upon inspection, it could be seen that some of the solids that had previously dissolved in methanol had precipitated to the bottom of the flask. However, it was believed that enough of each compound had remained dissolved to form a saturated solution. While this means that the initial concentrations of the six compounds in this stock solution are unknown and can only be estimated from available solubility data, this can be dealt with. An advantage of using a saturated solution of these low solubility compounds is that it allows the investigators to view a larger range of percent removals due to part of the detection limits of the GC.

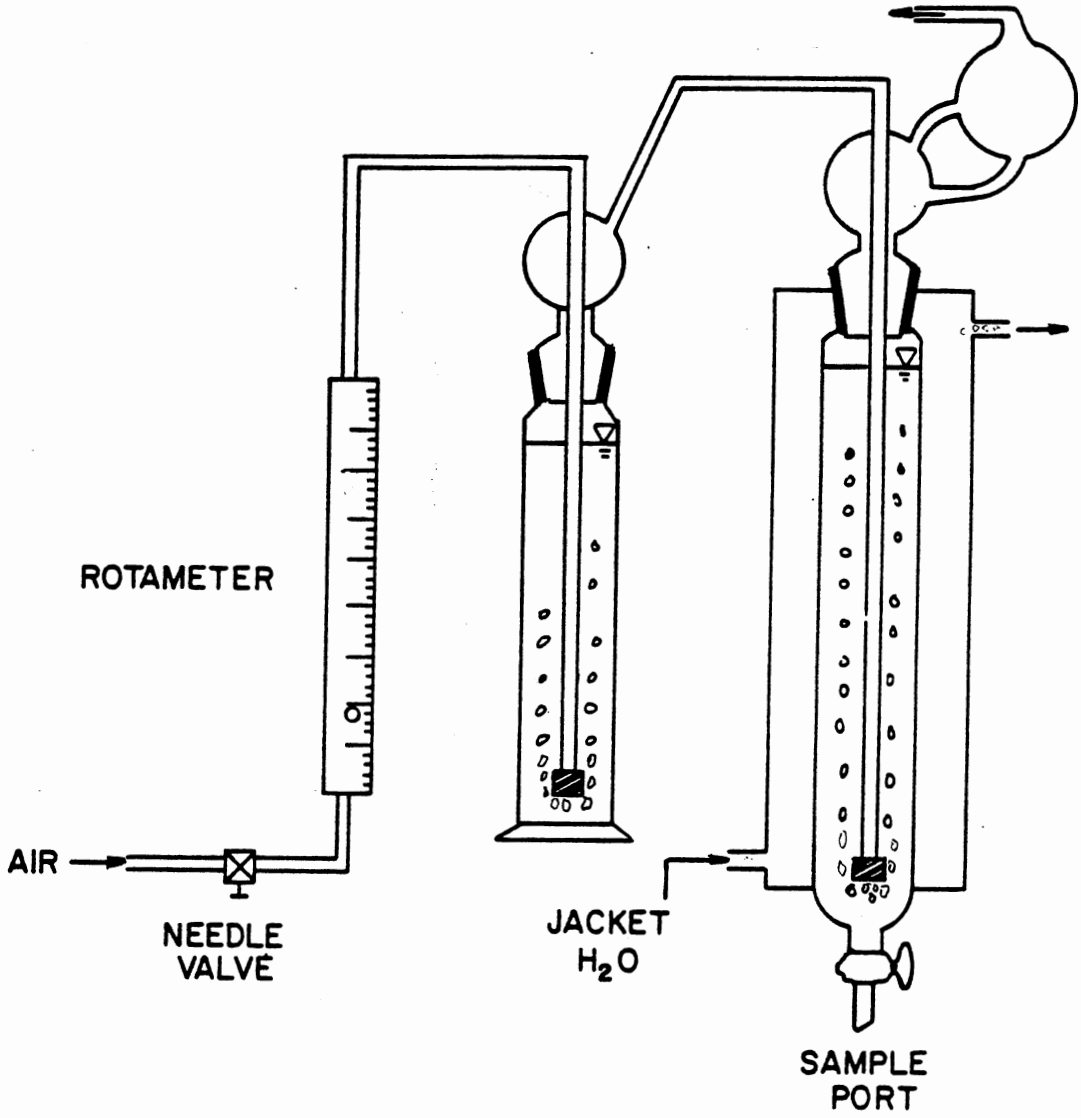
In the stripping tower experiments, three influent samples were taken and the average concentration in the feed solution could be determined from these samples. Whereas in the tests for the Henry's constant a sample was taken at time 0 and this was used to determine the initial feed concentration. At any given water temperature the concentration of the constituents of both stock solutions (first and second) in the feed solution varied by $\pm$ 20%. Since solubility is influenced by temperature, the concentration of the compounds making up the organic-saturated stock solution appeared in larger concentrations in the warmer feed solutions (i.e., 55°C).

Table IV presents the linear regression coefficients (between peak area and mass) for the standard curve (dilution curves) developed in the project. Since the correlation coefficients are very strong and most of the calculations used in this investigation use ratios, i.e., C_{in}/C_{out}, knowledge of the relative concentrations or mass should suffice. In this case, the relative peak areas were used in the calculation since

concentration over concentration or area over area both yield a dimensionless ratio. This was done as a time saving step due to the vast amount of data collected and calculation required in this project. However, this procedure was adopted only after it was compared against calculations made using concentration (or mass) ratios for tetrachloroethane. Tetrachloroethane has the weakest correlation coefficient, r = 0.9217, of all compounds tested and would, therefore, introduce the most error into the calculations using area ratios instead of mass ratios. For percent removal calculations, the area ratio method yielded results only 3.7% less than those using the actual mass. It was felt that this was well within the errors of the analytical procedures used in this project.

Determination of Henry's Constant by Batch Air Stripping

A tube reactor in 1 liter capacity was used for all batch air stripping Henry's constant determinations. The apparatus is shown in Figure 3. When the stripping column was full, the distance from the air stone to the liquid surface was approximately 50 cm. The entire reactor was operated isothermally, with water run continuously through a water jacket. The temperature of the system was controlled by recirculating hot or cold water from a 57 liter water bath (Precision Lo/Temptrol). The gas temperature was measured. During the longest stripping run, 30 minutes, in the batch reactor, the maximum variation of gas temperature observed was 0.4°C. The air was saturated with water vapor before entering the batch stripping reactor to prevent any loss of volume by evaporation.



Source: Gosset, "Solute Gas Equilibria in Multiorganic Aueous System," (1983).

Figure3. Batch Air-Stripping Apparatus

The following basic procedure was used in the temperature studies of Henry's constant for all air stripping experiments. One liter of distilled water containing the 15 saturated and unsaturated organic compounds was placed in the reactor. The controlled water temperature and water jacket were adjusted to the desired study temperature. The system was thermally equilibrated for approximately 1 hour to allow it to reach the correct experimental temperature. The air flow was turned on and adjusted to within the range of 350 to 400 ml/min. To confirm thermal equilibration of the system, the water and air temperatures were rechecked. Also, the inlet and outlet air flow rates were rechecked. Using a graduated cylinder, eight 25 ml samples were collected from the sample port for each Henry's constant determination, a 0, 1, 3, 5, 10, 15, 20, and 30 minutes. The samples collected were poured into 25 ml glass vials with teflon septum, capped sealed, labeled, and stored at 4°C until analysis. The same procedure was repeated three times at the same water temperature.

The apparatus, shown in Figure 3, used for Henry's constant determinations, depends upon two critical assumptions (76): (1) the liquid in the reactor must be completely mixed, (2) the concentration of organic compound in the exiting gas must reach equilibrium with the surrounding liquid before leaving the liquid surface. Under these assumptions, expressions can be derived which describe the removal efficiencies of volatile and slightly-volatile solvents from the batch reactor with time.

When the volume of the sample (25 ml) in the batch reactor was removed at each time interval, the liquid volume was reduced with each sequential sampling. From the previous assumptions regarding being

completely mixed and gas/liquid phase reaching equilibrium, purging during the ith interval can be defined as (12):

$$V_i \left(\frac{dC}{dt}\right) = \frac{-PG}{RT_g} \tag{3.1}$$

where: V_i = reactor sample volume during the ith interval, m^3
G = volumetric of air flow rate, m^3/min
R = gas constant = 8.2056×10^{-5} $(m^3\text{-atm})/(mole\text{-}°K)$
P = partial pressure of the solute substance in the gas phase, atm
T_g = temperature at which gas flow measured, °K

Equilibrium between a solute and its vapor is given by Henry's law as

$$P = HC \tag{3.2}$$

where: C = solute concentration in the liquid phase, $mole/m^3$
H = Henry's constant, $m^3.atm/mole$

Substitute partial pressure of the solute, P, into Equation 3.1

$$V_i \left(\frac{dC}{dt}\right) = \frac{-HC\ G}{RT_g} \tag{3.3}$$

rearranging,

$$\frac{dC}{C} = \frac{-H\ Gdt}{RT_g V_i} \tag{3.4}$$

Integrate:

$$C_i = C_{i-1} \quad \exp \quad \frac{-HG\ \Delta t_i}{RT_g V_i} \tag{3.5}$$

where: C_i = reactor concentration at the end of the ith interval, $mole/m^3$
t_i = time of ith interval, minutes

Thus:

$$\ln C_i = \ln C_o - \frac{HG}{RT_g} \sum_{i=1}^{i} \frac{\Delta t_i}{V_i} \tag{3.6}$$

where: C_o = initial concentration at time = 0, $mole/m^3$

A plot of $\ln(C_i/C_o)$ versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ should yield a straight line with a slope equal to $-HG/RT_g$. Therefore, H can be calculated.

The Temperature Dependence on Henry's Law Constant Equation

Goldstein (77) has presented equations to predict Henry's law constant by using a relationship with temperature. The following equations related to the compounds used in this study were developed by Goldstein (77).

Toluene

$$\log H(\text{mm Hg}) = 6.950 - \frac{1345}{(T + 219)} + \frac{1192}{(T + 273)}$$

Chlorobenzene

$$\log H(\text{mm Hg}) = 6.845 - \frac{1431}{(T + 218)} + \frac{1274}{(T + 273)}$$

Ethylbenzene

$$\log H(\text{mm Hg}) = 6.286 - \frac{1424}{(T + 213)} + \frac{1529}{(T + 273)}$$

Tetrachloroethane

$$\log H(\text{mm Hg}) = 7.540 - \frac{1683}{(T + 234)} + \frac{960}{(T + 273)}$$

1,3-Dichlorobenzene

$$\log H(\text{mm Hg}) = 7.300 - \frac{1782}{(T + 230)} + \frac{1407}{(T + 273)}$$

1,2-Dichlorobenzene

$$\log H(\text{mm Hg}) = 7.070 - \frac{1650}{(T + 213)} + \frac{1421}{(T + 273)}$$

Nitrobenzene

$$\log H(\text{mm Hg}) = 6.856 - \frac{1740}{(T + 200)} + \frac{1141}{(T + 273)}$$

Napthalene

$$\log H(\text{mm Hg}) = 7.010 - \frac{1734}{(T + 202)} + \frac{1473}{(T + 273)}$$

1-Chloronapthalene

$$\log H(\text{mm Hg}) = 9.930 - \frac{1644}{(T + 273)}$$

2,6-Dinitrotoluene

$$\log H(\text{mm Hg}) = 7.450 - \frac{1238}{(T + 273)}$$

Fluorene

$$\log H(\text{mm Hg}) = 8.060 - \frac{1301}{(T + 273)}$$

2,4-Dinitrotoluene

$$\log H(\text{mm Hg}) = 7.450 - \frac{1238}{(T + 273)}$$

Hexachlorobenzene

$$\log H(\text{mm Hg}) = 9.836 - \frac{4630}{(T + 356)} + \frac{2138}{(T + 273)}$$

Phenanthrene

$$\log H(\text{mm Hg}) = 7.260 - \frac{2379}{(T + 204)} + \frac{2022}{(T + 273)}$$

Fluoranthene

Data uncertain

where: T = temperature in °C

Packed Tower Air Stripping Studies

This study is an outgrowth of preliminary work conducted by Pakanati (11) at Oklahoma State University, in which he found water temperature to be more dominant than air temperature for the removal of volatile and a slightly-volatile (nitrobenzene) organic compounds. Specifically this study intends to examine the process of using elevated water temperatures for removing volatile and slightly-volatile organic compounds. The project is aimed toward compounds that are predominately liquid phase controlled, Henry's law constant less than 6×10^{-3} atm.m^3/mole. By increasing the energy state of the controlling phase, liquid, the volatility of the lesser volatile compounds will be raised, therefore, making them amenable to removal by stripping. The data collected in

this work were used to evaluate the accuracy of the Reference Methods and Onda correlations for predicting overall mass transfer coefficients in packed tower air stripping of dilute, volatile and slightly-volatile organics over a range of water temperatures. A list of the chemical compounds used in this study along with their volatility are shown in Table V. Volatility was based on type of GC column to elute the compound (i.e., volatile or non-volatile column) (78).

TABLE V

CHEMICAL COMPOUNDS AND THEIR VOLATILITY

Compound	Volatility
Toluene	Volatile
Chlorobenzene	Volatile
Ethylbenzene	Volatile
Tetrachloroethane	Volatile
1,3-Dichlorobenzene	Volatile
1,2-Dichlorobenzene	Volatile
Nitrobenzene	Slightly Volatile
Napthalene	Slightly Volatile
1-Chloronapthalene	Slightly Volatile
2,6-Dinitrotoluene	Slightly Volatile
Fluorene	Slightly Volatile
2,4-Dinitrotoluene	Slightly Volatile
Hexachlorobenzene	Slightly Volatile
Phenanthrene	Slightly Volatile
Fluoranthene	Slightly Volatile

Equipment

Packed Column

The experimental apparatus is shown in Figure 3. The system was composed of a glass column with an inside diameter of 7.52 cm (3 in) and

a length of 1.83 m (6 ft). The column consisted of three different sections, a 1.4 m (4 ft) high center piece, open at both ends, and two 0.35 m (1 ft) long end pieces each sealed at one end. The inlet and outlet ports for the gas and liquid streams and the manometer ports were placed in the end pieces. The three pieces were connected with two 88 mm (3 in) stainless steel clamps having teflon gaskets. A 6mm (1/4 in) hardware cloth having a diameter equal to the inside diameter of the column was fixed in place between the center column and the lower end piece to hold up the packing. The teflon gasket in the stainless clamp supported the hardware cloth. The entire column was insulated and then mounted at the top and bottom with steel clamps on an 0.91 m x 1.22 m (3 ft x 4 ft) sheet of plywood. The plywood board was supported by vertical cross members to form a stand.

A water-filled manometer was connected to the column by two pieces of tygon tubing as shown in Figure 4. A three-way valve was placed in the tubing connecting the lower section of the column. The pressure difference across the packing was measured as the difference between the water levels in the two manometer arms when the three-way valve connected the manometer with the lower section of the column. The column pressure, above ambient, at the end of the column was measured by opening the manometer, connected to the lower section of the column, to the atmosphere using the three-way valve. The manometer also was mounted on the plywood board.

Liquid Flow System

Twenty-five liter glass bottles were used as the liquid feed reservoirs. The water in the bottles was adjusted to the desired feed water

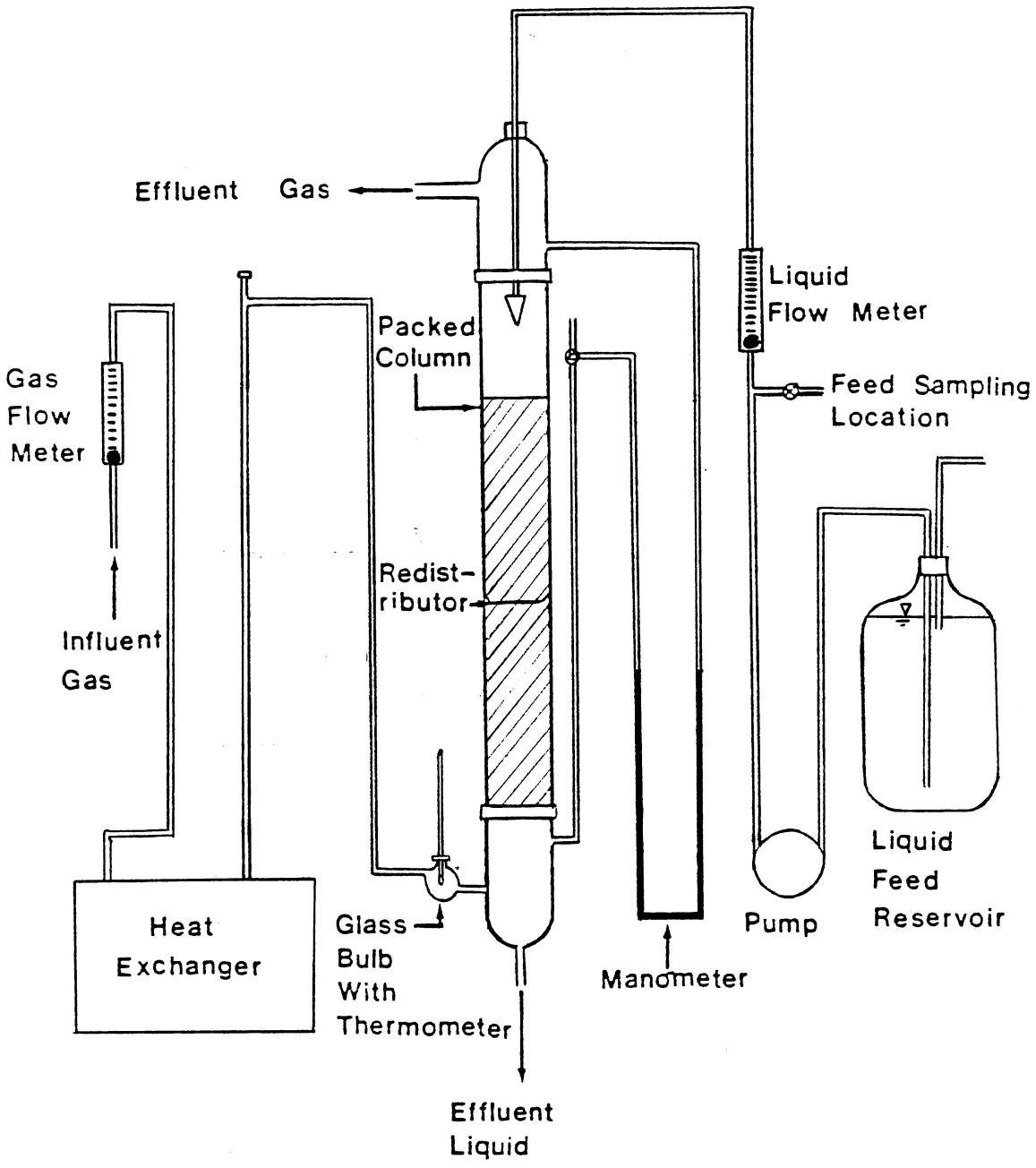


Figure 4. Packed Column Apparatus

temperature. The bottles were positioned at a height about 7.5 cm (3 in) higher than the liquid feed pump to provide a positive pressure on the pump. A variable speed Masterflex peristaltic pump, with a 7018 head, was employed to pump the feed solution. Liquid was withdrawn through a glass tube extending to the bottom of the glass bottle, through a two-holed rubber stopper. Through the other hole, a short glass tube packed with glasswool was inserted to serve as a vent. An 8 mm (5/16 in) i.d. teflon tube was employed to carry the liquid to the top of the column. A Dwyer "Rate-Master" flow meter, model RMB-84-SSV, with a stainless steel float and a control valve at the inlet, was placed in the line above the pump to measure the water flow rate. The flowmeter was able to measure from 0.2 to 2.4 liters/min. The flowmeter was mounted on the plywood sheet. Ahead of the flowmeter a glass "T" was inserted in the line. A glass valve was connected to the free end of the "T" to facilitate feed sampling. Stainless steel clamps were employed at all joints.

The influent was introduced into the column through a 6 mm (1/4 in) steel pipe passing through a screw-type glass adaptor, placed at the top center of the upper end piece of the column. The adaptor provided an airtight seal. A 6.35 cm (2 1/2 in) O.D. steel shower spray nozzle was connected to the end of the steel pipe. This pipe extended down into the column and allowed a 15 cm (6 in) distance between the nozzle and the packing. To hold the steel pipe (and the nozzle) at the center and away from the sides of the column, it was passed through a 6 mm (1/4 in) hardware cloth fixed in the upper steel clamps. An even distribution of the liquid over the top of the packing, for different liquid flow rates, was maintained by adjusting the orifice of the nozzle.

The effluent from the column exited through a glass port at the bottom of the lower end piece of the column. The effluent flow was controlled by raising the effluent tube to an appropriate height over the glass port. Liquid flow rate was measured at the column drain using a 2 liter volumetric flask and a stopwatch to calibrate the flowmeter exactly at each flow rate.

Gas Flow System

Laboratory compressed air was employed as the gas supply to the column. The gas was first passed through a Dwyer "Rate-Master" flowmeter, model RMB-57-SSU, mounted on the plywood board next to the water flowmeter. Teflon tubing, 8 mm (5/16 in) in diameter, was employed to carry the gas from the flowmeter to the column.

From the flowmeter the gas was passed through a heat exchanging coil. The coil consisted of two 15 m (50 ft) long, 1 cm (3/8 in) copper tubing wound side by side into a 0.3 m (1 ft) diameter ring. The two coils were brazed together for better heat conductivity. Hot or cold water from a 57 liter "Precision Lo/Temptrol" water bath was circulated through one of the tubes, while the gas passed through the other tube in the opposite direction. The heat exchanger was located in a corrugated box filled with styrofoam packing peanuts to serve as insulation. Once equilibrium was reached, the heat exchanging system was capable of maintaining the required constant gas temperature for an extended period of time, at all combinations of temperatures and gas flows.

The gas from the heat exchanger was then entered the column through a 2 cm diameter glass bulb connected to the inlet port of the column. A thermometer was inserted into the center of the glass bulb through an

airtight thermometer adaptor to measure the gas temperature. The complete gas line system from the heat exchanger to the inlet port of the column was insulated with pipe wrap.

The gas which was introduced above the liquid level, in the lower end piece of the column, passed through the packing and exited the column through a 2 cm exit port placed in the upper end piece of the column. A 2 cm rubber hose connected to the exit port removed the off-gas out of the room, through a nearby window, and released it to the atmosphere.

Procedures

Packing the Column

The following procedure was employed to pack the column. The upper end of the column was removed. The manometer port and the liquid exit port in the lower end piece of the column were clamped shut. The gas inlet line to the column was temporarily disconnected at the glass "T" near the gas sampling port and held at a height of about 15 cm below the top of the center piece of the column. The column was filled with water until it was overflowing through the disconnected end of the gas line. Ceramic Intalox saddles, 0.95 cm (3/8 in) in diameter, were used as packing material. The packing material was poured through the standing water in small batches until a 0.6 m depth of the packing was reached. A plastic funnel, with the bottom cut off, having a diameter at the top equal to the inside diameter of the column, was positioned at the mid-depth of the packing to serve as a redistributer. The water from the overflow was collected and measured. This gave the volume displaced by the packing alone. The void volume was calculated from this and the

total volume of the packed bed, and was found to average 78% of the total bed volume. The tower was then drained, the gas line reconnected, and the upper end piece of the column replaced. The same procedure was repeated at 0.9 and 1.2 m bed depths, and the average void volumes were determined to be 75 and 80%, respectively.

Gas and Liquid Loading Rates Studies (Flooding)

At 0.6 m bed depth, the liquid feed pump was turned on and set at a flow rate of 18.95 l/hr (5 GPH) on the flowmeter. The pump was allowed to run for sufficient time to warm up and reach a constant pumping rate. The flow rate was measured at the column drain using a 2 liter volumetric flask and a stopwatch. Keeping the liquid flow rate constant, the gas flow rate was increased in increments of 708 l/hr, starting from zero to a point at which column flooding was observed. At each gas flow, the pressure drop across the packing and the column pressure at the top of the packing were measured and recorded. The gas flow rate at the column flooding was noted and the gas-to-liquid ratio at the point of flooding was calculated. The liquid flow rate was raised in increments of 18.95 l/hr until it reached 151.6 l/hr; the entire process was repeated at each flow rate. The same procedure was repeated at 0.9 and 1.2 m bed depths.

Preparation of Stock and Feed Solutions for
Packed Tower Air Stripping Studies

Two stock solutions were prepared and combined to make the feed solution for packed tower air stripping studies. The first stock solution contained toluene, chlorobenzene, ethylbenzene, 1,3-dichlorobenzene,

1,2-dichlorobenzene, nitrobenzene, napthalene, and 1-chloronapthalene (organic-unsaturated stock solution). The concentration of each of these constituents in the stock solution was 2.5 mg/ml. This stock solution was made up in methanol. Twenty-five ml of this solution was prepared and it was stored at 4°C in a 40 ml glass vial with a teflon line septum cap. The second stock solution was composed of 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene. Each of these compounds are solids and are only slightly soluble in water. The concentration of each of these constituents in the second stock solution was 2.5 mg/ml. This stock solution was made up in methanol. Twenty-five ml of this solution was prepared and it was stored at 4°C in a 40 ml glass vial with a teflon lined septum cap.

To make the composite (feed) solution, the second stock was added to 25 liters of tap water in a 26.5 liter bottle. The bottle was capped, shaken vigorously for 10 minutes, and allowed to stand undistributed for 1 hour. This solution consisted of a layer of saturated water floating over a layer of undissolved organic compounds. In order to obtain a composite solution that contained 15 compounds, 25 ml of the first stock was introduced into the 26.5 liter bottle containing the second stock solution. The bottle was capped tightly and shaken for a few minutes. Twenty liters of composite solution was withdrawn from the center (top layer) of the 26.5 liter bottle and transferred to a second 26.5 liter bottle. To provide an adequate volume of feed to the air stripping tower, four 26.5 liter bottles were used to composite and mix the two stock solutions. Twenty liters from three of these bottles were then transferred into three clean 26.5 liter bottles. Five liters from the remaining fourth bottle was transferred into each of the three

bottles containing 20 liters to give them a total of 25 liters per bottle. The composite solutions were capped and stored at 4°C. A list of feed solution compounds and their properties is shown in Table VI.

TABLE VI

FEED SOLUTION COMPONENTS AND THEIR PROPERTIES

Compound	Boiling Point (°C)	Molecular Weight (gm/gm.mole)	Solubility (mg/1)	Vapor Pressure (mm.Hg)	Estimated* Henry's Constant (H_c)
Toluene	111.0	92.14	515	28	0.27[b]
Chlorobenzene	132.0	117.6	448	15	0.19[c]
Ethylbenzene	136.0	106.1	152	7	0.27[a]
Tetrachloroethane	147.0	167.9	3000	6.5	0.02[b]
1,3-Dichlorobenzene	172.0	147.0	123	2	0.13[a]
1,2-Dichlorobenzene	179.0	147.0	100	1	0.081[a]
Nitrobenzene	210.0	123.0	1900	0.15	0.0005[a]
Napthalene	127.7	128.2	30	0.87	0.017[a]
1-Chloronapthalene	259.3	162.6			
2,6-Dinitrotoluene	285.0	182.1			
Fluorene	298.0	166.2	1.90	0.012	0.0564[b]
2,4-Dinitrotoluene	300.0	182.1			
Hexachlorobenzene	332.0	284.8	0.100	0.0034	0.0006[b]
Phenanthrene	340.0	178.2	1.18		
Fluoranthene	384.0	202.3			

*Innovative and Alternative Technology Assessment, EPA-430/9-78-009.
[a]20°C.
[b]25°C.
[c]30°C.

The following procedure was followed to obtain the three different temperatures for the feed water. The cold and hot water from the tap had an average temperature of 15° and 60°C, respectively. For the 15°C feed solution, about 25 liters of cold tap water was collected directly in a 25 liter glass bottle. The water temperature remained constant at

this temperature for a long time period and at most increased 1°C over a period of 3 hours. To prepare the 35°C water, 14 liters of hot water were added to about 11 liters of cold tap water in a 25 liter glass bottle. For 55°C water, about 22.5 liters of hot water were added to about 2.5 liters of cold tap water in a 25 liter glass bottle. After the feed water was adjusted to the desired study temperature, a 2 in long teflon coated magnetic stirring bar was then placed at the bottom of the bottle and the stirrer was turned on. The water was stirred about 6, 3, and 1 hours for the feed water temperatures 15°, 35°, and 55°C respectively.

Column Operation

The stripping of the volatile and slightly volatile organic compounds were studied under several different conditions: three different gas-to-liquid ratios, three water temperatures, three air temperatures, and three different bed depths. The gas and liquid flow rates used were obtained from the hydraulic loading studies and were one-half those that would cause flooding at each ratio. Table VII contains the experiment values of gas-to-liquid ratios (G/L), tower depths, water temperatures, and air temperatures.

To begin each run, the water batch was turned on and the thermostat was adjusted to the required temperature. When the water batch reached a temperature close to the desired air temperature, the gas flow was turned on and the desired flow rate set. The gas was allowed to run through the system until the thermometer in the gas line showed a steady temperature. At this point, the temperature of the air entering the column was adjusted exactly to the desired temperature by a trial-and-

TABLE VII

EXPERIMENTAL VALUES

Bed Depth = 0.6 m

Water Temperature (°C)	Air Temperature (°C)	G/L Ratio
15	5	30
15	5	90
15	5	150
15	15	30
15	15	90
15	15	150
15	25	30
15	25	90
15	25	150
35	5	30
35	5	90
35	5	150
35	15	30
35	15	90
35	15	150
35	25	30
35	25	90
35	25	150
55	5	30
55	5	90
55	5	150
55	15	30
55	15	90
55	15	150
55	25	30
55	25	90
55	25	150

All studies were repeated at 0.9 and 1.2 m bed depths.

error adjustment of the thermostat on the water bath. When a steady state temperature was reached, the system was capable of delivering gas to the column at the set temperature for an extended period of time. Once adjusted, the gas flow system was not disturbed until the completion of the run. By adjusting the variable speed controller, the feed pump was set to pump the desired flow. Twenty-five liters of feed water having the same water temperature as the feed solution was first pumped into the column to bring the liquid feedline and the packed column to a thermal equilibrium. The suction tube was then moved to the feed solution bottle and the flow rate of gas and liquid were rechecked.

The sample collection began after 5 liters of the feed solution was pumped into the column. Twenty-five ml glass vials with teflon lined septum caps were used to collect samples to be analyzed for both volatile and slightly-volatile compounds. The influent and effluent of samples were collected in pairs. The influent samples were collected immediately after the effluent samples. Three pairs of samples were collected for each run. At least 5 liters of feed solution was permitted to run through the column between the sample collection to allow adequate time (5 to 10 minutes) for steady state to be reached again. During this period, the pressure drop across the packing, the column pressure at the time, and effluent temperature of water and air were measured. After all samples were collected, the liquid flow rate was rechecked and in all cases was found to be nearly the same as the flow rate set initially. The gas flow was turned off and the feedline suction tube was moved to another 25 liter bottle, and about 15 liters of tap water was pumped into the column to rinse the packing. The samples collected were labeled and stored at 4°C until analysis.

Analytical Techniques

Glassware Cleaning

All glassware was first washed with "Alconox" detergent and rinsed with warm tap water. The glassware was then filled with cleaning nitric acid (1:1) and soaked overnight (12 hours). The acid was removed by sequential rinsing several times with tap and distilled water. The glassware was then oven dried at 200°C for at least 6 hours.

All caps and teflon seals were washed with detergent and rinsed several times with tap water. They were then submerged in distilled water for 24 hours, rinsed several times with distilled water, and oven dried at 50°C at least 6 hours. The cleaned glassware was then sealed with the appropriate caps or stoppers.

Microextraction

Microextraction techniques have been developed to aid in the analysis of organic chemicals. These techniques, coupled with gas chromatography (GC), have been used to analyze a wide variety of volatile and slightly-volatile organic compounds. Rhodes and Nulton (79) stated that four advantages of the microextraction over multiple extractions are: (1) technique is easy to perform, (2) requires minimal use of glassware and sample handling, (3) solvent concentration is not needed, therefore, both volatile and slightly-volatile organic compounds can be analyzed in the same extract, and (4) reliable data is generated with one step extraction method.

In this study, pentane was chosen as the extracting solvent because of its low solubility in water (0.04 gm/l) (79) and its low polarity

which favors easy extraction of an organic solute. Pentane is also a very volatile compound, which is a very suitable quality for GC analyses.

Microextraction Procedure

The same microextraction technique was used on samples obtained in both phases of this study (79, 80). All 25 ml samples were stored at 4°C in glass containers with teflon lined lids. Each 25 ml sample was poured into a 50 ml volumetric flask. Prior to extraction, the sample was saturated with Na_2SO_4. This salt was added to clean water sample. In this experiment, the sample was saturated with approximately 4 gm Na_2SO_4. Next, 100 ul of pentane was added and the volumetric flask was capped tightly with a teflon stopper and shaken very vigorously for 3 minutes. This sample was allowed to stand quietly in an ice bath in contact with extracting solvent pentane for 15 minutes. The teflon stopper was then removed and the volumetric flask was backfilled rapidly with 4°C water until the lower level of pentane rose to the lower part of the neck. The sample was allowed to stand in an ice bath again for 10 minutes. A few microliters of pentane in the neck of the extraction flask could be removed by a microsyringe and injected directly into the column of the gas chromatograph, or the extracted compounds could be removed with a 1 ml (100 ul of solvent plus 900 ul of liquid) syringe and stored at 4°C in a 1 ml glass vial with a teflon lined septum cap for later analysis.

Quality Assurance Studies

Standard Solutions

The standard solutions used in this study, along with the USEPA quality control standards from the USEPA Repository for Toxic and Hazardous Materials standards, were made up in methanol so that they contained approximately a 2.5 mg/l concentration of the compounds of interest. Both standards were analyzed by directly injecting 2 ul of the solution into the gas chromatograph. The electronic integator calculated the peak areas versus mass of the standards injected. Qualitative determination of the standard compounds in this study was made comparing the peak retention times with that of USEPA standard compounds, while quantitative determination was based on the peak areas. Table VIII shows the average (average of 3) percent difference in the mass between the known USEPA standard (250 ng) and the value obtained from the standard curve developed in this project along with the percent difference in area at the 250 ng mass level.

Recovery Test

Sample Solution

Two new stock solutions were prepared for use in determining the extraction efficiency (percent recovery) of the microextraction procedure used in the study. The first stock solution contained toluene, chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, and 1-chloronapthalene (organic-unsaturated stock solution). The concentration of each of these constituents in the stock solution was 2.5 mg/ml. Only 1 ml of this solution was prepared

TABLE VIII

AVERAGE PERCENT DIFFERENCE IN MASS AND AREA BETWEEN STANDARD CURVE DEVELOPED FOR THIS STUDY AND EPA'S QUALITY CONTROL STANDARDS

Compound	EPA Mass (ng)	EPA Mass Read From Standard Curves (ng)	% Difference mass (ng)	% Difference area
Toluene	250.0	287.5	- 15.0	6.5
Chlorobenzene	250.0	230.0	8.0	2.8
Ethylbenzene	250.0	287.5	- 15.0	11.9
Tetrachloroethane	250.0	225.0	11.1	13.4
1,3-Dichlorobenzene	250.0	287.5	- 15.0	5.1
1,2-Dichlorobenzene	250.0	289.5	- 15.0	- 2.6
Nitrobenzene	250.0	230.0	8.0	- 10.6
Napthalene	250.0	240.0	4.0	2.5
1-Chloronapthalene	250.0	235.0	6.0	2.8
2,6-Dinitrotoluene	250.0	270.0	7.4	- 1.8
Fluorene	250.0	287.0	- 15.0	6.8
2,4-Dinitrotoluene	250.0	245.0	4.0	3.0
Hexachlorobenzene	250.0	270.0	7.4	3.0
Phenanthrene	250.0	287.5	- 15.0	1.6
Fluoranthene	250.0	287.5	- 15.0	10.0

and it was stored at 4°C in a 1 ml glass vial to minimize available head space, with a teflon lined septum cap. The second stock solution was composed of 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene. Each of these compounds are solids and are only slightly soluble in water. To insure total dissolution of each of these compounds in the second stock solution, only 0.1 mg of each of these compounds were added to 999 ml of tap water in a 2000 ml volumetric flask. The flask was stoppered and shaken vigorously for 10 minutes. The flask was allowed to stand undistributed

for 1 hour at which time the solution was inspected to verify that all the compounds added had dissolved.

In order to obtain a composite solution that contained all 15 compounds, 1 ml of the first stock solution was introduced into the 2 liter volumetric flask containing the second stock solution. The flask was capped tightly, shaken, and stored at 4°C.

Analyze Organic Compounds in Sample Solution

Three 25 ml of the composite solution were extracted in accordance with the microextraction procedure described previously. The precent recovery shown in Table IX is the average of the three samples extracted. In addition, three samples of a standard solution (2.5 mg/ml) obtained from the USEPA were also extracted as a cross check against the standard prepared by the author.

TABLE IX

RESULTS OF THE AVERAGE PERCENTAGE RECOVERY BY MICROEXTRACTION IN THIS STUDY AND PREVIOUS STUDIES

Compound	Average % Recovery from USEPA Standards	Average % Recovery in This Study	Average % Recovery from Previous Studies
Toluene	80	87	95[a]
Chlorobenzene	95	96	86[b]
Ethylbenzene	94	89	93[a]
Tetrachloroethane	83	89	
1,3-Dichlorobenzene	89	96	
1,2-Dichlorobenzene	96	96	90[b]
Nitrobenzene	68	69	75[a]
Napthalene	83	95	90[a]
1-Chloronapthalene	87	97	
2,6-Dinitrotoluene	77	72	
Fluorene	87	94	91[a]
2,4-Dinitrotoluene	70	68	
Hexachlorobenzene	86	81	87[a]
Phenanthrene	84	90	95[a]
Fluoranthene	88	94	95[a]

[a]Microextraction as an Approach to Analysis for Priority Pollutants in Industrial Wastewater, Rhodes and Nulton (79).

[b]Extraction of Organic Compounds from Water Using Small Amounts of Solvent, Junk, Ogawa, and Svec (80).

CHAPTER IV

RESULTS

Henry's Constant

Measurement of Henry's Constant Effect of Temperature

The accurate measurement of Henry's constant requires that the (experimental) system must be completely mixed and the gas exiting from the liquid is in equilibrium with the liquid with respect to the compound of interest. These requirements were assumed since the apparatus and flow conditions used in this study were similar to those of Gosset et al. (12) and Mackay et al. (76). These authors also assumed these conditions to be met. The experimental derived Henry's constant from the batch air stripping experiments are temperature dependent. The values of $\ln(C_i/C_o)$ and $\sum_{i=1}^{i} (\Delta t_i/V_i)$ are presented in Appendix B, while Figures 5 through 19 show the relationship between $\ln (C_i/C_o)$ and $\sum_{i=1}^{i} (\Delta t_i/V_i)$ for all the compounds used in this study. The plots of the natural log of Henry's constant versus the reciprocal of absolute temperature are shown in Figures 20 through 34. These plots illustrate the temperature dependence of the Henry's constant for each compound used in this study. Table X lists the temperature regression equations and correlation coefficients for each of the compounds used in this study. In this study, the high correlation coefficients obtained in all the experiments

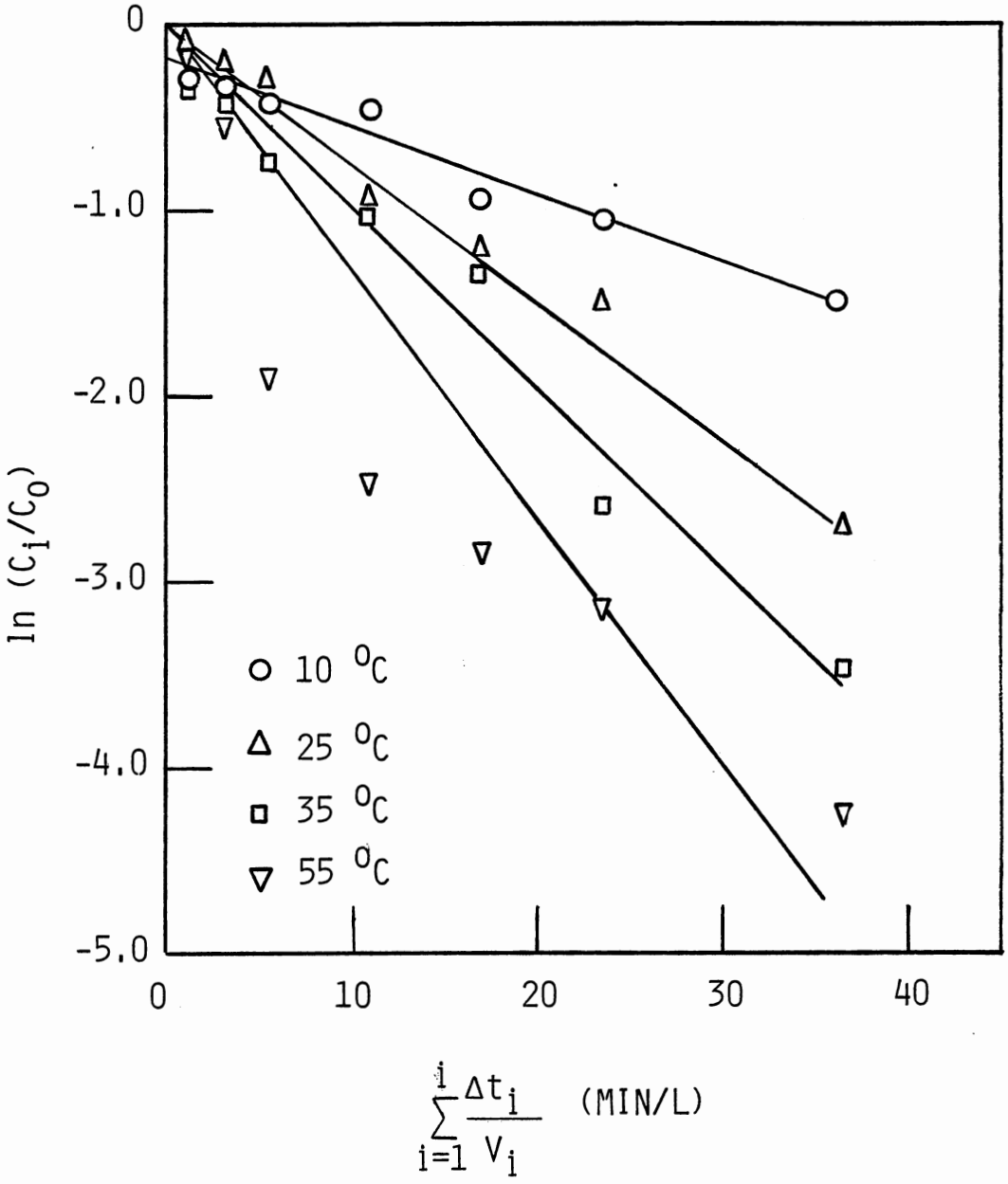


Figure 5. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Toluene

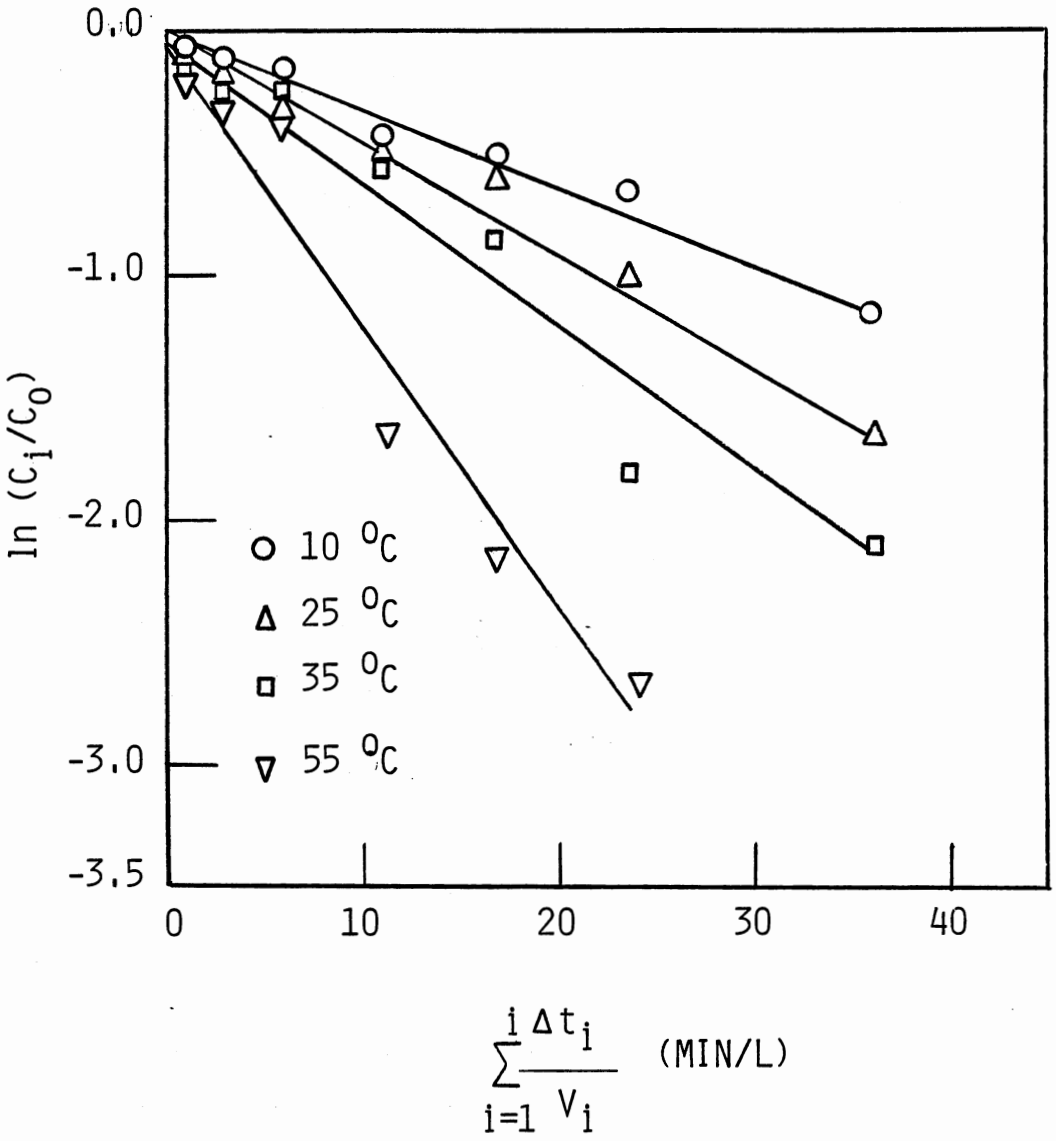


Figure 6. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Chlorobenzene

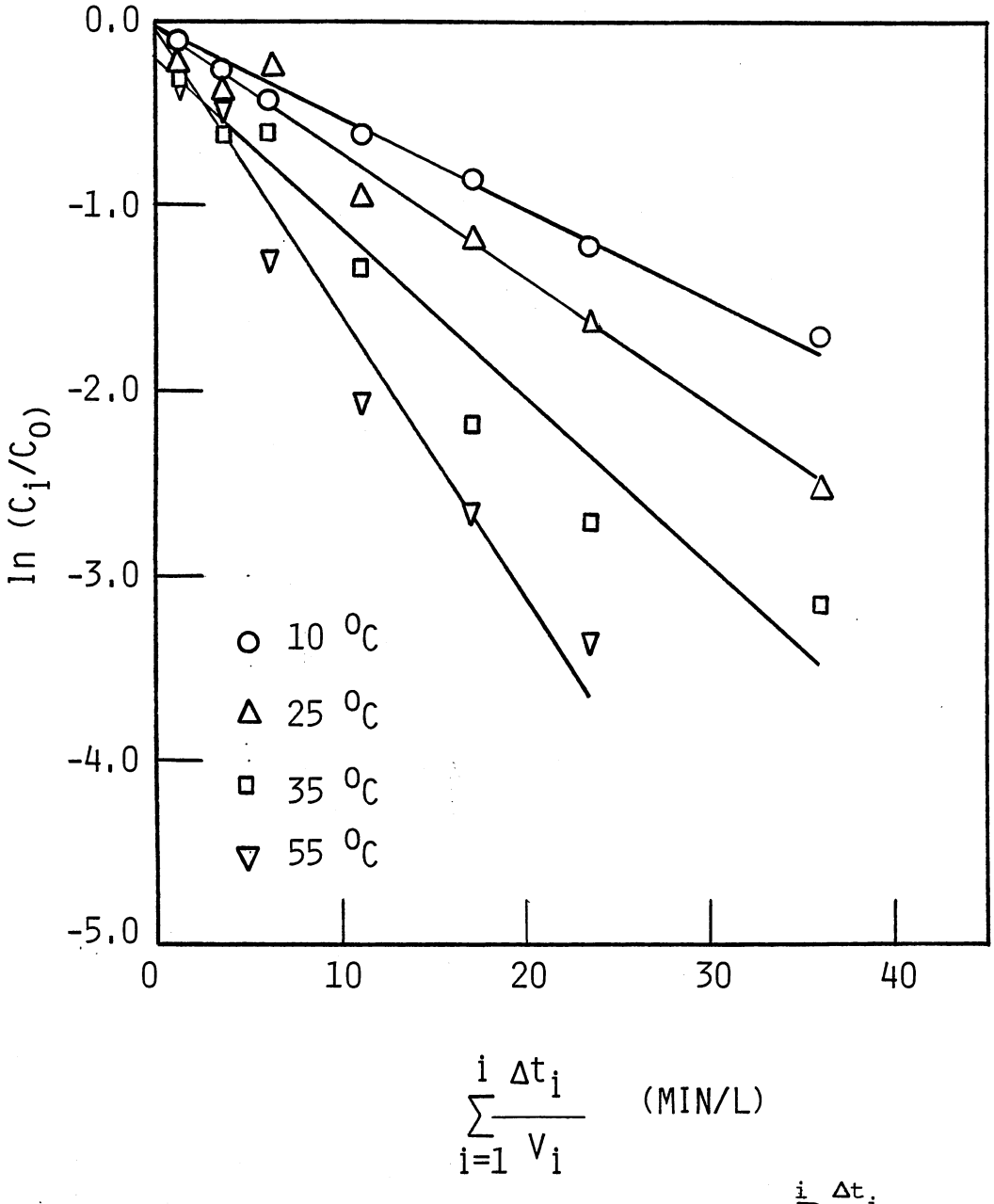


Figure 7. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Ethylbenzene

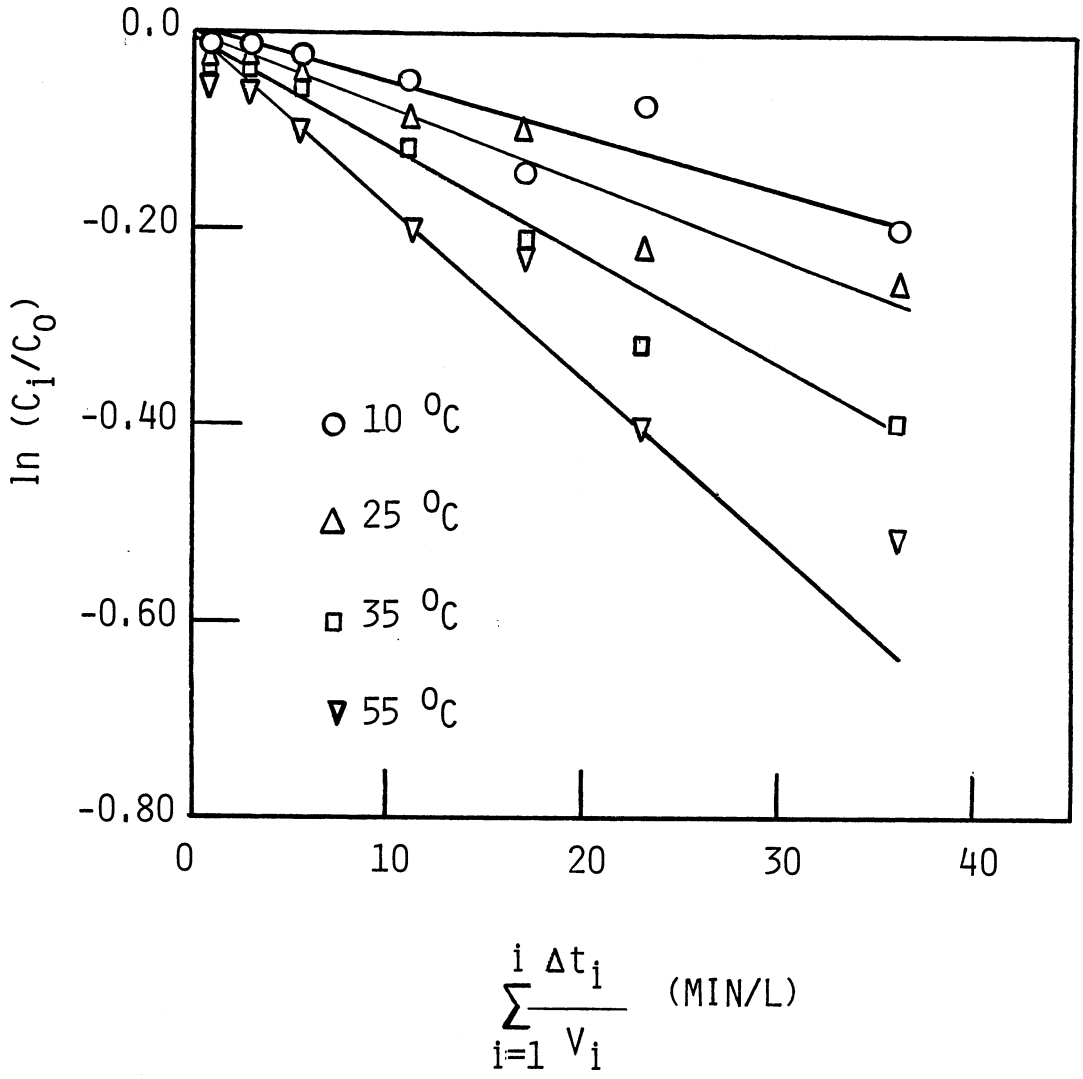


Figure 8. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Tetrachloroethane

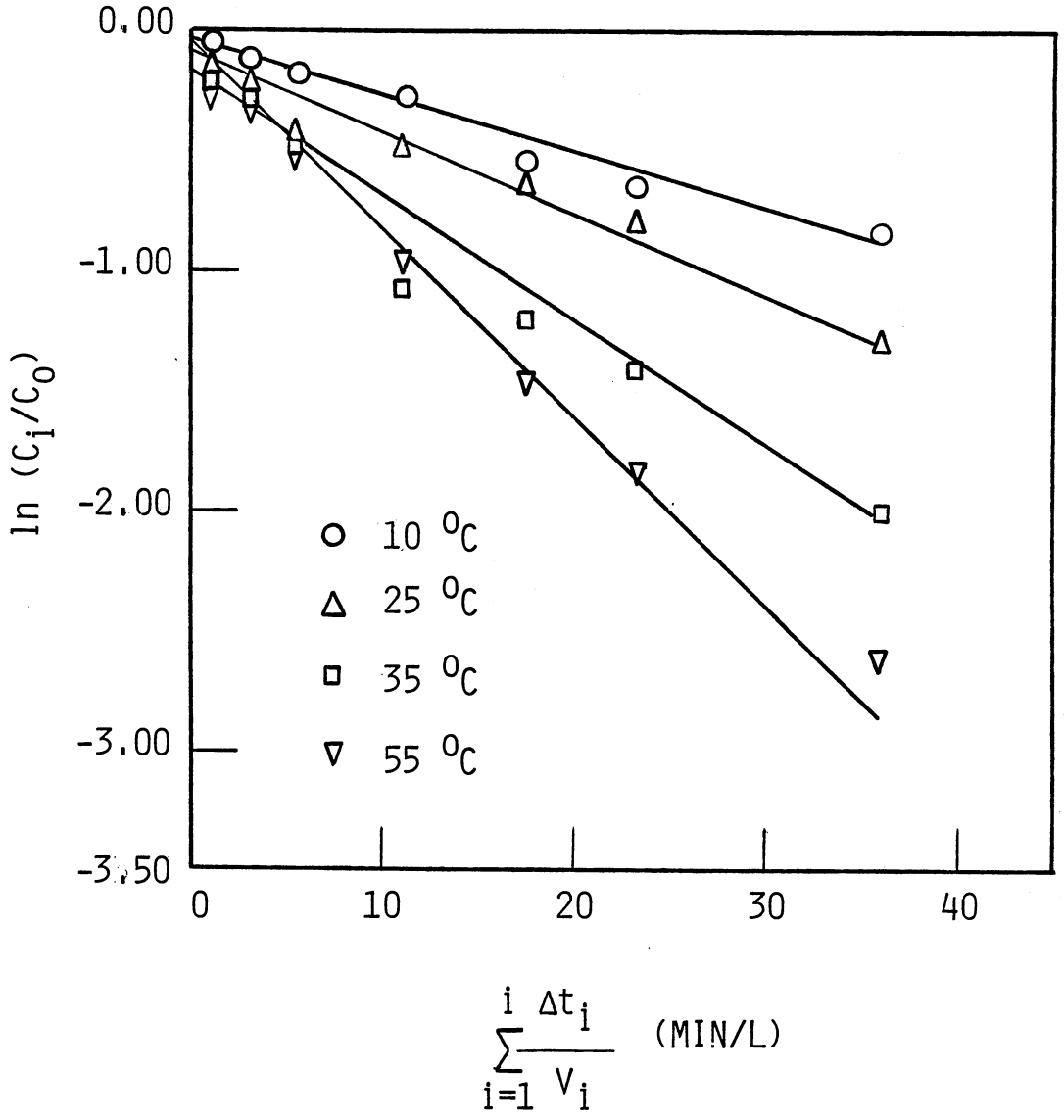


Figure 9. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for 1,3-Dichlorobenzene

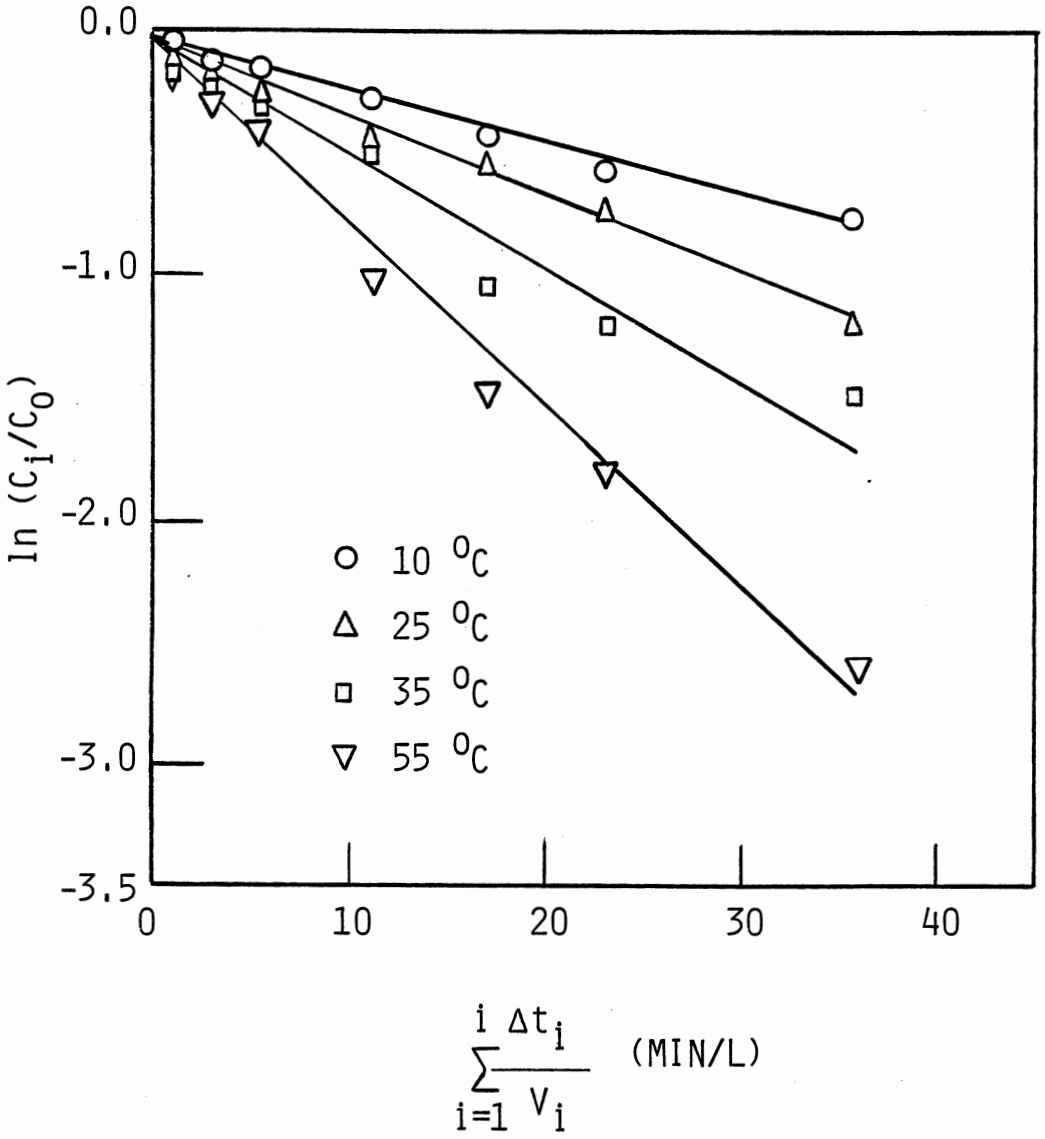


Figure 10. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for 1,2-Dichlorobenzene

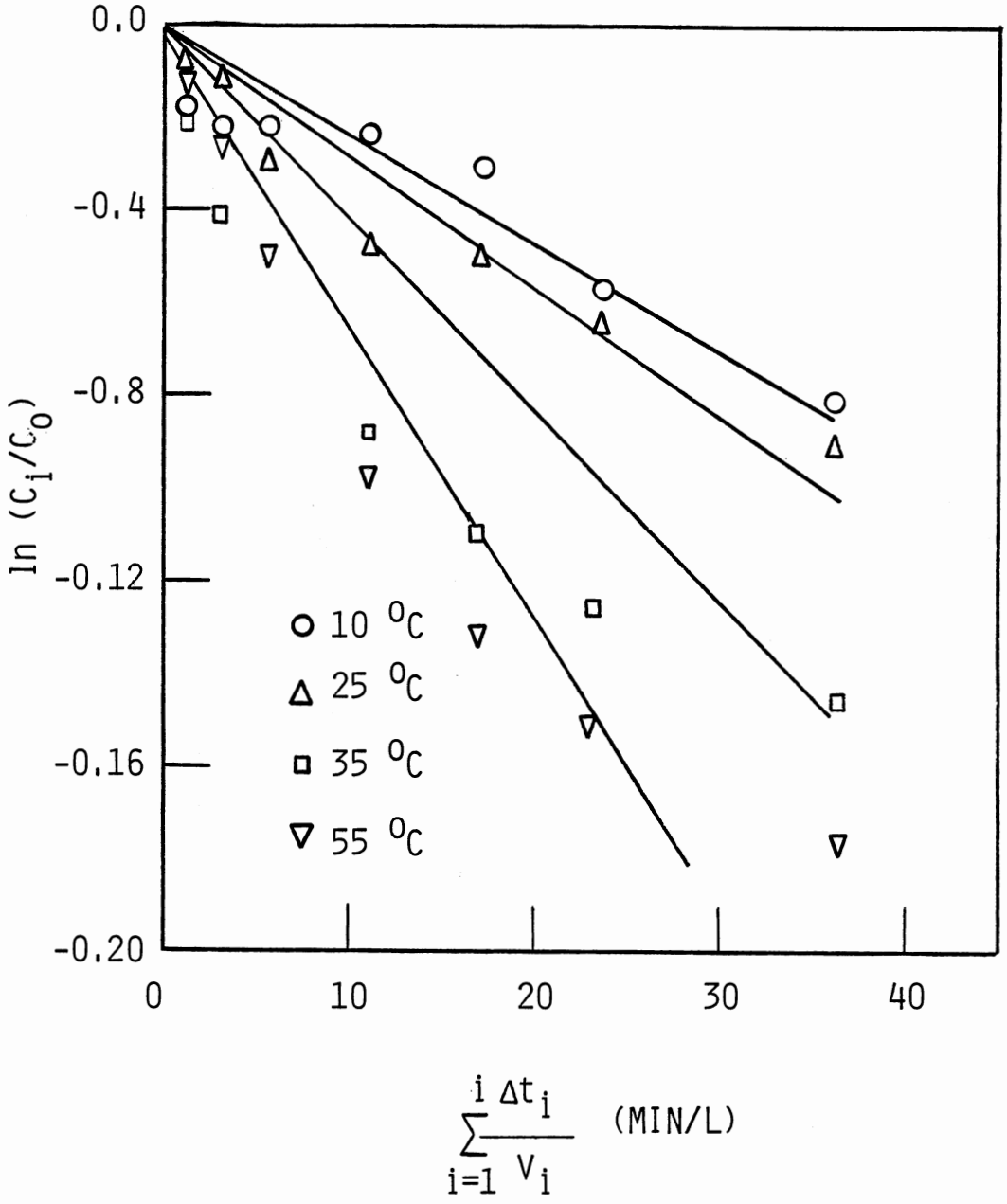


Figure 11. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Nitrobenzene

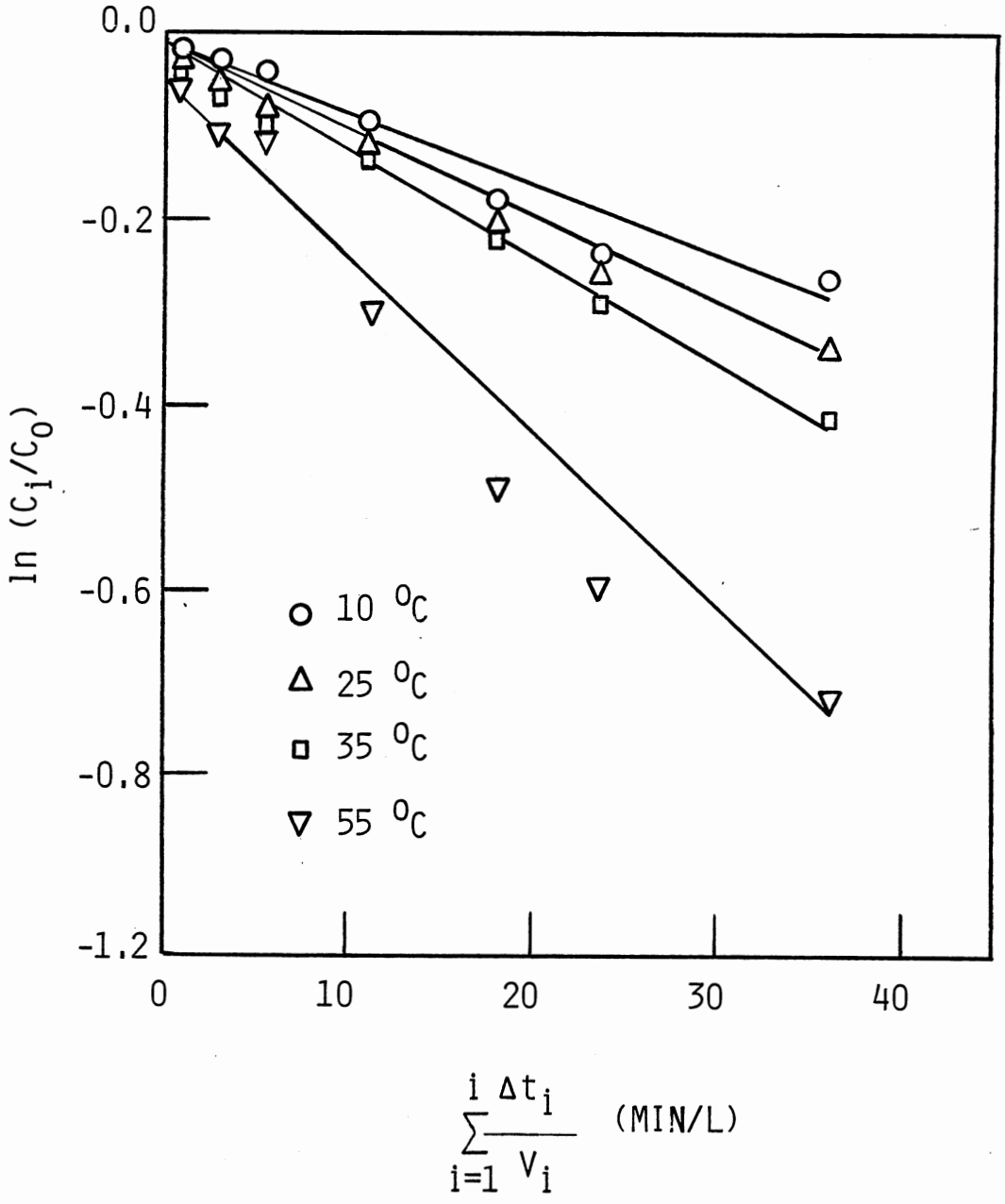


Figure 12. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Napthalene

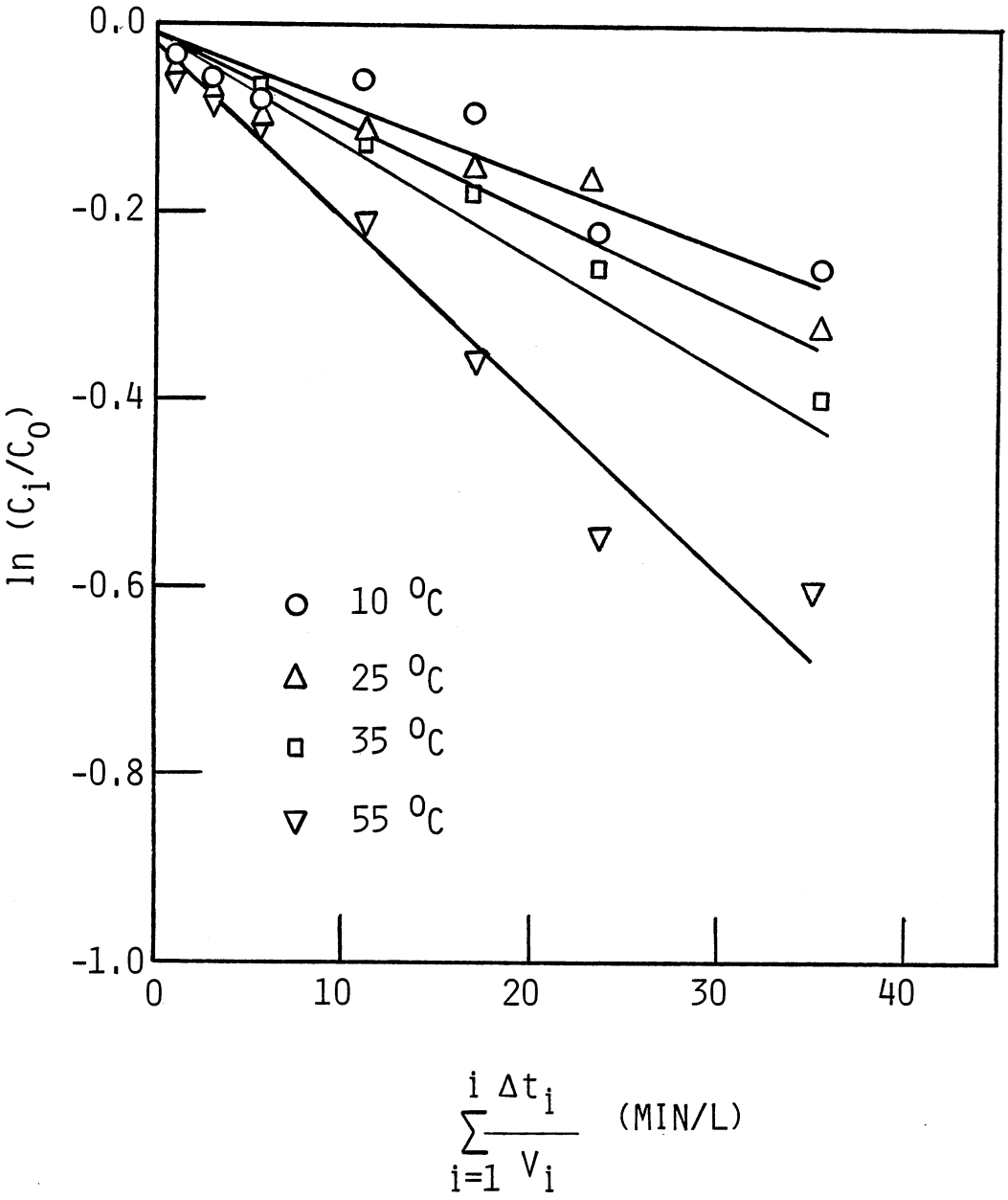


Figure 13. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for 1-Chloronapthalene

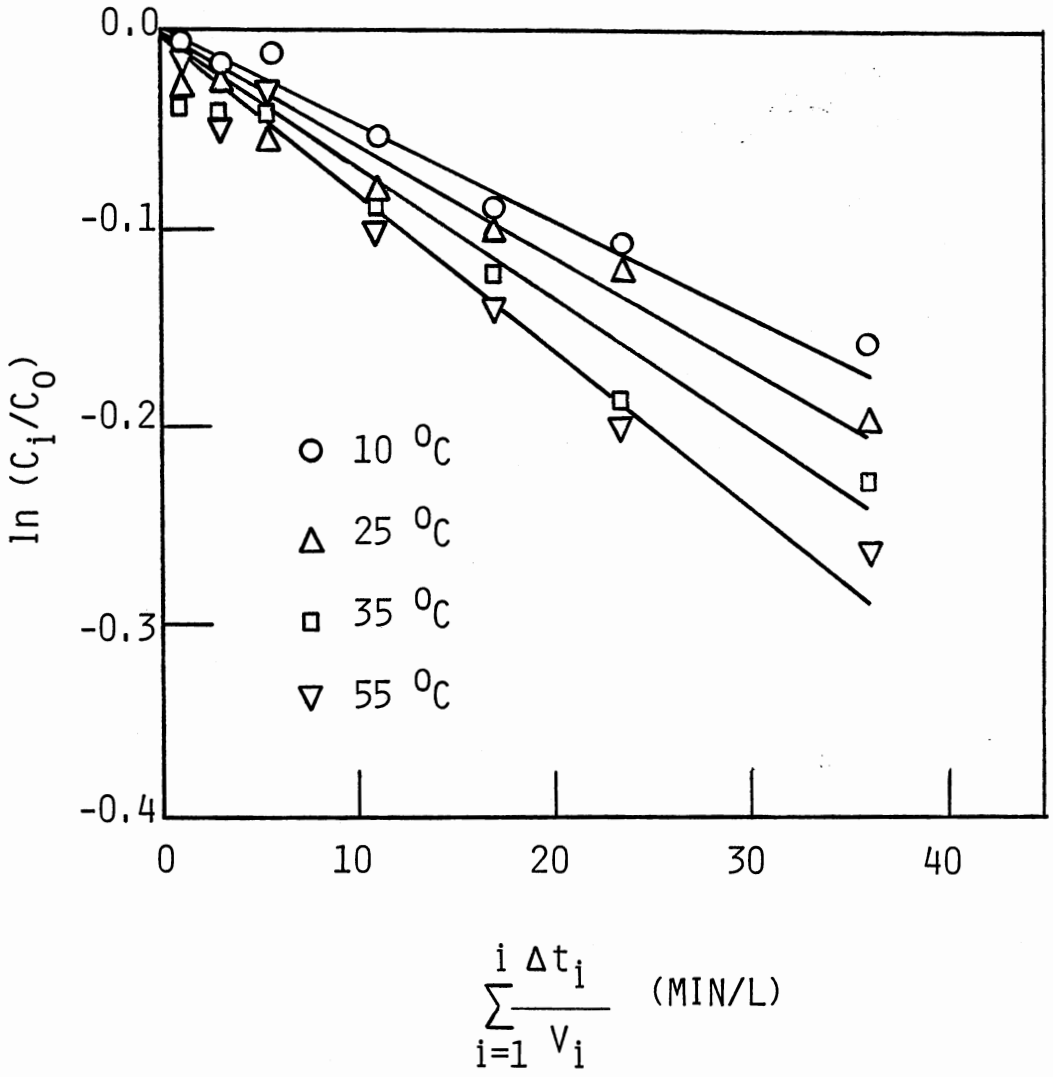


Figure 14. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for 2,6-Dinitrotoluene

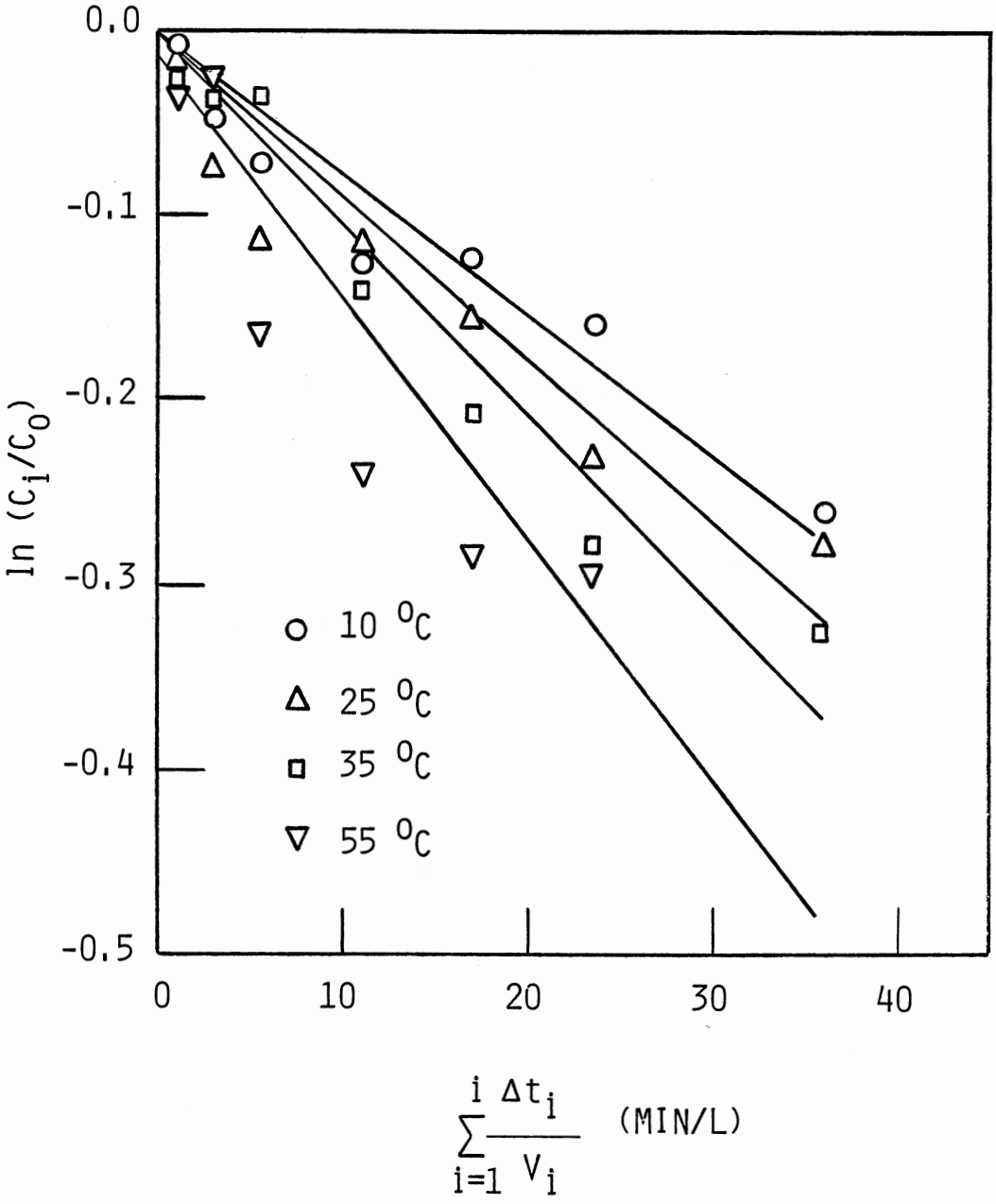


Figure 15. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Fluorene

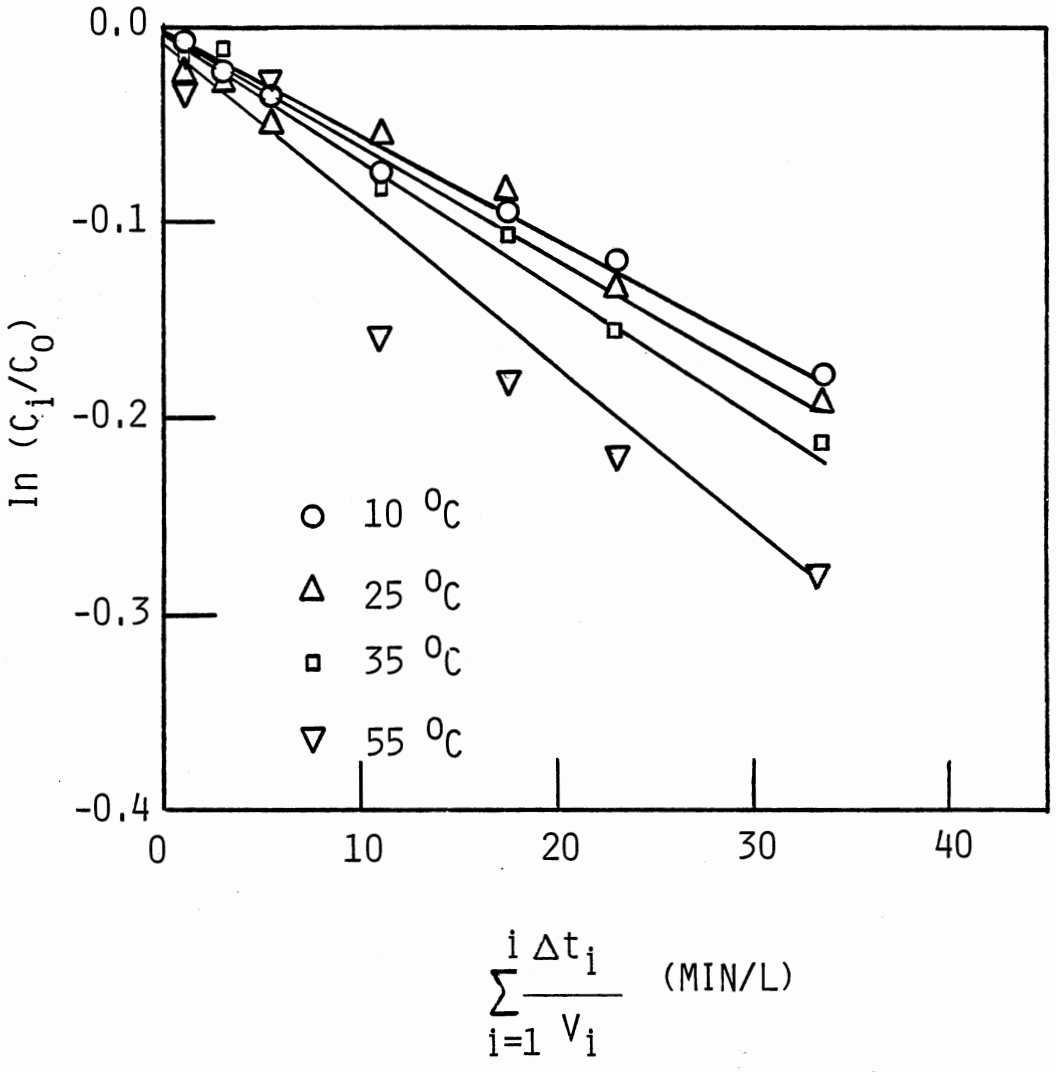


Figure 16. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for 2,4-Dinitrotoluene

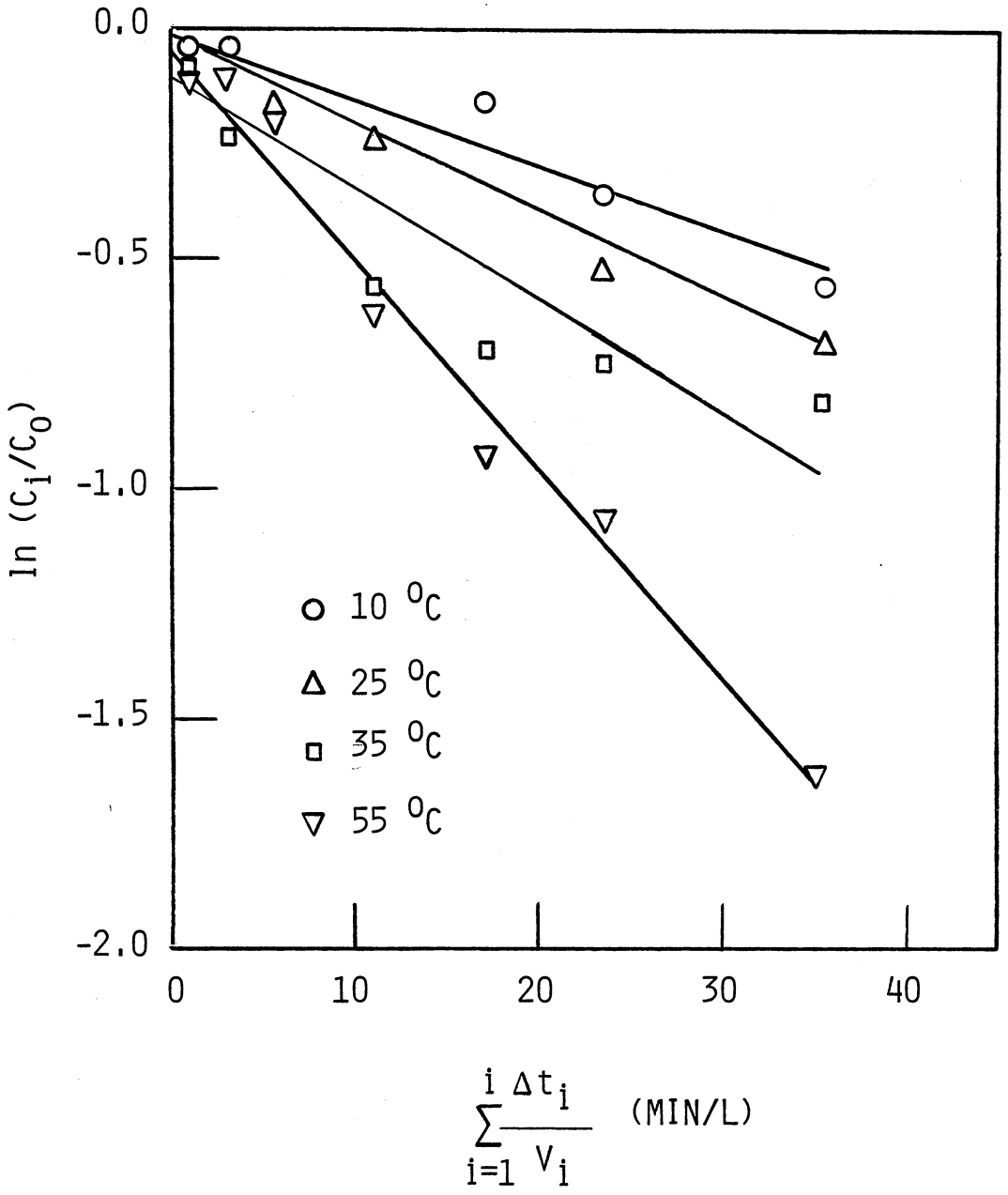


Figure 17. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Hexachlorobenzene

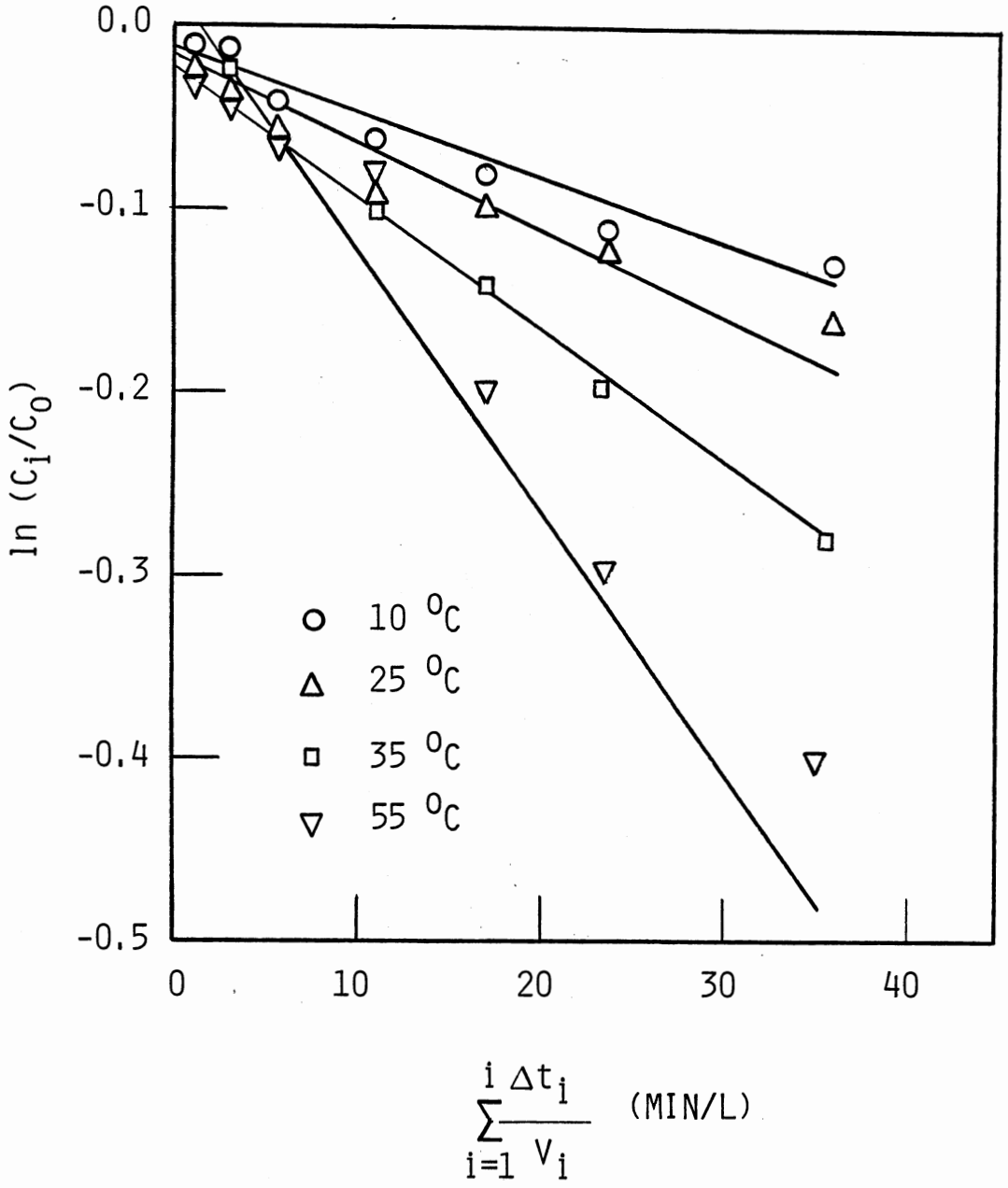


Figure 18. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Phenanthrene

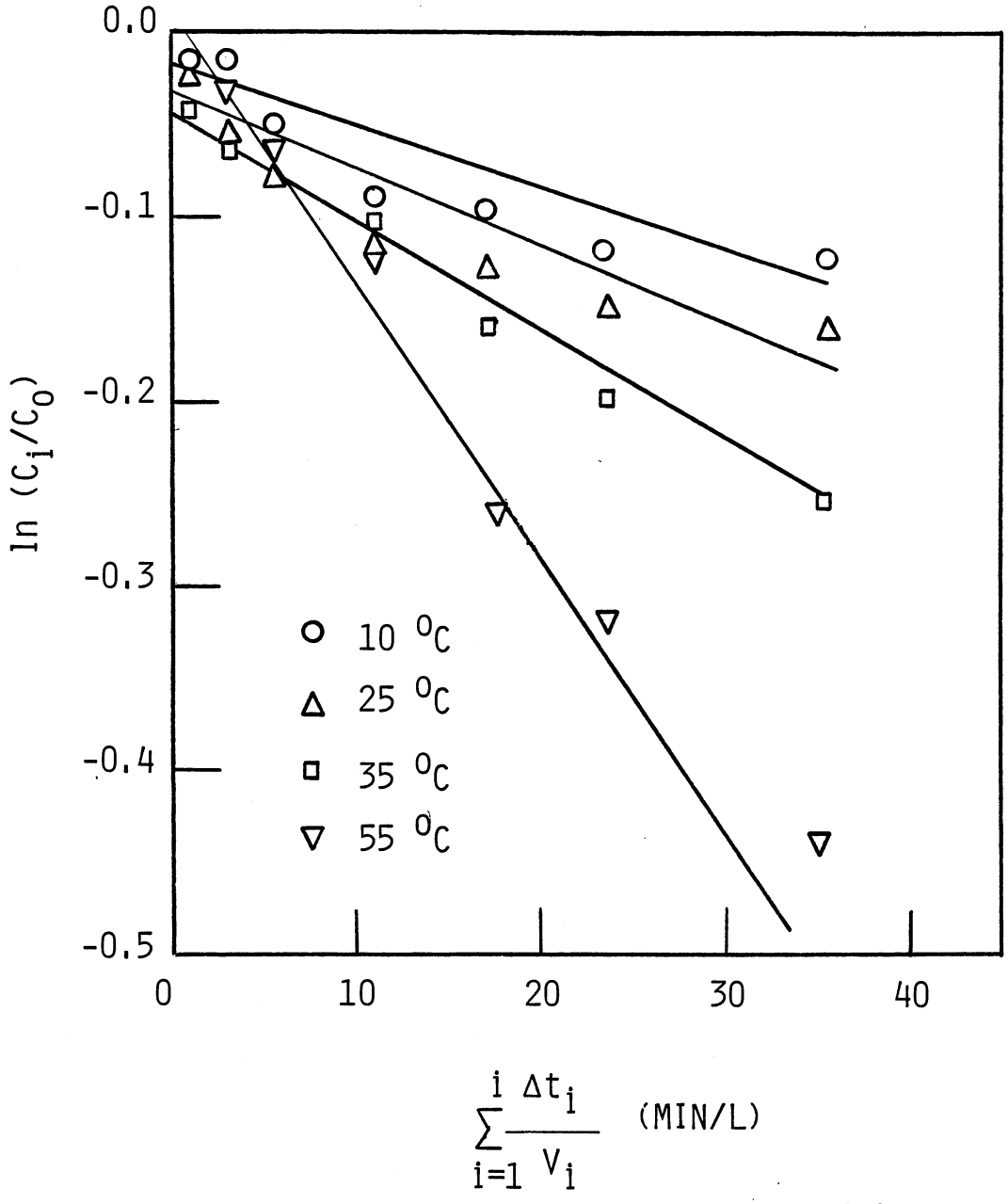


Figure 19. Plot of $\ln(C_i/C_o)$ Versus $\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ for Fluoranthene

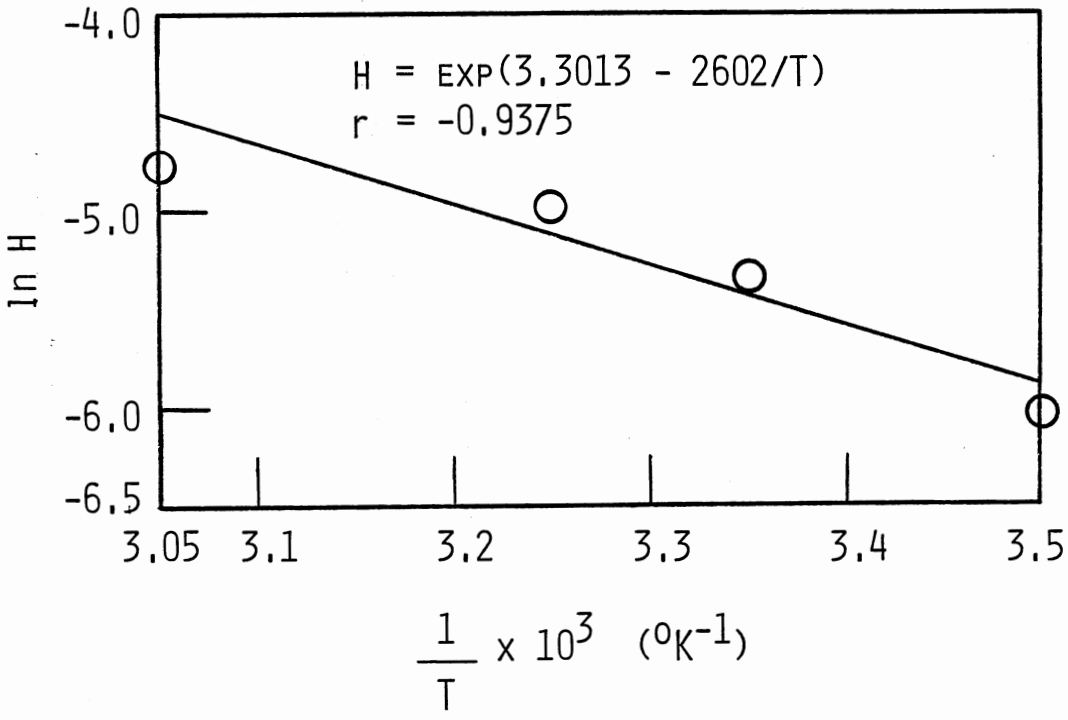


Figure 20. Temperature Dependence of Henry's Constant for Toluene

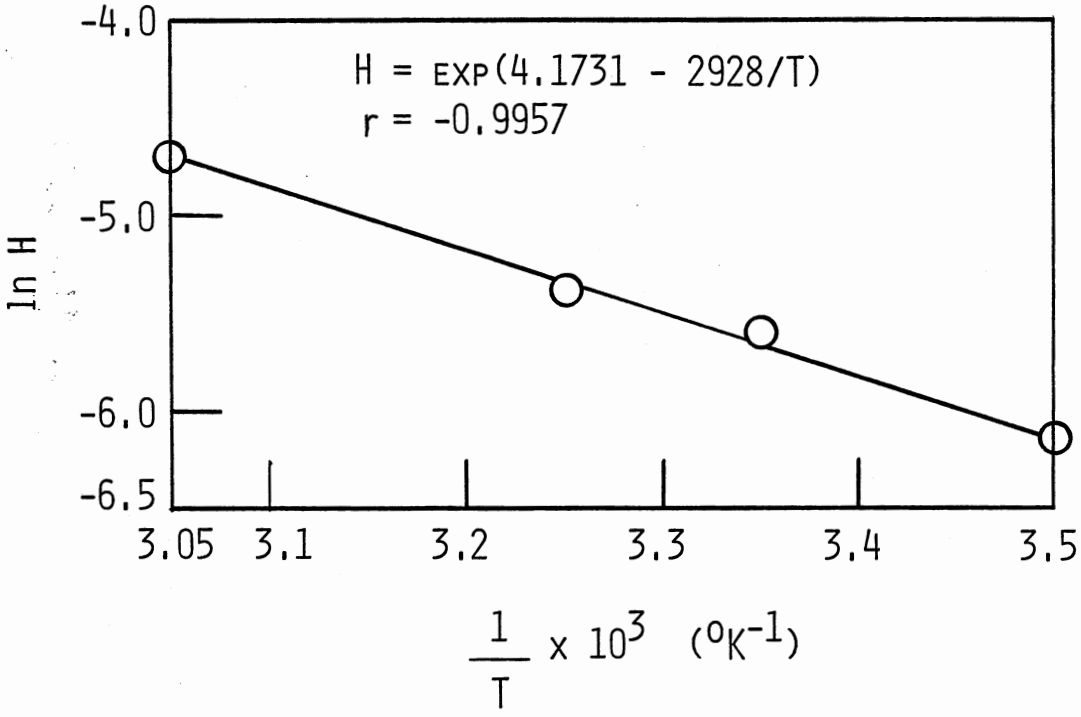


Figure 21. Temperature Dependence of Henry's Constant for Chlorobenzene

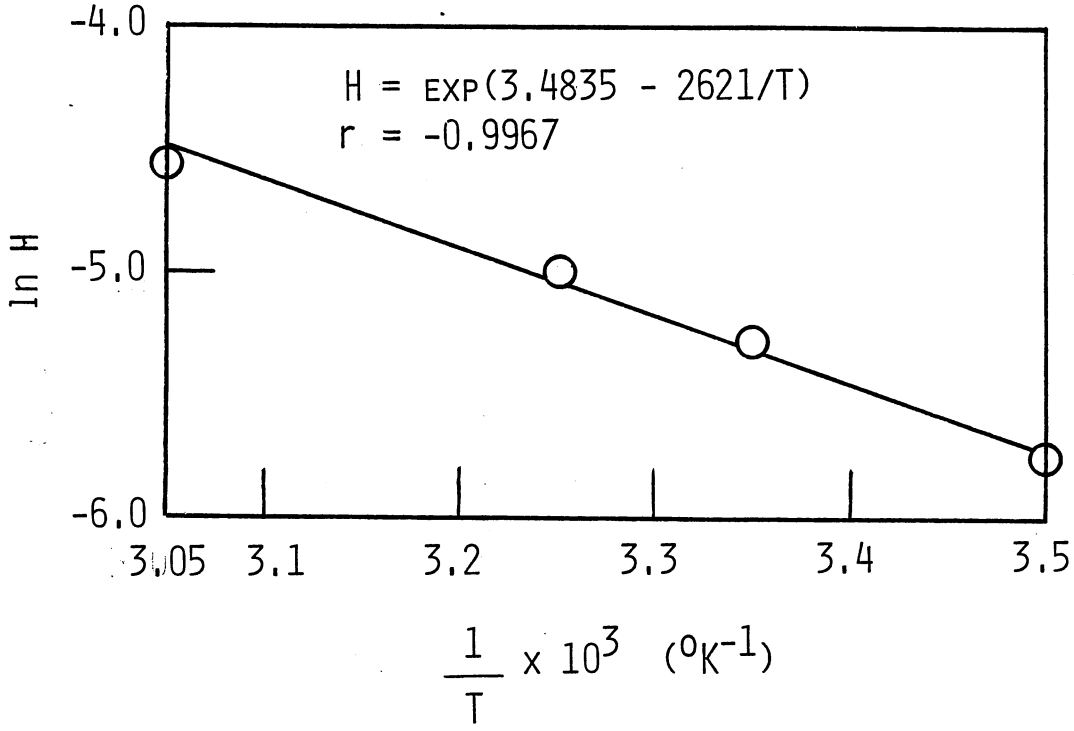


Figure 22. Temperature Dependence of Henry's Constant for Ethylbenzene

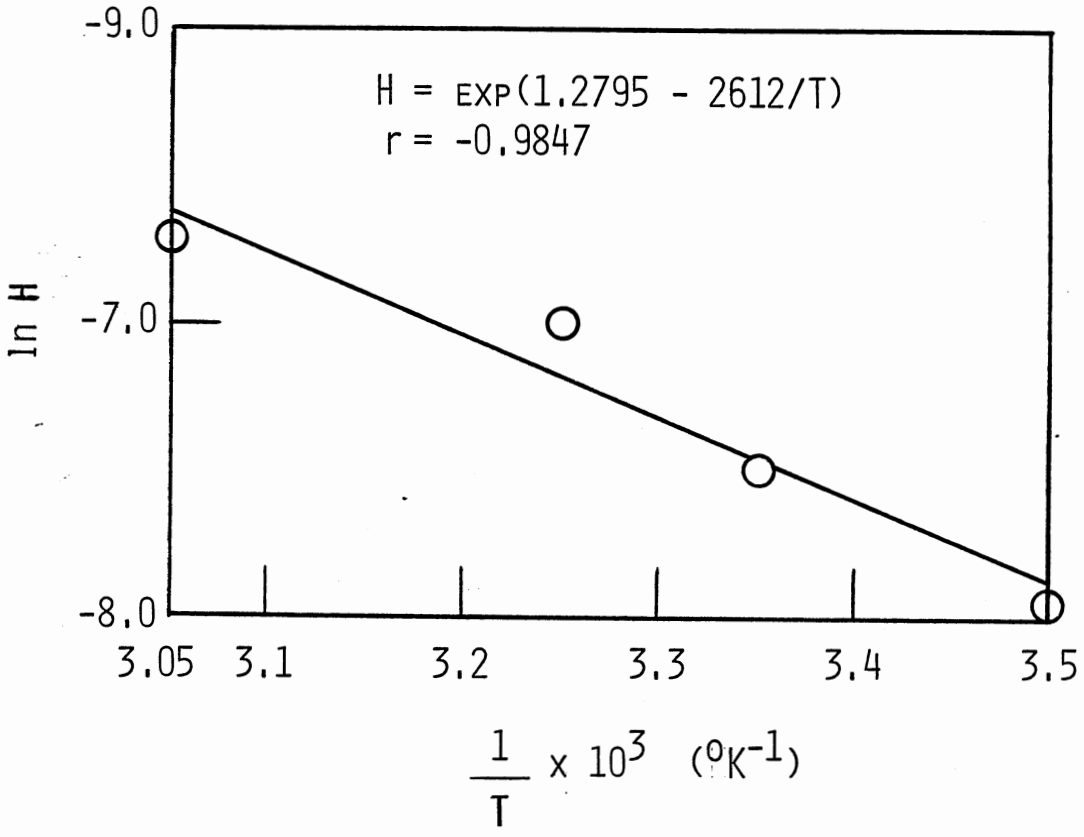


Figure 23. Temperature Dependence of Henry's Constant for Tetrachloroethane

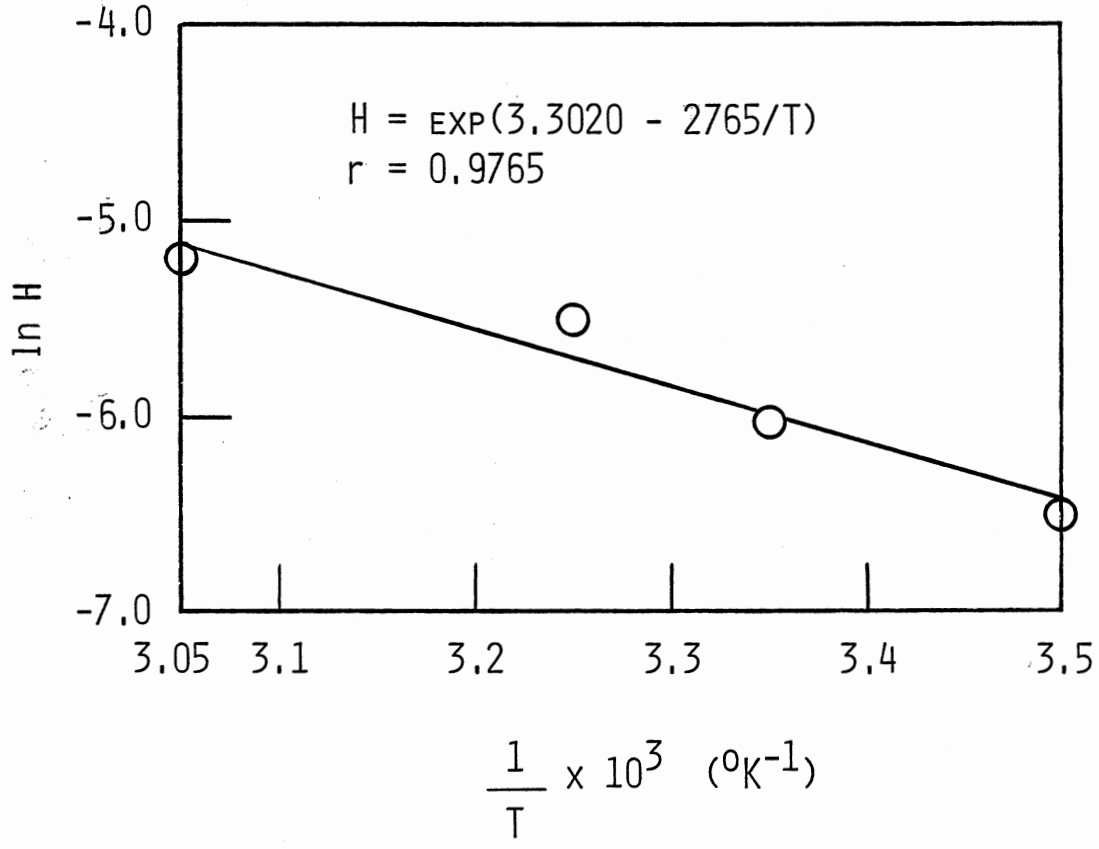


Figure 24. Temperature Dependence of Henry's Constant for 1,3-Dichlorobenzene

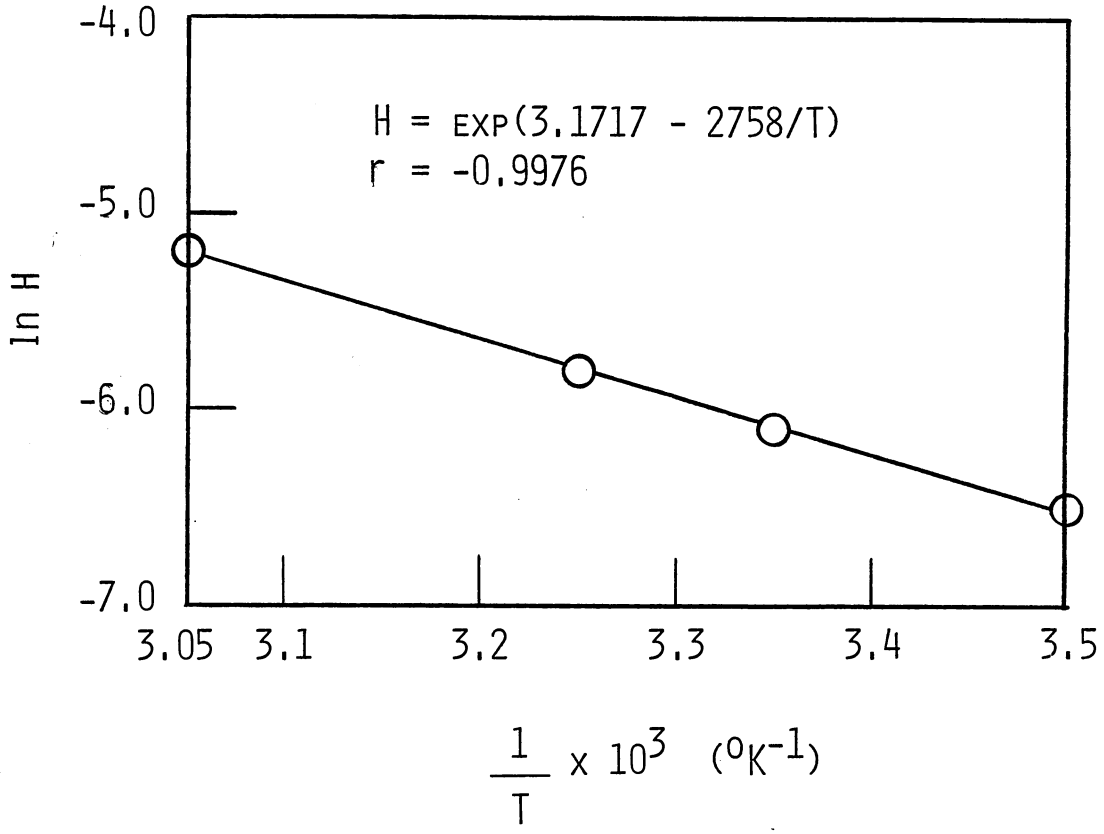


Figure 25. Temperature Dependence of Henry's Constant for 1,2-Dichlorobenzene

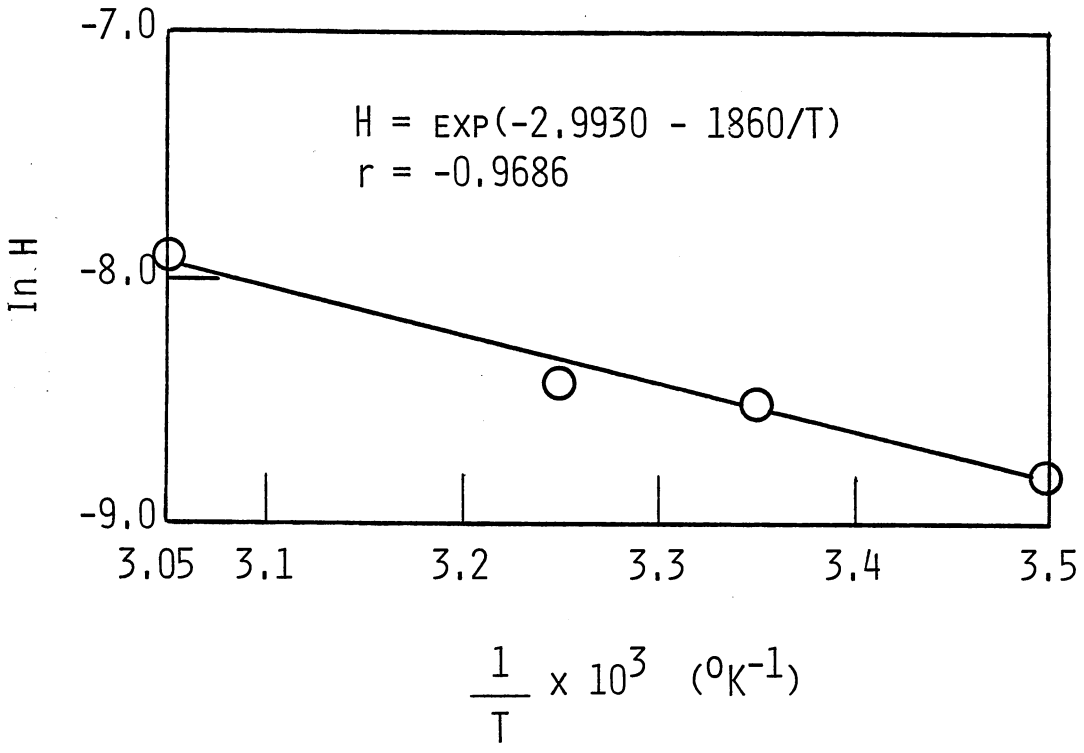


Figure 26. Temperature Dependence of Henry's Constant for Nitrobenzene

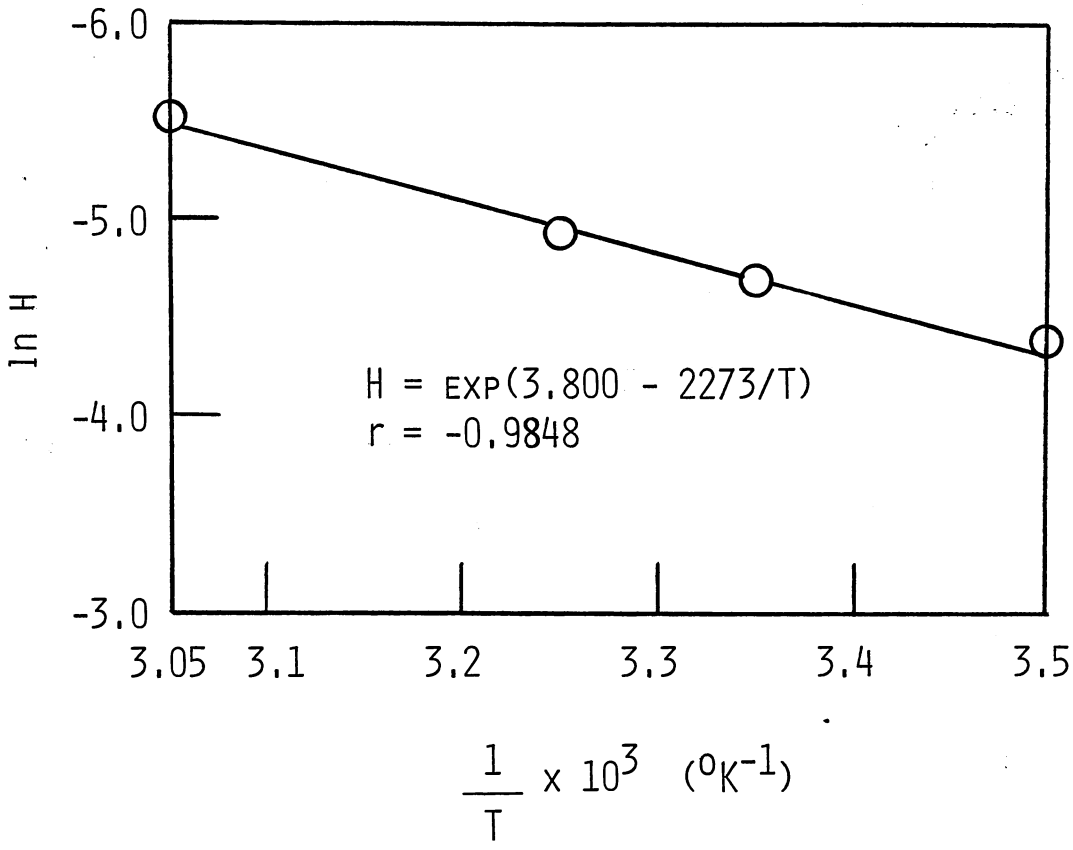


Figure 27. Temperature Dependence of Henry's Constant for Napthalene

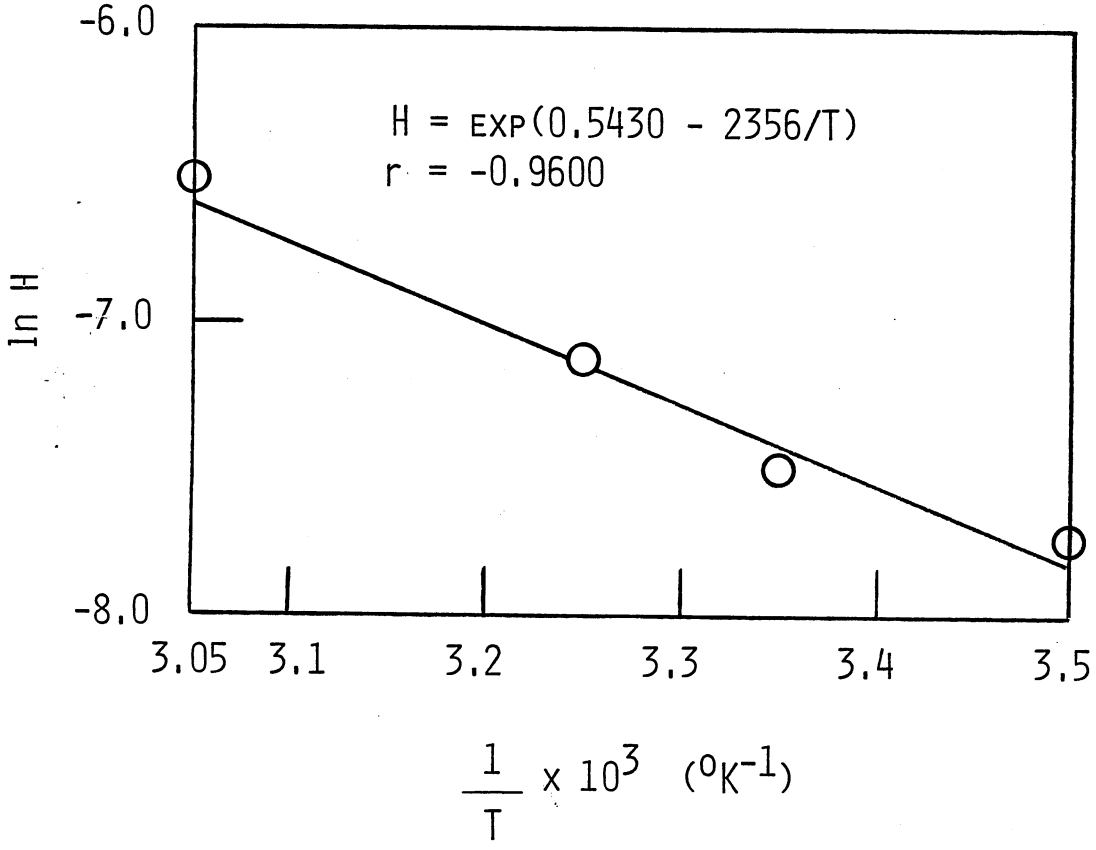


Figure 28. Temperature Dependence of Henry's Constant for 1-Chloronapthalene

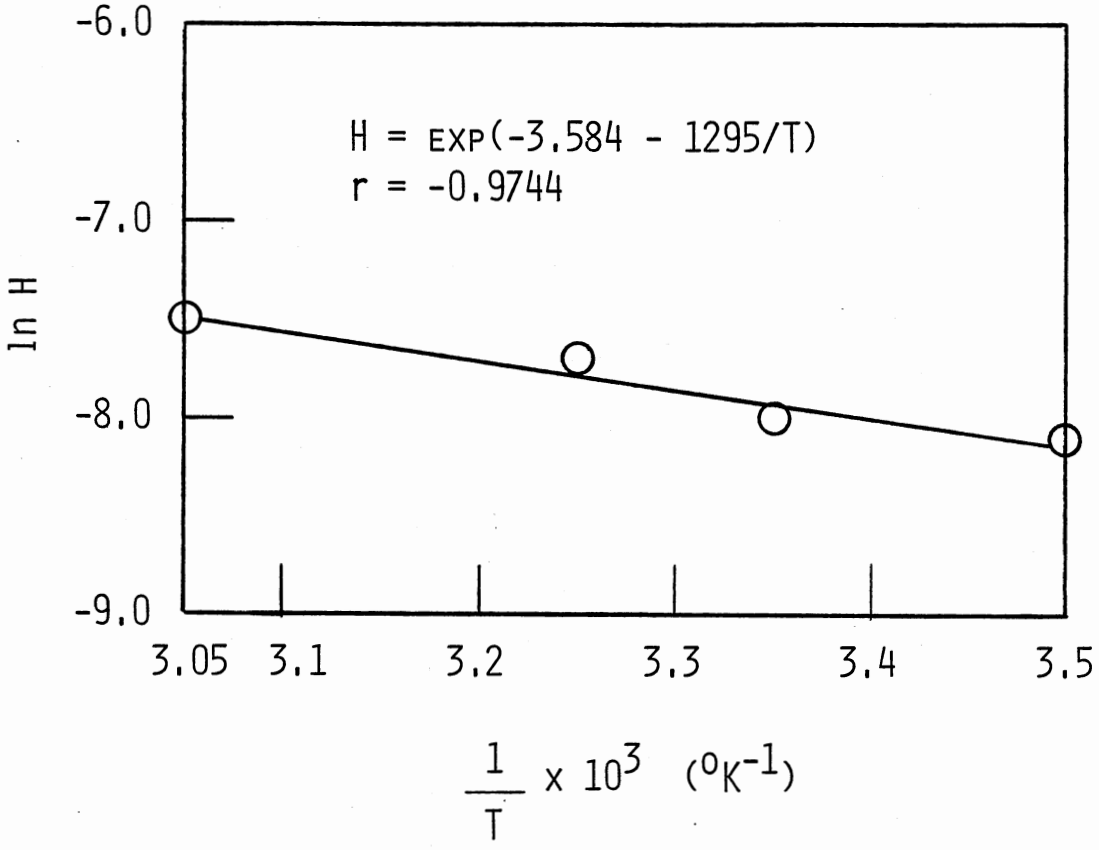


Figure 29. Temperature Dependence of Henry's Constant for 2,6-Dinitrotoluene

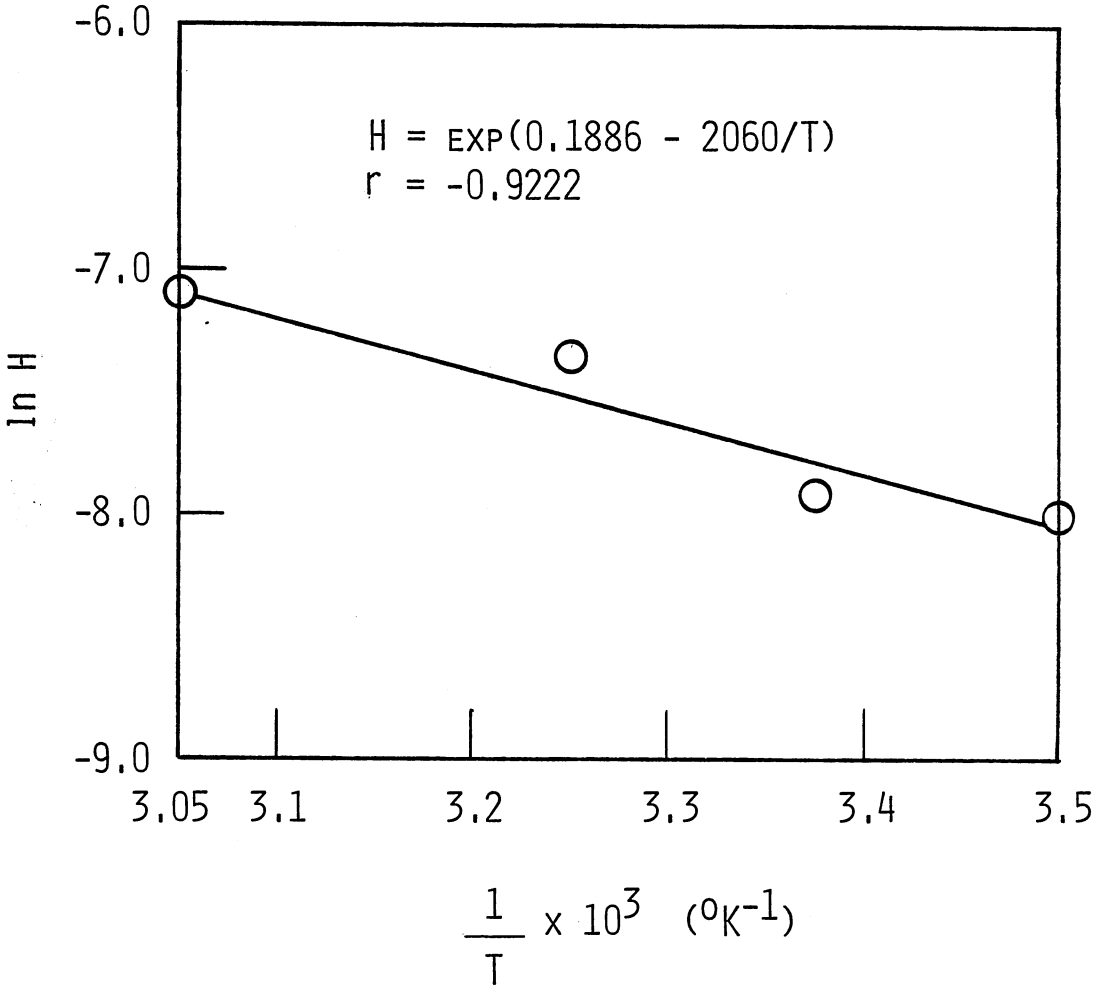


Figure 30. Temperature Dependence of Henry's Constant for Fluorene

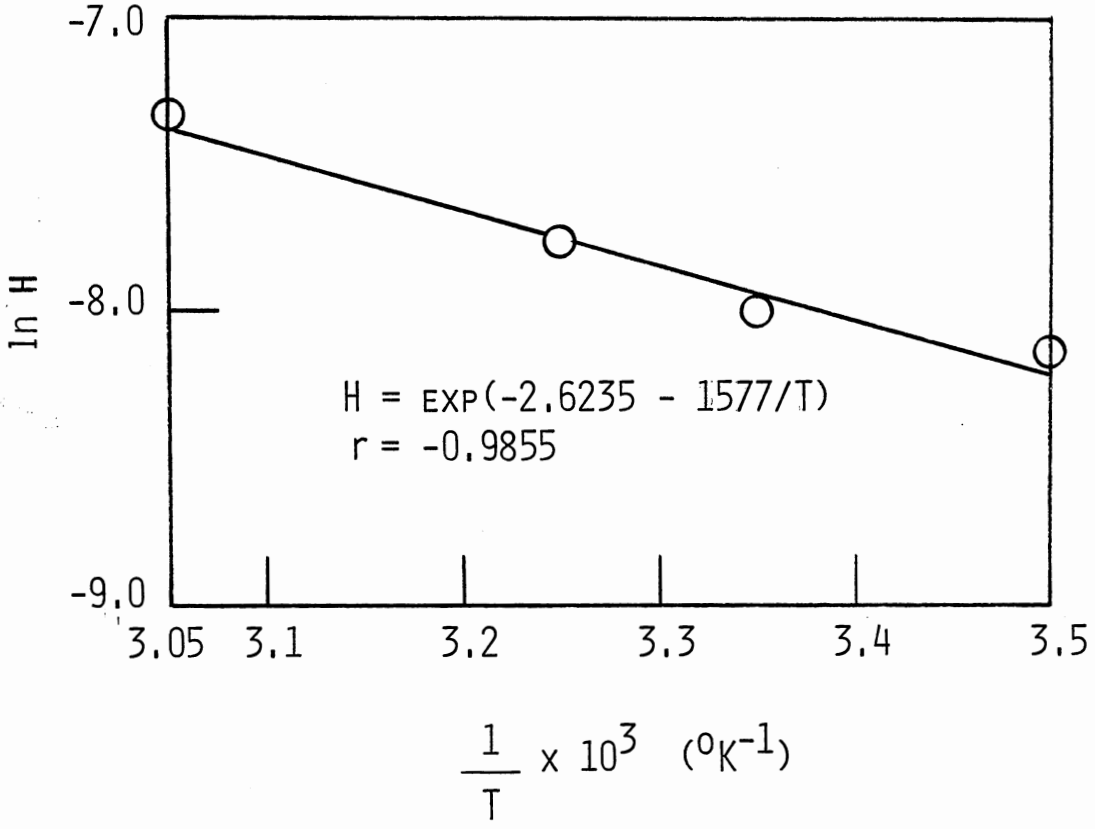


Figure 31. Temperature Dependence of Henry's Constant for 2,4-Dinitrotoluene

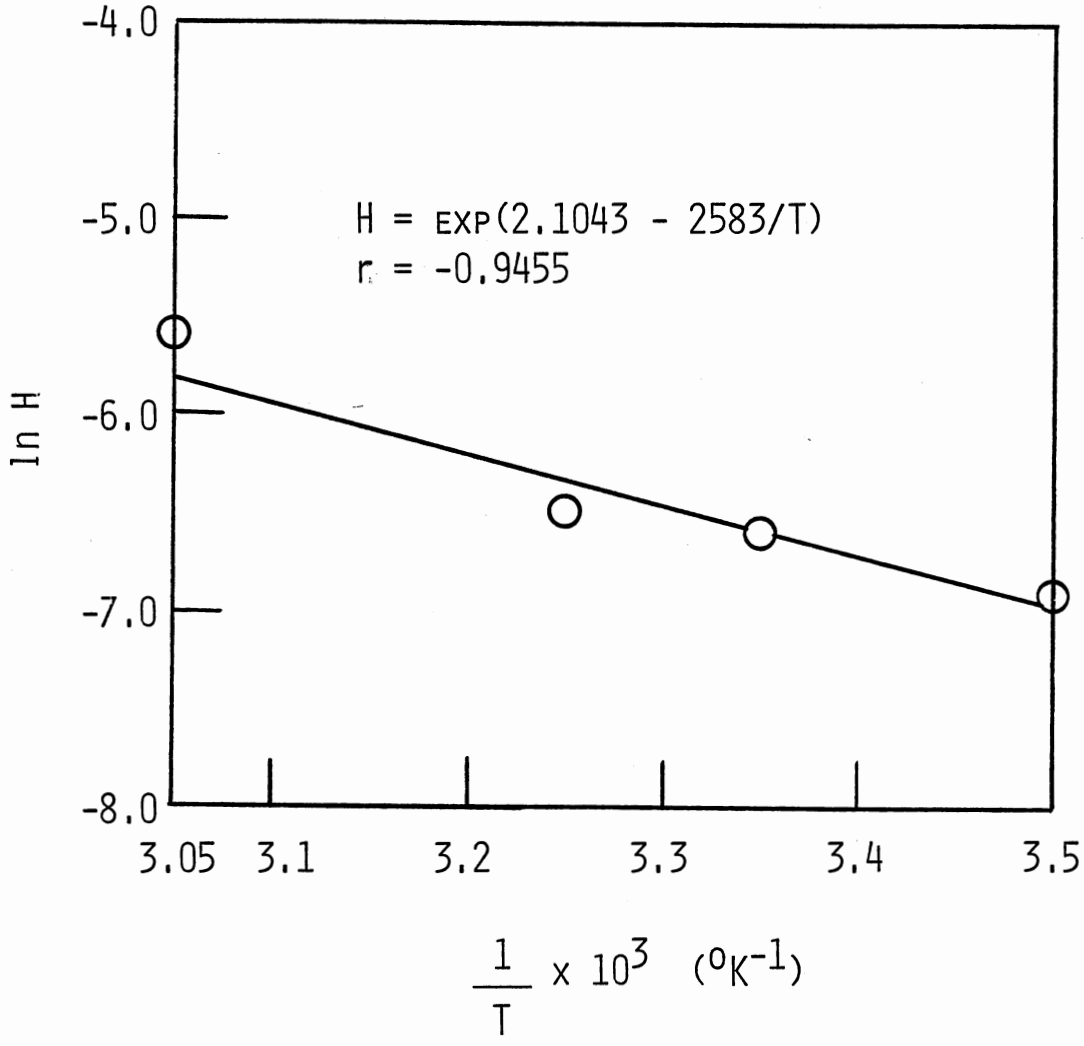


Figure 32. Temperature Dependence of Henry's Constant for Hexachlorobenzene

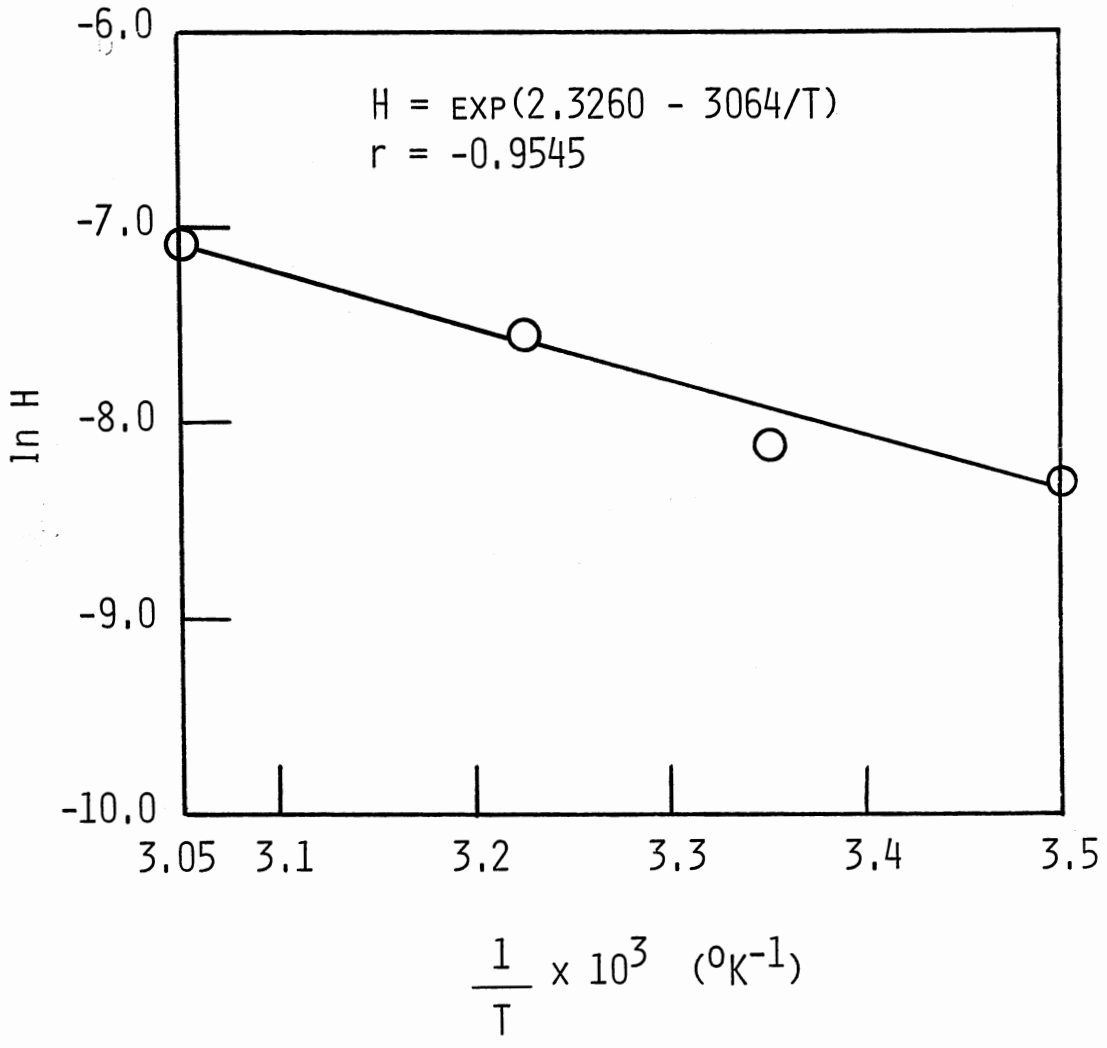


Figure 33. Temperature Dependence of Henry's Constant for Phenanthrene

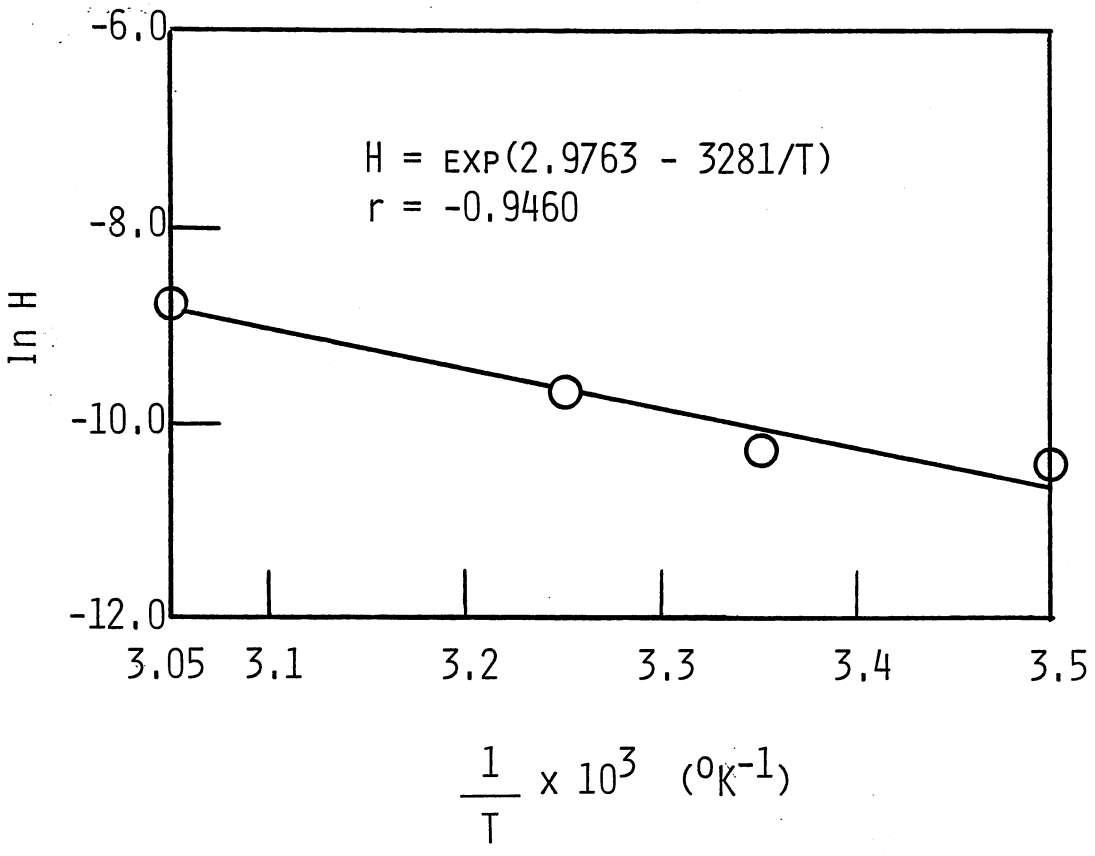


Figure 34. Temperature Dependence of Henry's Constant for Fluoranthene

TABLE X

HENRY'S CONSTANT TEMPERATURE DEPENDENCIES
DETERMINED BY BATCH AIR STRIPPING

Compound	Temperature Dependence Regression Equation (T, °K)	Correlation Coefficient
Toluene	H = exp (3.303 - 2602/T)	-0.9375
Chlorobenzene	H = exp (4.173 - 2928/T)	-0.9957
Ethylbenzene	H = exp (3.483 - 2621/T)	-0.9967
Tetrachloroethane	H = exp (1.280 - 2612/T)	-0.9947
1,3-Dichlorobenzene	H = exp (3.302 - 2765/T)	-0.9765
1,2-Dichlorobenzene	H = exp (3.172 - 2758/T)	-0.9976
Nitrobenzene	H = exp (-2.993 - 1860/T)	-0.9686
Napthalene	H = exp (3.800 - 2273/T)	-0.9848
1-Chloronapthalene	H = exp (0.546 - 2356/T)	-0.9600
2,6-Dinitrotoluene	H = exp (-3.584 - 1295/T)	-0.9744
Fluorene	H = exp (0.188 - 2060/T)	-0.9222
2,4-Dinitrotoluene	H = exp (-2.623 - 1577/T)	-0.9855
Hexachlorobenzene	H = exp (2.104 - 2583/T)	-0.9455
Phenanthrene	H = exp (2.326 - 3060/T)	-0.9545
Fluoranthene	H = exp (2.976 - 3281/T)	-0.9460

agree with the results obtained in the model Equation 3.6 given by Gosset et al. (12).

Estimate Henry's Constant by Using Temperature Dependence Correlation (11)

In Chapter II, the dependency of Henry's constant upon temperature was given by

$$\ln H = \frac{-\Delta H}{RT} + K \tag{4.1}$$

The determination of ΔH, the change in enthalpy due to the dissolution of the component in water, requires knowledge of enthalpies of the solutions at the same reference state, before and after dissolution. Since this information is not easily available, the H can be determined by plotting ln H versus 1/T in accordance with Equation 4.2 which would yield a plot like in Figure 35. The slope of these lines would give $\Delta H/R$. The Henry's constant values at various temperatures can be calculated as the ratio of the vapor pressure to solubility at the same temperature, as suggested previously (11). The following equation can be used to evaluate H at any temperature if its value at some temperature is known.

$$\ln \frac{H}{H_1} = \frac{-\Delta H}{R} \left(\frac{1}{T} - \frac{1}{T_1}\right) \tag{4.2}$$

Tables XI, XII, XIII, XIV, and XV list data on vapor pressure and solubility as a function of temperature for toluene, chlorobenzene, 1,3-dichlorobenzene, 1,2-dichlorobenzene, and tetrachloroethane respectively. The Henry's constant (H) calculated as vapor pressure/solubility

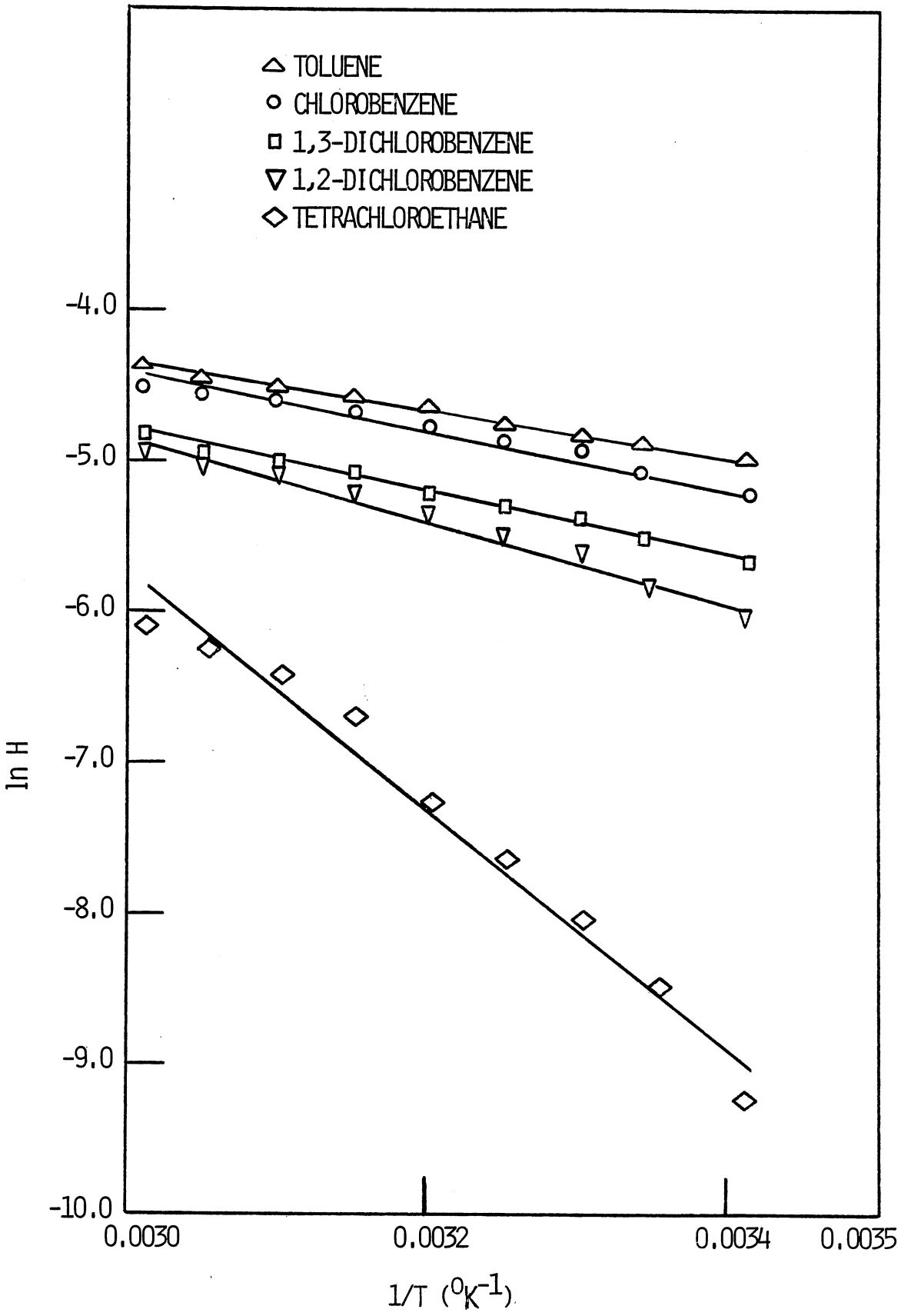


Figure 35. Temperature Dependence of Henry's Constant

TABLE XI

VAPOR PRESSURE AND SOLUBILITY AS A FUNCTION OF TEMPERATURE FOR TOLUENE

Temperature (°C)	Solubility* (mole/m^3)	Vapor** Pressure (VP) (atm)	Henry's Law Constant H-VP/Sol ($atm-m^3$/mole)	1/T (°K)	ln H
15	4.30	0.02506	0.005828	0.00347	-5.14
20	4.88	0.03466	0.007102	0.00341	-4.94
25	5.43	0.04424	0.008147	0.00336	-4.81
30	5.90	0.05383	0.009124	0.00330	-4.69
35	6.53	0.06340	0.009709	0.00325	-4.63
40	6.94	0.07300	0.01052	0.00320	-4.55
45	7.46	0.08258	0.01107	0.00315	-4.50
50	8.00	0.09217	0.01152	0.00310	-4.46
55	8.51	0.1018	0.01196	0.00305	-4.40
60	9.03	0.1113	0.1232	0.00301	-4.39

*Solubility of Inorganic and Organic Compounds, Pergamon Press, New York, 1963.

**R.H. Perry and C.H. Chilton, Chemical Engineer's Handbook, McGraw Hill Co., New York, 1973.

TABLE XII

VAPOR PRESSURE AND SOLUBILITY AS A FUNCTION OF TEMPERATURE FOR CHLOROBENZENE

Temperature (°C)	Solubility* (mole/m^3)	Vapor** Pressure (VP) (atm)	Henry's Law Constant H-VP/Sol ($atm-m^3$/mole)	1/T (°K)	ln H
15	4.02	0.005526	0.001346	0.00347	-5.589
20	4.13	0.01295	0.003134	0.00341	-5.765
25	4.38	0.02037	0.004651	0.00336	-5.371
30	4.77	0.02779	0.005826	0.00330	-5.145
35	5.30	0.03521	0.006643	0.00325	-5.014
40	5.97	0.04263	0.007141	0.00320	-4.942
45	6.78	0.05005	0.007382	0.00315	-4.909
50	7.74	0.05747	0.007425	0.00310	-4.903
55	8.85	0.06490	0.007333	0.00305	-4.915
60	10.12	0.07232	0.007146	0.00301	-4.941

*Solubility of Inorganic and Organic Compounds, Pergamon Press, New York, 1963.

**R.H. Perry and C.H. Chilton, Chemical Engineer's Handbook, McGraw Hill Co., New York, 1973.

TABLE XIII

VAPOR PRESSURE AND SOLUBILITY AS A FUNCTION OF TEMPERATURE FOR 1,3-DICHLOROBENZENE

Temperature (°C)	Solubility* ($mole/m^3$)	Vapor** Pressure (VP) (atm)	Henry's Law Constant H-VP/Sol ($atm-m^3/mole$)	1/T (°K)	ln H
15	0.679	0.001566	0.002306	0.00347	-6.072
20	0.686	0.002972	0.004332	0.00341	-5.442
25	0.719	0.004585	0.006377	0.00336	-5.055
30	0.773	0.005788	0.007488	0.00330	-4.894
35	0.843	0.007196	0.008536	0.00325	-4.763
40	0.924	0.008604	0.009312	0.00320	-4.676
45	1.014	0.01002	0.009882	0.00315	-4.617
50	1.107	0.01142	0.01036	0.00310	-4.574
55	1.198	0.01283	0.01071	0.00305	-4.537
60	1.284	0.01423	0.01108	0.00301	-4.502

*Solubility of Inorganic and Organic Compounds, Pergamon Press, New York, 1963.

**R.H. Perry and C.H. Chilton, Chemical Engineer's Handbook, McGraw Hill Co., New York, 1973.

TABLE XIV

VAPOR PRESSURE AND SOLUBILITY AS A FUNCTION OF TEMPERATURE FOR 1,2-DICHLOROBENZENE

Temperature (°C)	Solubility* ($mole/m^3$)	Vapor** Pressure (VP) (atm)	Henry's Law Constant H-VP/Sol ($atm\text{-}m^3/mole$)	1/T (°K)	ln H
20	0.944	0.0007526	0.0007972	0.00341	-6.234
25	0.994	0.002196	0.002209	0.00336	-6.115
30	1.06	0.003639	0.003433	0.00330	-5.674
35	1.114	0.005083	0.004563	0.00325	-5.390
40	1.23	0.006526	0.005306	0.00320	-5.239
45	1.32	0.007970	0.006038	0.00315	-5.110
50	1.42	0.009413	0.006629	0.00310	-5.016
55	1.53	0.01086	0.007098	0.00305	-4.948
60	1.62	0.01230	0.007593	0.00301	-4.881

*Solubility of Inorganic and Organic Compounds, Pergamon Press, New York, 1963.

**R.H. Perry and C.H. Chilton, Chemical Engineer's Handbook, McGraw Hill Co., New York, 1973.

TABLE XV

VAPOR PRESSURE AND SOLUBILITY AS A FUNCTION OF TEMPERATURE FOR TETRACHLOROETHANE

Temperature (°C)	Solubility* (mole/m^3)	Vapor** Pressure (VP) (atm)	Henry's Law Constant H-VP/Sol ($atm-m^3$/mole)	1/T (°K)	ln H
20	16.39	0.0015789	0.0009633	0.00341	-9.248
25	17.15	0.007303	0.0004258	0.00336	-8.761
30	17.91	0.01303	0.0007275	0.00330	-7.226
35	18.67	0.01896	0.0010053	0.00325	-7.902
40	19.42	0.02447	0.0012718	0.00320	-6.667
45	20.18	0.03019	0.001496	0.00315	-6.505
50	20.94	0.03592	0.001754	0.00310	-6.368
55	21.70	0.04164	0.001919	0.00305	-6.256
60	22.46	0.04737	0.002109	0.00301	-6.162

*Halogenated Hydrocarbon, A.L. Harvath, New York, 1982.
**R.H. Perry and C.H. Chilton, Chemical Engineer's Handbook, McGraw Hill Co., New York, 1973.

and the calculated 1/T and ln H are also presented in these tables. The slope ($\Delta H/R$) for each organic compound can be obtained by linear regression of these values (1/T and H). The results are presented with the correlation coefficients in Table XVI. Table XVII shows Henry's constant values at 15° and 55°C determined experimentally in this study from Goldstein's equation, and the ratio of vapor pressure to solubility at the same temperature. The Henry's constant at the two temperatures for toluene, chlorobenzene, and 1,3-dichlorobenzene obtained by using experimental H from this study, Goldstein's equation, and the ratio of vapor pressure to solubility at the same temperature are all close (65%) to each other. Henry's constant at the two temperatures for ethylbenzene, tetrachloroethane, 1,2-dichlorobenzene, napthalene, 1-chloronapthalene, fluorene, and hexachlorobenzene obtained by using experimental H from this study and Goldstein's equation are also close to each other. There are significant differences between the Henry's constant at the two temperatures for nitrobenzene, 2,6-dinitrotoluene, 2,4-dinitrotoluene, and phenanthrene obtained by using an experimentally determined H from this study and the Goldstein's equation. Table XVIII shows Henry's constant values as a function of temperature for oxygen.

Tower Characteristics

Determination of the operating gas and liquid flow rates at various gas-to-liquid ratios is necessary for operating a countercurrent packed column. Both gas and liquid operating flow rates are generally chosen so the pressure drop across the packing is well below the flooding point.

TABLE XVI

CORRECTION FACTOR $\Delta H/R$ FOR THE TEMPERATURE DEPENDENCE OF HENRY'S CONSTANT H

Compound	Correction Factor $\Delta H/R$	Correlation Coefficient
Toluene	-1857	-0.9430
Chlorobenzene	-2908	-0.9220
1,3-Dichlorobenzene	-2866	-0.9505
1,2-Dichlorobenzene	-4706	-0.9311
Tetrachloroethane	-6332	-0.9277

TABLE XVII

HENRY'S LAW CONSTANT AS A FUNCTION OF TEMPERATURE

Compound	Experimental Value ($atm-m^3/mole$)		Goldstein's Equation ($atm-m^3/mole$)		Pakanti (11) Corrected H ($atm-m^3/mole$)	
	15°C	55°C	15°C	55°C	15°C	55°C
Toluene	0.003236	0.009738	0.005192	0.01121	0.005828	0.01196
Chlorobenzene	0.002495	0.008619	0.003170	0.007274	0.005526	0.00733
Ethylbenzene	0.003635	0.01103	0.005295	0.01020	---	---
Tetrachloroethane	0.0004139	0.001217	0.0003080	0.0010418	---	0.001919
1,3-Dichlorobenzene	0.001839	0.005929	0.001934	0.0051463	0.002306	0.01071
1,2-Dichlorobenzene	0.001654	0.005317	0.001385	0.004169	---	0.007098
Nitrobenzene	0.0001573	0.0003457	0.00001257	0.00007684	---	---
Napthalene	0.0005463	0.001430	0.0003086	0.001343	---	---
1-Chloronapthalene	0.0004820	0.001303	0.0003949	0.001960	---	---
2,6-Dinitrotoluene	0.0003095	0.0005353	0.00003353	0.0001222	---	---
Fluorene	0.0009451	0.002261	0.00008269	0.002938	---	---
2,4-Dinitrotoluene	0.0003038	0.0005923	0.00003353	0.0001222	---	---
Hexachlorobenzene	0.001044	0.003118	0.001427	0.002908	---	---
Phenanthrene	0.0002453	0.0008979	0.00006243	0.0004109	---	---
Fluoranthene	0.0002213	0.0008878	NA	NA	---	---
Oxygen					0.6421	

NA = Not Available.

TABLE XVIII

HENRY'S LAW CONSTANT AS A FUNCTION OF TEMPERATURE FOR OXYGEN

T (°C)	Henry's Law Constant ($atm-m^3/mole$)
10	0.58015*
15	0.6421*
20	0.7208**
22	0.7547*
25	0.7954*
30	0.8677*
35	0.9399*

*Mumford and Schnoor (48).
**Roberts et al. (72).

The operating flow rates for this study were determined from the hydraulic loading studies. Data from the hydraulic loading studies were plotted on log-log plots with the pressure drop as an ordinate and the gas loading rate as an abscissa. Each of the Figures, 36, 37, and 38, are plots of the eight water loading rates that were selected to cover the range of the liquid feed rate for 0.6, 0.9, and 1.2 M bed depths. These figures show that at fixed water loading rates, the pressure drops increase with increased gas flow rates. This is principally because of the reduced free cross section area available for the flow of water. There are three distinct regions which can be identified in the curve of Figure 36 (0.6 M bed depth). Initially, the increase in the pressure drop is gradual. Then, there is a sharp increase characterizing the column. Finally, as the gas loading rate is further increased, a sharp increase in the pressure drop occurs. At this point, called the "flooding point", liquid holdup at the top of the packing and/or other places of intermediate restriction in the packing (such as at the redistributer) begin to appear. At the same time, there was an increase in the entrainment of liquid by the off gas. The same trends occurred at 0.9 and 1.2 M bed depths (Figures 37 and 38).

The air loading rates at flooding, obtained from the hydraulic loading studies, are presented in Table XIX. Gas and liquid loading rates for the operating conditions of the three bed depths were in the range of 50-60% of the flooding points. The operating flow rates of air and water are presented in Table XX.

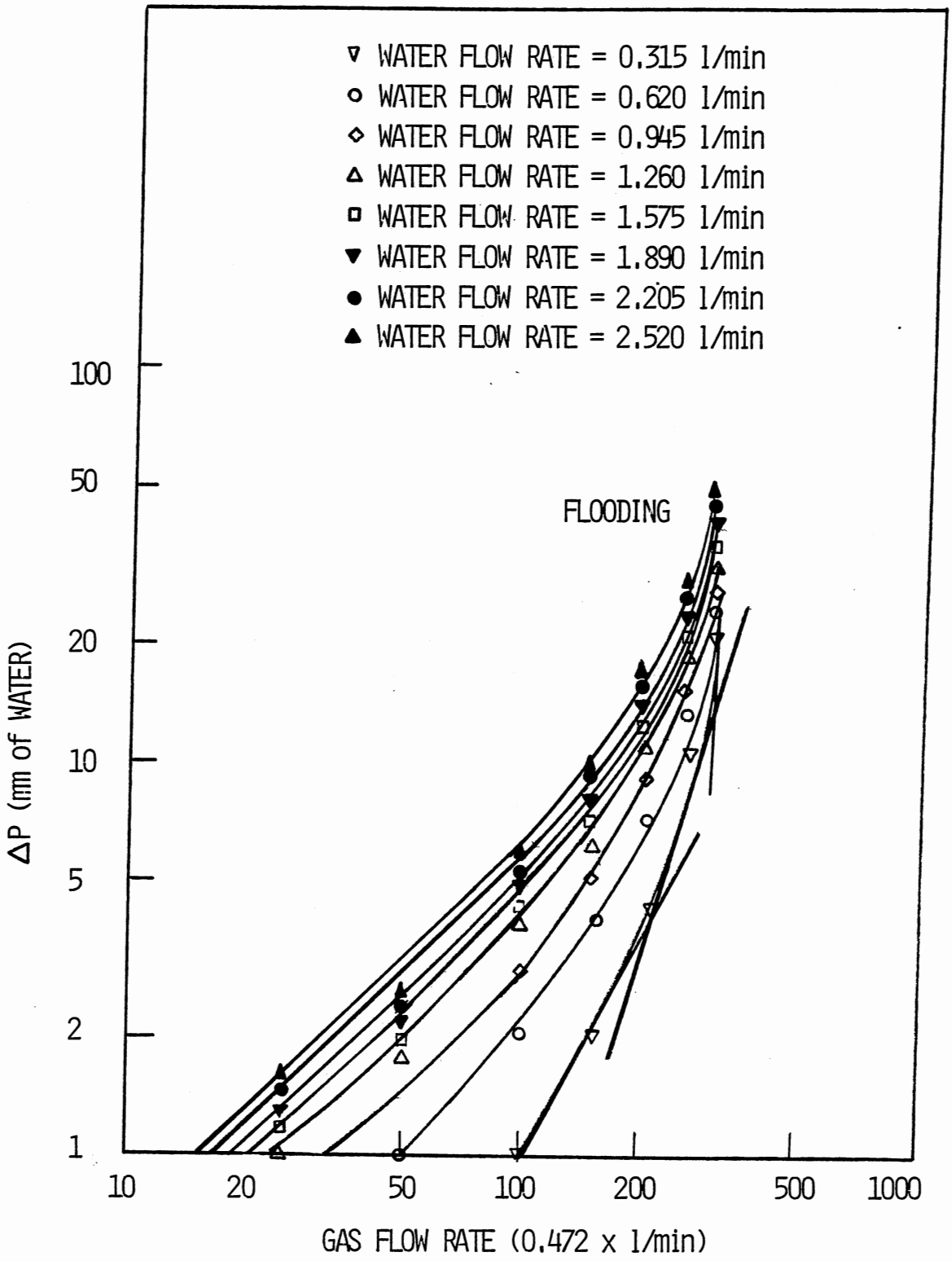


Figure 36. Pressure Drop Across Packing Versus Gas Loading Rate for 0.6 m Bed Depth

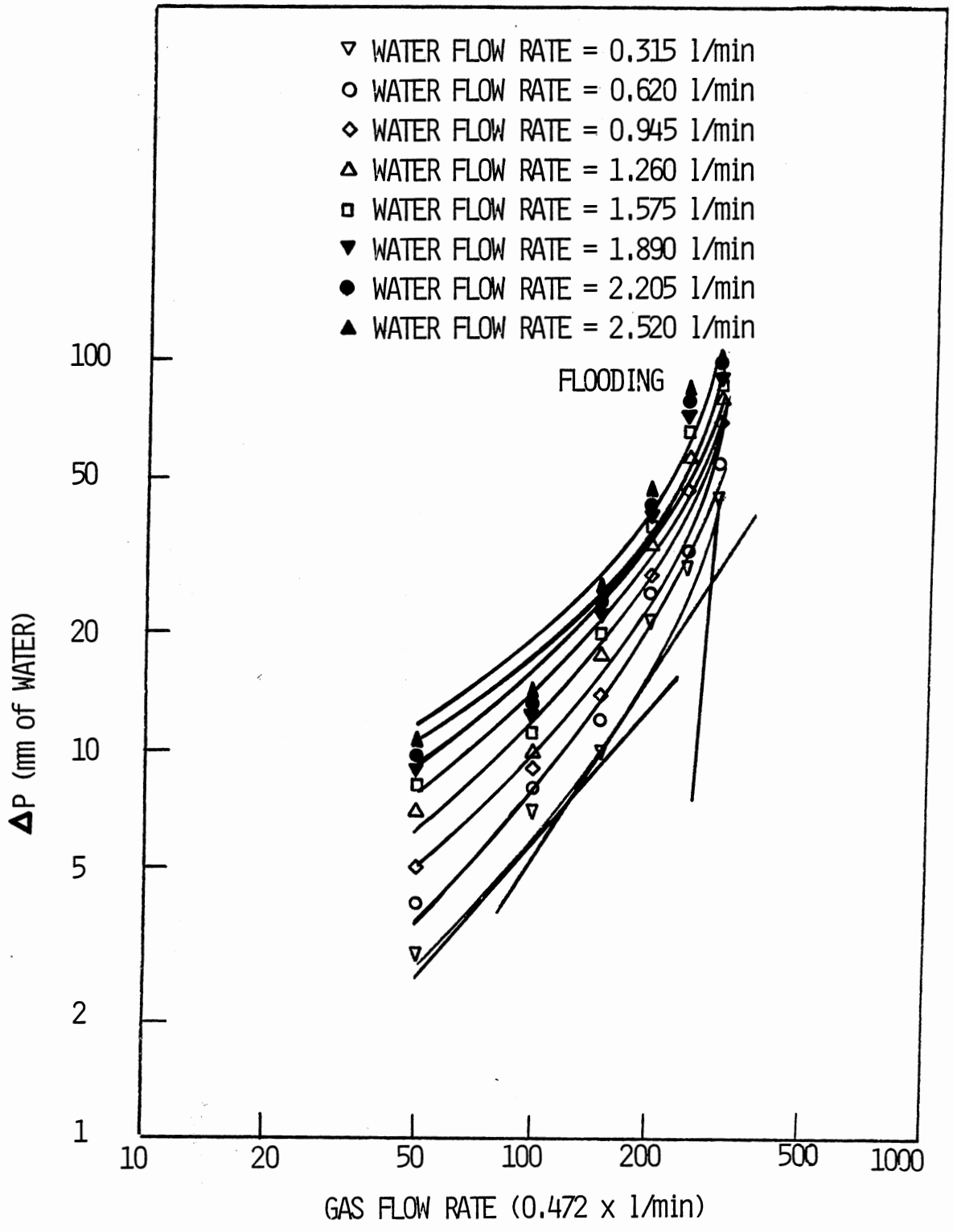


Figure 37. Pressure Drop Across Packing Versus Gas Loading Rate for 0.9 m Bed Depth

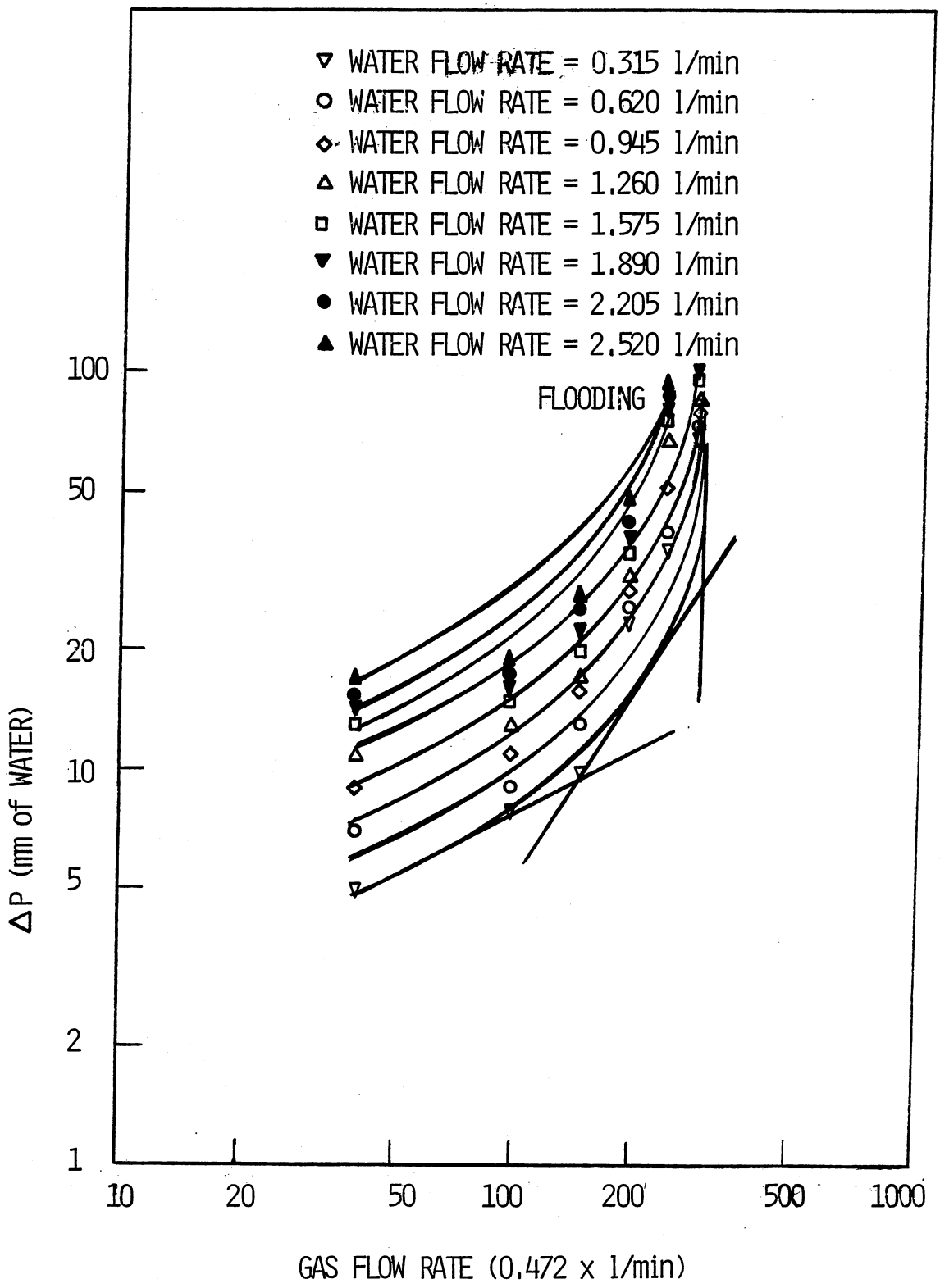


Figure 38. Pressure Drop Across Packing Versus Gas Loading Rate for 1.2 m Bed Depth

TABLE XIX

RESULTS OF HYDRAULIC LOADING STUDY

Water Loading Rates (L) (m^3/m^2-hr)	0.6 M Bed Depth Air Loading Rate at Flooding (m^3/m^2-hr)	0.9 M Bed Depth Air Loading Rate at Flooding (m^3/m^2-hr)	1.2 M Bed Depth Air Loading Rate at Flooding (m^3/m^2-hr)
4.27	1920	1920	1920
8.53	1920	1920	1920
12.80	1920	1920	1760
17.07	1920	1760	1760
21.33	1760	1760	1760
25.66	1760	1760	1600
29.87	1600	1600	1600
34.13	1600	1600	1600

TABLE XX

OPERATING FLOW RATE OF AIR AND WATER
AT 0.6, 0.9, AND 1.2 M BED DEPTHS

G/L	Air Loading (m^3/m^2-hr)	Liquid Loading (m^3/m^2-hr)
30	960	32
90	960	10.7
150	960	6.4

Effect of Water Temperature, Gas-to-Liquid Ratio, Air Temperature, and Bed Depths on Percent of Removal for Volatile and Slightly-Volatile Organic Compounds

The results of the percent removal of the volatile compounds at all combinations of water temperatures, bed depths, gas-to-liquid ratios, and air temperatures are presented in Appendix C (for toluene, "-" is a symbol of percent removal greater than 99.5). The range of percent removal of toluene for water temperatures 15°, 35°, and 55°C measured at all combinations of bed depths (0.6, 0.9, and 1.2 M), gas-to-liquid ratios (30, 90, and 150), and air temperatures (5°, 15°, and 25°C) was 76.3 to >99.5, >99.5 to >99.5, and >99.5 to >99.5 respectively.

The range of percent removal of chlorobenzene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 66.2 to 94.7, 90.2 to 99.5, and 94.0 to 99.5 respectively. The range of percent removal of ethylbenzene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 65.6 to 94.1, 90.2 to 99.2, and 94.01 to 99.3 respectively. The range of percent removal of tetrachloroethane for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 19.7 to 58.3, 52.3 to 96.0, and 74.7 to 95.4 respectively. The range of percent removal of 1,3-dichlorobenzene temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 64.9 to 95.0, 86.3 to 98.8, and 91.4 to 97.1 respectively. The range of percent

removal of 1,2-dichlorobenzene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 58.2 to 95.0, 86.6 to 98.8, and 90.4 to 98.9 respectively.

The results of the percent removal of slightly-volatile compounds (operational defined as H less than that of napthalene) at all combinations of water temperatures, bed depths, gas-to-liquid ratios are presented in Appendix C. The range of percent removal of nitrobenzene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 7.1 to 25.6, 20.3 to 59.6, and 21.8 to 73.8 respectively. The range of percent removal of napthalene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 31.1 to 81.7, 65.7 to 96.9, and 80.5 to 99.1 respectively. The range of percent removal of 1-chloronapthalene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 30.2 to 81.4, 63.1 to 96.9, and 75.8 - 98.1 respectively. The range of percent removal of 2,6-dinitrotoluene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 8.5 to 33.1, 11.9 to 45.6, and 27.1 to 39.9 respectively. The range of percent removal of fluorene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 19.2 to 62.1, 39.31 to 67.6, and 38.4 to 80.0 respectively. The range of percent removal of 2,4-dinitrotoluene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 7.6 to 33.3, 12.8

to 40.8, and 25.9 to 47.4 respectively. The range of percent removal of hexachlorobenzene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 19.0 to 56.6, 26.8 to 71.6, and 34.1 to 73.7 respectively. The range of percent removal of phenanthrene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 13.4 to 56.7, 22.0 to 52.6, and 26.2 to 46.3 respectively. The range of percent removal of fluoranthene for water temperatures 15°, 35°,and 55°C measured at all combinations of bed depths, gas-to-liquid ratios, and air temperatures was 19.1 to 51.1, 21.9 to 52.6, and 24.4 to 53.3 respectively.

The percentage removal of the volatile and slightly-volatile organic compounds at a constant 0.6 M bed depth and an air temperature of 5°C are presented in Table XXI as a function of gas-to-liquid ratio and water temperature. Table XXII shows similar information for a 0.6 M bed depth and air temperature 25°C. These results for each organic compound are explained as follows.

The removal of toluene ranged from 76.3 to 85.2, 79.1 to 99.2, and 85.7 to 94.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of toluene ranged from 92.9 to 98.9, 95.9 to 99.2, and 98.8 to > 99.5% at the gas-to-liquid ratio of 30, 90, and 15, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of toluene ranged from 95.7 to 99.5, 95.5 to >99.5, and 96.2 to >99.5% at the gas-to-liquid ratio of 30, 90, and 150, respectively.

TABLE XXI

THE PERCENT REMOVAL OF ORGANIC COMPOUNDS AT 5°C AIR TEMPERATURE, 0.6 M BED DEPTH, AND ALL COMBINATIONS OF WATER TEMPERATURES ALONG WITH GAS-TO-LIQUID RATIOS (G/L)

Compound	% Removal 0.6 M Bed Depth G/L = 30 Water Temperature			% Removal 0.6 M Bed Depth G/L = 90 Water Temperature			% Removal 0.6 M Bed Depth G/L = 150 Water Temperature		
	15°C	35°C	55°C	15°C	35°C	55°C	15°C	35°C	55°C
Toluene	76.3	92.9	95.7	79.1	95.9	95.5	85.7	98.8	96.2
Chlorobenzene	66.2	88.1	94.0	75.8	90.0	95.6	84.1	92.8	96.7
Ethylbenzene	65.6	90.2	92.1	77.7	92.3	95.6	80.7	94.2	95.7
Tetrachloroethane	19.7	52.2	72.7	27.1	76.2	85.8	29.5	80.9	88.6
1,3-Dichlorobenzene	64.9	86.3	91.4	81.8	90.0	95.1	82.0	91.7	96.3
1,2-Dichlorobenzene	58.2	86.5	90.4	79.1	88.3	95.8	83.4	90.3	97.4
Nitrobenzene	7.1	20.3	21.8	7.9	29.5	40.4	10.8	31.9	40.4
Napthalene	31.2	65.6	80.5	57.9	83.5	93.6	68.9	87.8	94.9
1-Chloronapthalene	30.2	63.1	75.8	53.3	83.1	92.2	66.4	86.5	94.0
2,6-Dinitrotoluene	8.5	11.9	27.1	11.7	12.3	29.4	15.4	21.6	30.4
Fluorene	19.2	38.3	38.4	37.8	50.5	40.5	42.9	60.9	76.3
2,4-Dinitrotoluene	7.6	12.8	25.9	14.0	22.4	20.5	18.1	20.2	29.2
Hexachlorobenzene	19.0	26.9	34.1	22.9	25.1	38.7	27.8	38.9	52.9
Phenanthrene	13.4	22.0	26.2	22.6	33.0	40.7	26.4	36.7	45.7
Fluoranthene	19.1	21.9	24.4	20.7	24.3	34.2	24.8	30.0	41.5

TABLE XXII

THE PERCENT REMOVAL OF ORGANIC COMPOUNDS AT 25°C AIR TEMPERATURE, 0.6 M BED DEPTH, AND ALL COMBINATIONS OF WATER TEMPERATURES ALONG WITH GAS-TO-LIQUID RATIOS (G/L)

Compound	% Removal 0.6 M Bed Depth G/L = 30 Water Temperature			% Removal 0.6 M Bed Depth G/L = 90 Water Temperature			% Removal 0.6 M Bed Depth G/L = 150 Water Temperature		
	15°C	35°C	55°C	15°C	35°C	55°C	15°C	35°C	55°C
Toluene	85.2	98.9	99.5	91.5	99.2	99.5	94.1	99.5	99.5
Chlorobenzene	75.0	88.9	94.1	79.6	95.6	97.1	85.5	95.7	97.0
Ethylbenzene	71.5	90.5	92.7	78.3	94.2	96.8	83.1	96.9	97.4
Tetrachloroethane	33.6	72.9	78.9	34.0	80.1	93.1	43.6	83.6	95.1
1,3-Dichlorobenzene	69.4	90.0	95.7	84.2	94.1	98.0	86.8	94.1	99.1
1,2-Dichlorobenzene	68.0	89.6	92.9	83.8	92.5	97.1	86.1	93.8	97.4
Nitrobenzene	14.5	23.3	28.3	16.3	29.4	40.0	21.6	36.7	45.3
Napthalene	47.7	77.4	87.0	64.3	87.0	94.0	70.3	90.6	96.2
1-Chloronapthalene	45.8	70.0	80.6	64.2	84.3	92.6	68.1	89.5	94.7
2,6-Dinitrotoluene	11.7	25.7	40.3	15.0	26.4	45.7	22.1	29.0	46.0
Fluorene	31.8	41.6	50.4	42.3	52.2	63.1	47.0	62.1	73.6
2,4-Dinitrotoluene	11.3	26.5	44.6	17.8	28.3	46.8	41.9	35.3	45.7
Hexachlorobenzene	29.1	29.3	43.6	33.1	41.7	56.7	31.8	49.0	58.2
Phenanthrene	25.6	43.3	43.3	27.4	35.1	47.9	31.6	38.3	47.9
Fluoranthene	26.9	33.2	33.2	27.0	34.3	38.6	33.9	40.5	44.8

These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of chlorobenzene ranged from 66.2 to 85.2, 75.8 to 79.6, and 84.1 to 85.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of chlorobenzene ranged from 88.1 to 88.9, 90.0 to 95.6, and 92.8 to 95.7% at the gas-to-liquid ratio 30, 90, and 150, respectively. These percent removals were determined at a water temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of chlorobenzene ranged from 94.0 to 94.1, 96.5 to 97.1, and 96.7 to 97.0% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of ethylbenzene ranged from 65.6 to 71.5, 77.7 to 78.3, and 80.7 to 83.1% at the gas to liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of ethylbenzene ranged from 90.2 to 90.5, 92.3 to 94.2, and 94.2 to 96.9% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature from 5to 25°C. The removal of ethylbenzene ranged from 92.1 to 92.7, 95.6 to 96.8, and 95.7 to 97.4% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of tetrachloroethane ranged from 19.7 to 33.6, 27.1 to

34.0, and 29.4 to 43.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of tetrachloroethane ranged from 52.2 to 72.9, 87.2 to 80.1, and 80.9 to 83.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of tetrachloroethane ranged from 72.7 to 78.9, 85.8 to 93.1, and 88.6 to 97.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of 1,3-dichlorobenzene ranged from 64.9 to 69.4, 81.8 to 84.2, and 82.0 to 86.8% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 1,3-dichlorobenzene ranged from 86.3 to 90.0, 90.0 to 94.1, and 91.7 to 94.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 1,3-dichlorobenzene ranged from 91.4 to 95.7, 95.1 to 98.0, and 96.3 to 99.1% at the gas-to-liquid ratio 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The range of percent removal of 1,2-dichlorobenzene 58.2 to 68.0, 79.1 to 83.8, and 83.4 to 86.1% at at gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water

temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of 1,2-dichlorobenzene ranged from 86.5 to 89.6, 88.3 to 92.5, and 90.3 to 93.8% at the gas-to-liquid ratio 30, 90, and 150, respectively. These percent removals were determined at a water temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 1,2-dichlorobenzene ranged from 90.4 to 92.9, 95.8 to 97.1, and 97.4 to 98.4% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of nitrobenzene ranged from 7.1 to 14.5, 7.9 to 16.3, and 10.8 to 21.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of nitrobenzene ranged from 20.3 to 23.3, 29.4 to 29.5, and 31.9 to 36.7% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of nitrobenzene ranged from 21.8 to 28.3, 40.0 to 40.4, and 40.4 to 45.3% at the gas-to-liquid ratio 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of napthalene ranged from 31.2 to 47.7, 57.9 to 64.3, and 69.9 to 70.3% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of napthalene ranged from 65.6 to 77.4, 83.5 to 87.0, and 87.8

to 90.6% at the gas-to-liquid ratio 30, 90, and 150, respectively. These percent removals were determined at a water temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of napthalene ranged from 80.5 to 87.0, 93.6 to 94.0, and 94.9 to 96.2% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of 1-chloronapthalene ranged from 30.2 to 45.8, 53.3 to 64.2, and 66.4 to 68.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 1-chloronapthalene ranged from 63.1 to 70.0, 83.1 to 84.3, and 86.5 to 89.5% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 1-chloronapthalene ranged from 75.8 to 80.6, 92.2 to 92.6, and 94.0 to 94.7% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of 2,6-dinitrotoluene ranged from 8.5 to 11.7, 11.7 to 15.0, and 15.4 to 22.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of 2,6-dinitrotoluene ranged from was 11.9 to 25.7, 12.3 to 26.4, and 21.6 to 29.0% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water

temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 2,6-dinitrotoluene ranged from 27.1 to 40.3, 29.4 to 45.7, and 30.4 to 46.0% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of fluorene ranged from 19.2 to 31.8, 37.8 to 42.3, and 42.9 to 47.0% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of fluorene ranged from 38.3 to 41.6, 50.5 to 52.2, and 60.9 to 62.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of fluorene ranged from 38.4 to 50.4, 40.5 to 52.2, and 73.3 to 76.3% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature of 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of 2,6-dinitrotoluene ranged from 7.6 to 11.3, 14.0 to 12.8, and 8.1 to 41.9% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0. 6M, and air temperatures 5 to 25°C. The removal of 2,6-dinitrotoluene ranged from 12.8 to 26.5, 22.4 to 28.3, and 20.2 to 35.3% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of 2,6-dinitrotoluene ranged from 25.9 to 44.6, 20.5

to 46.8, and 29.2 to 48.7% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of hexachlorobenzene ranged from 19.0 to 29.1, 22.9 to 33.1, and 27.8 to 31.8% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of hexachlorobenzene ranged from 26.9 to 29.3, 25.1 to 41.7, and 38.9 to 49.0% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of hexachlorobenzene ranged from 34.1 to 43.6, 38.7 to 56.7, and 52.9 to 58.2% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

The removal of phenanthrene ranged from 13.4 to 25.6, 22.6 to 27.4, and 26.4 to 31.6% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C. The removal of phenanthrene ranged from 22.0 to 33.9, 33.0 to 35.1, and 36.7 to 38.1% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of phenanthrene ranged from 26.2 to 43.3, 40.7 to 47.9, and 45.7 to 47.9% at the gas-to-liquid ratio of 30, 90, and 150, respectively.

These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures 5 to 25°C.

The removal of fluoranthene ranged from 19.1 to 26.9, 20.7 to 27.0, and 24.8 to 33.9% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 15°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of fluoranthene ranged from 21.9 to 32.2, 24.3 to 34.3, and 30.0 to 40.5% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 35°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C. The removal of fluoranthene ranged from 24.4 to 33.2, 34.2 to 38.6, and 41.5 to 44.8% at the gas-to-liquid ratio of 30, 90, and 150, respectively. These percent removals were determined at a water temperature at 55°C, a packing depth of 0.6 M, and air temperatures from 5 to 25°C.

Tables XXI and XXII show the effect of the temperature of water and gas-to-liquid ratio on the removal of both volatile and slightly-volatile compounds. The percentage removal of each of the contaminants increased as the water temperature, gas-to-liquid ratio, and air temperature increased. The results of the percent removal of volatile and slightly-volatile compounds at 0.9 and 1.2 M bed depths, as shown in Appendix C, at all combinations of water temperatures, gas-to-liquid ratios, and air temperatures were higher than the 0.6 M bed depth by 4 to 12% and 6 to 16% respectively.

Effect of Water Temperature, Gas-to-Liquid Ratio, Air Temperature, and Bed Depth on Measured Overall Mass Transfer Coefficients (K_1a)

In Chapter II, equations were presented to design a packed column. Using these equations and the experimental data of Henry's constant along with the percent removal, the overall mass transfer coefficients (K_1a) of the 15 study compounds were calculated. The procedure is outlined in Table XXIII. The K_1a values, number of transfer units (NTU), and height transfer unit (HTU) are presented in Appendix C. The range of measured K_1a values for all organic compounds at constant gas-to-liquid ratios, 30, 90, and 150, at all combinations of water temperatures, air temperatures, and bed depths are listed in Table XXIV. All of the compounds in this study show the range of the K_1a values decreasing with increasing gas-to-liquid ratio.

A plot of the mass transfer coefficients show a positive slope versus water temperature, which suggests that a linear regression can correlate mass transfer coefficients with water temperatures. The data for mass transfer coefficients (K_1a) and water temperatures at all combinations of bed depths, air temperatures, and gas-to-liquid ratios for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, and 1,2-dichlorobenzene exhibit approximately the same range of values (as seen from the data in Table XXIV). Plots of these compounds (K_1a's) versus water temperatures displayed the same trends. Thus, chlorobenzene can be selected as representative to show the behavior of the mass transfer coefficients as a function of water

TABLE XXIII

SUMMARY OF PROCEDURE USED TO CALCULATE THE EXPERIMENTAL MASS TRANSFER COEFFICIENT (K_1a)

Calculate NTU, using G/L, measured H, and the fraction of the influent contaminant remaining:

$$NTU = \frac{1}{1 - \frac{RTL_m}{HG_m}} \ln \left[\frac{C_1^2}{C_1^1} \left(1 - \frac{RTL_m}{HG_m}\right) + \frac{RTL_m}{HG_m} \right]$$

Calculate HTU as:

$$HTU = \frac{Z}{NTU}$$

Calculate the mass transfer coefficients:

$$K_1a = \frac{Lm}{HTU}$$

TABLE XXIV

THE RANGE OF MEASURED OVERALL MASS TRANSFER COEFFICIENTS K_1a VALUES FOR ORGANIC COMPOUNDS AT CONSTANT GAS-TO-LIQUID 30, 90, AND 150 CALCULATED AT ALL COMBINATIONS OF WATER TEMPERATURES, BED DEPTHS, AND AIR TEMPERATURES

Compounds	The Range of K_1a Values Measured at a Constant G/L = 30 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Measured at a Constant G/L = 90 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Measured at a Constant G/L = 150 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures
Toluene	NA	NA	NA
Chlorobenzene	68.91 - 152.30	27.81 - 46.80	20.44 - 27.84
Ethylbenzene	64.18 - 129.50	28.93 - 42.28	18.05 - 25.14
Tetrachloroethane	15.67 - 248.80	6.55 - 43.09	4.01 - 21.73
1,3-Dichlorobenzene	70.70 - 166.70	34.58 - 47.25	19.31 - 25.55
1,2-Dichlorobenzene	58.48 - 148.50	31.73 - 44.57	20.42 - 25.40
Nitrobenzene	5.19 - 35.54	1.66 - 15.52	1.30 - 11.25
Napthalene	28.82 - 259.20	19.62 - 50.16	14.50 - 30.39
1-Chloronapthalene	29.81 - 229.50	16.91 - 49.59	13.78 - 25.56
2,6-Dinitrotoluene	5.47 - 26.76	2.42 - 5.58	1.86 - 3.01
Fluorene	12.70 - 93.51	9.36 - 23.92	6.26 - 11.00
2,4-Dinitrotoluene	4.80 - 20.32	2.99 - 6.41	2.25 - 3.54
Hexachlorobenzene	12.51 - 27.99	4.98 - 9.05	3.56 - 7.47
Phenanthrene	10.90 - 55.14	5.62 - 6.73	3.66 - 3.71
Fluoranthene	24.52 - 101.10	5.09 - 8.87	4.00 - 4.68

NA = Not Applicable.

temperatures. Figures 39 through 47 present the plotted graphs of mass transfer coefficients versus water temperatures for chlorobenzene at all combinations of bed depths, air temperatures, and gas-to-liquid ratios.

The data for mass transfer coefficients (K_1a) and water temperatures at all combinations of bed depths, air temperatures, and gas-to-liquid ratios for napthalene, 1-chloronapthalene, and fluorene exhibit approximately the same range of values (as seen from the data in Table XXIV). Plots of these compounds (K_1a's) versus water temperatures displayed the same trends. Thus, napthalene can be selected as representative to show the behavior of the mass transfer coefficients as a function of water temperatures. Figures 48 through 56 present the plotted graphs of mass transfer coefficients versus water temperatures for napthalene at all combinations of bed depths, air temperatures, and gas-to-liquid ratios.

The data for mass transfer coefficients and water temperatures at all combinations of bed depth, air temperatures, and gas-to-liquid ratios for nitrobenzene, 2,6-dinitrotoluene, 2,3-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene exhibit approximately the same range of values (as seen from the data in Table XXIV). Plots of these compounds (K_1a's) versus water temperatures displayed the same trends. Thus, 2,6-dinitrotoluene can be selected as representative to show the behavior of the mass transfer coefficients as a function of water temperatures. Figures 57 through 65 present the plotted graphs of mass transfer coefficients versus water temperatures for 2,6-dinitrotoluene at all combinations of bed depths, air temperatures, and gas-to-liquid ratios.

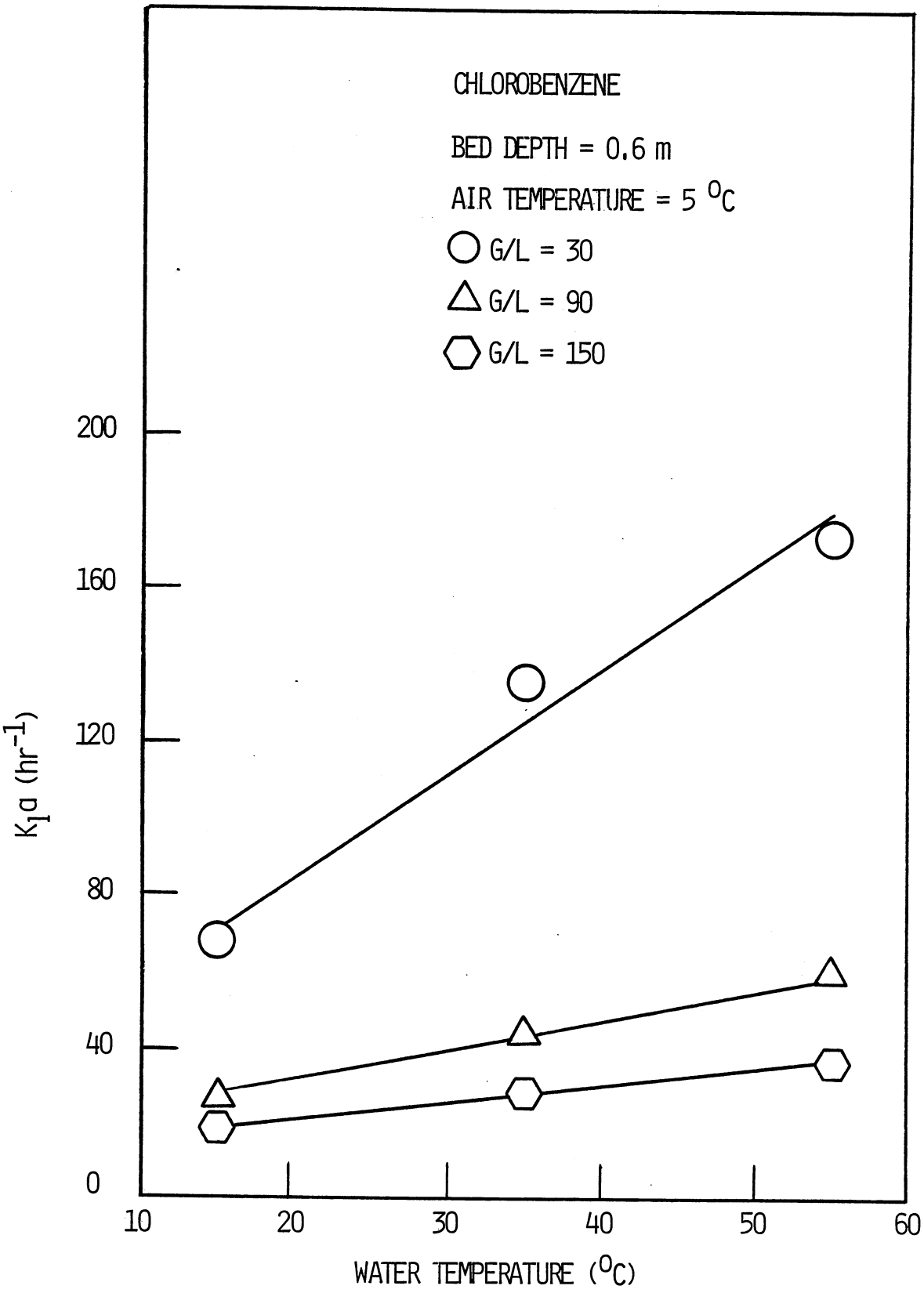


Figure 39. Measured Mass Transfer Coefficient Versus Influent Water Temperature

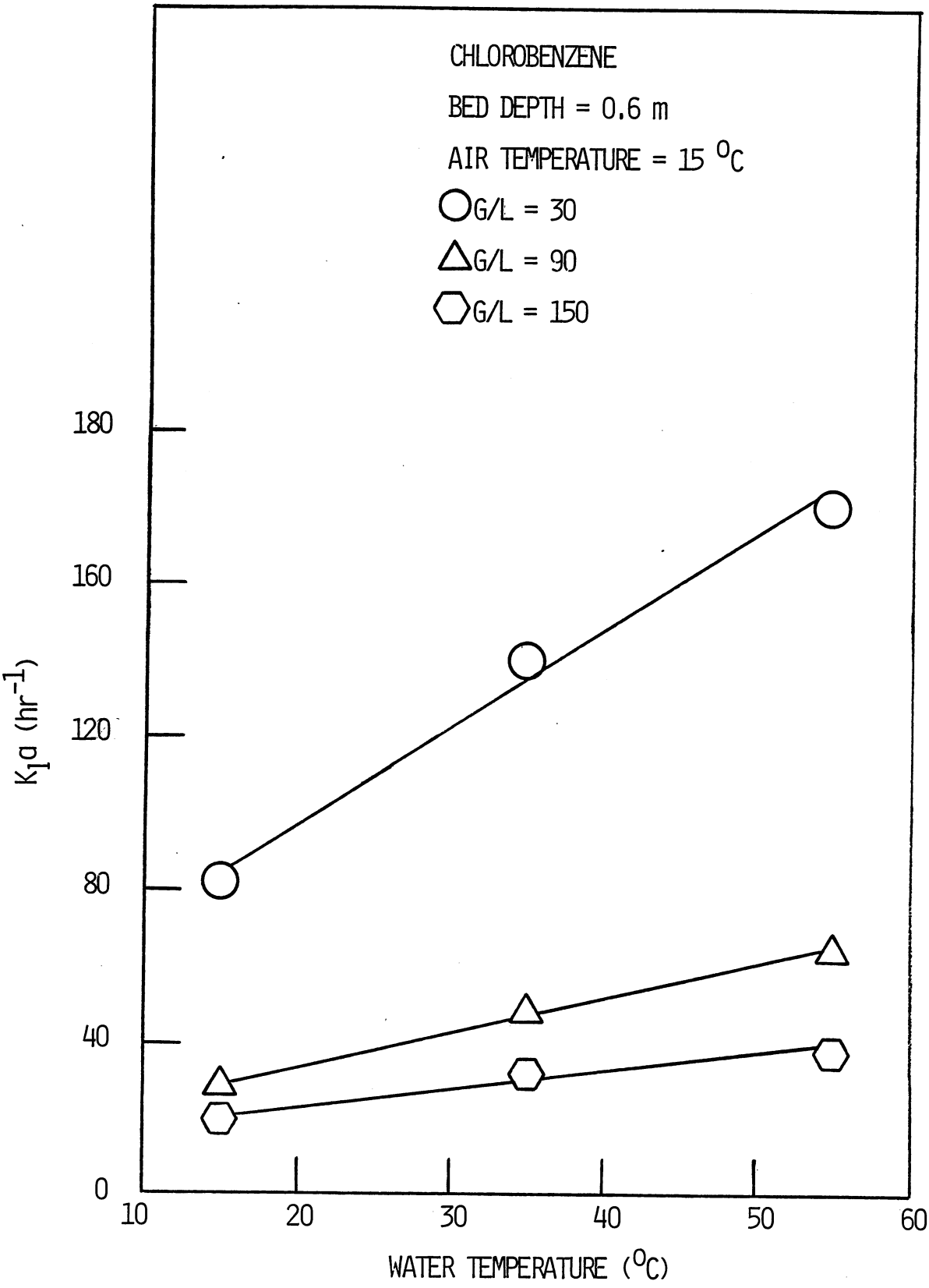


Figure 40. Measured Mass Trasfer Coefficients Versus Influent Water Temperature

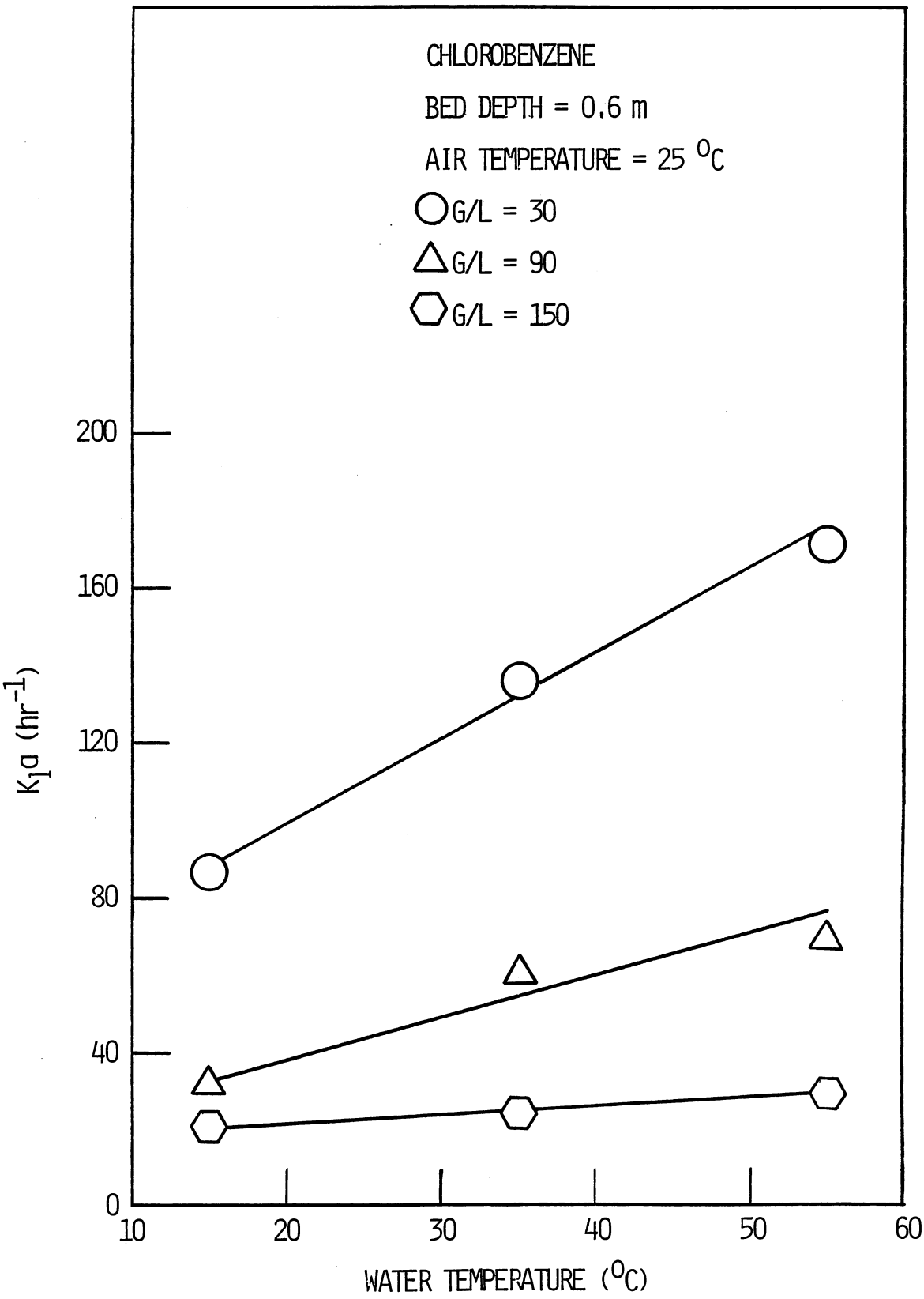


Figure 41. Measured Mass Transfer Coefficients Versus Influent Water Temperature

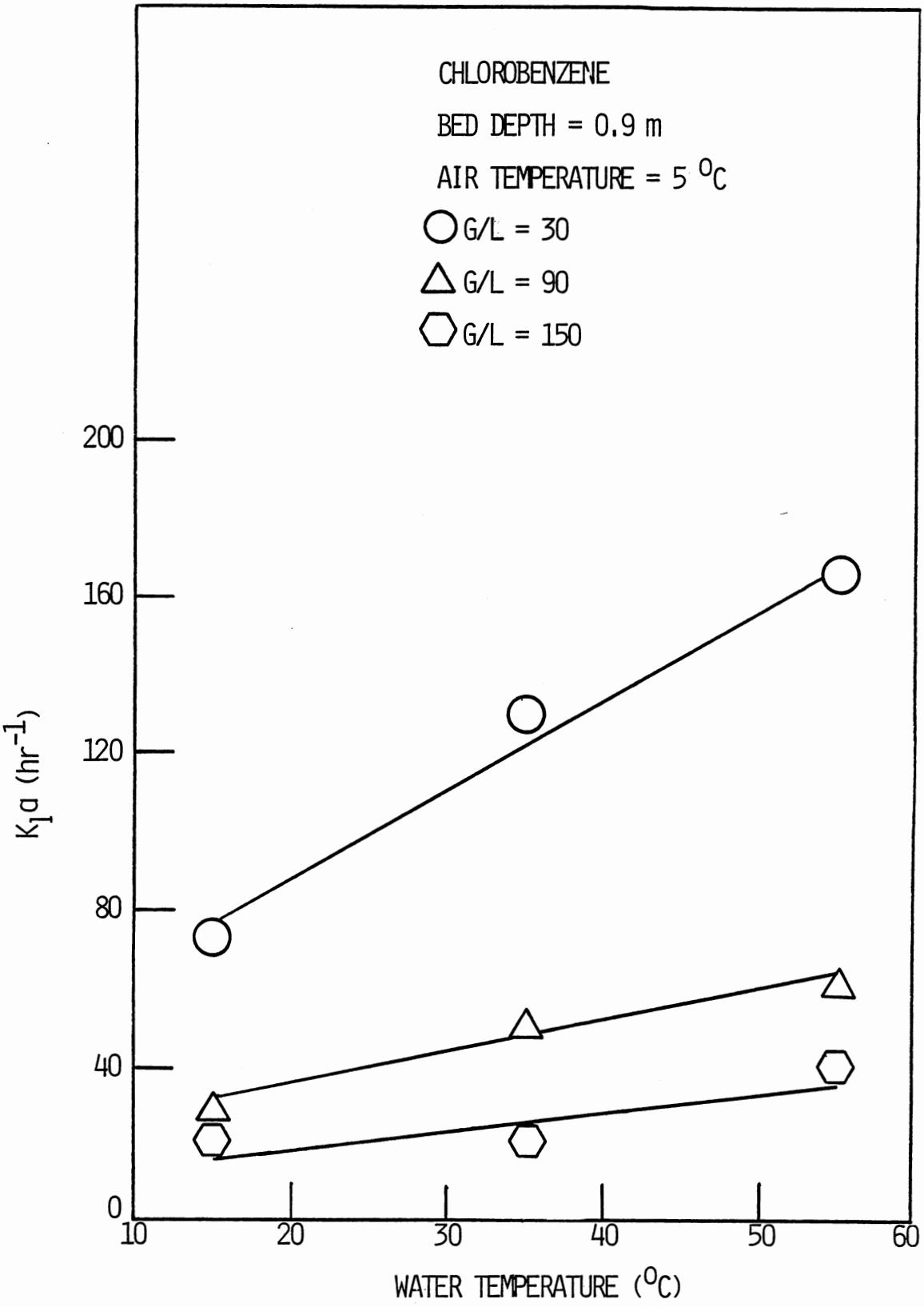


Figure 42. Measured Mass Transfer Coefficients Versus Influent Water Temperature

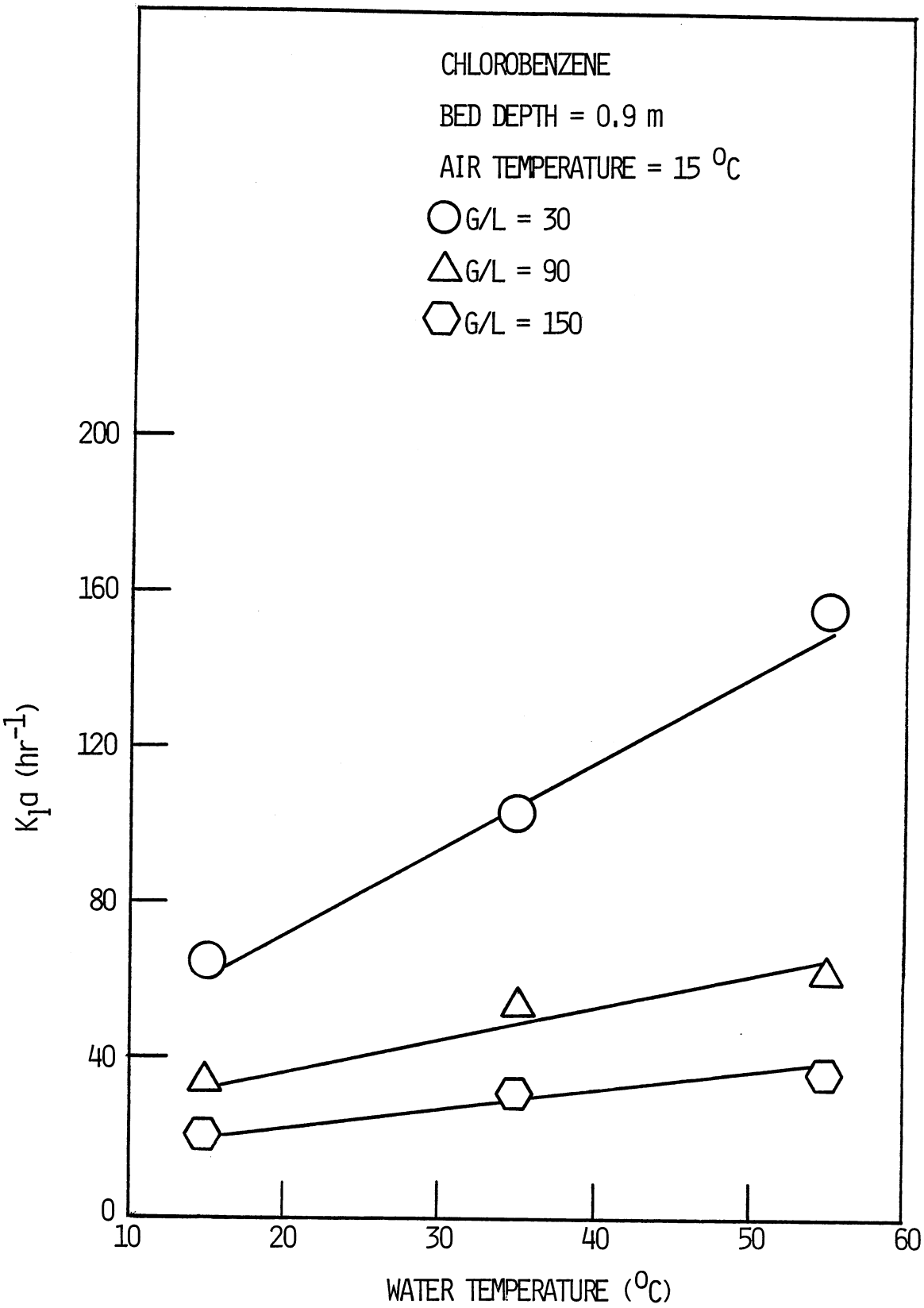


Figure 43. Measured Mass Transfer Coefficients Versus Influent Water Temperature

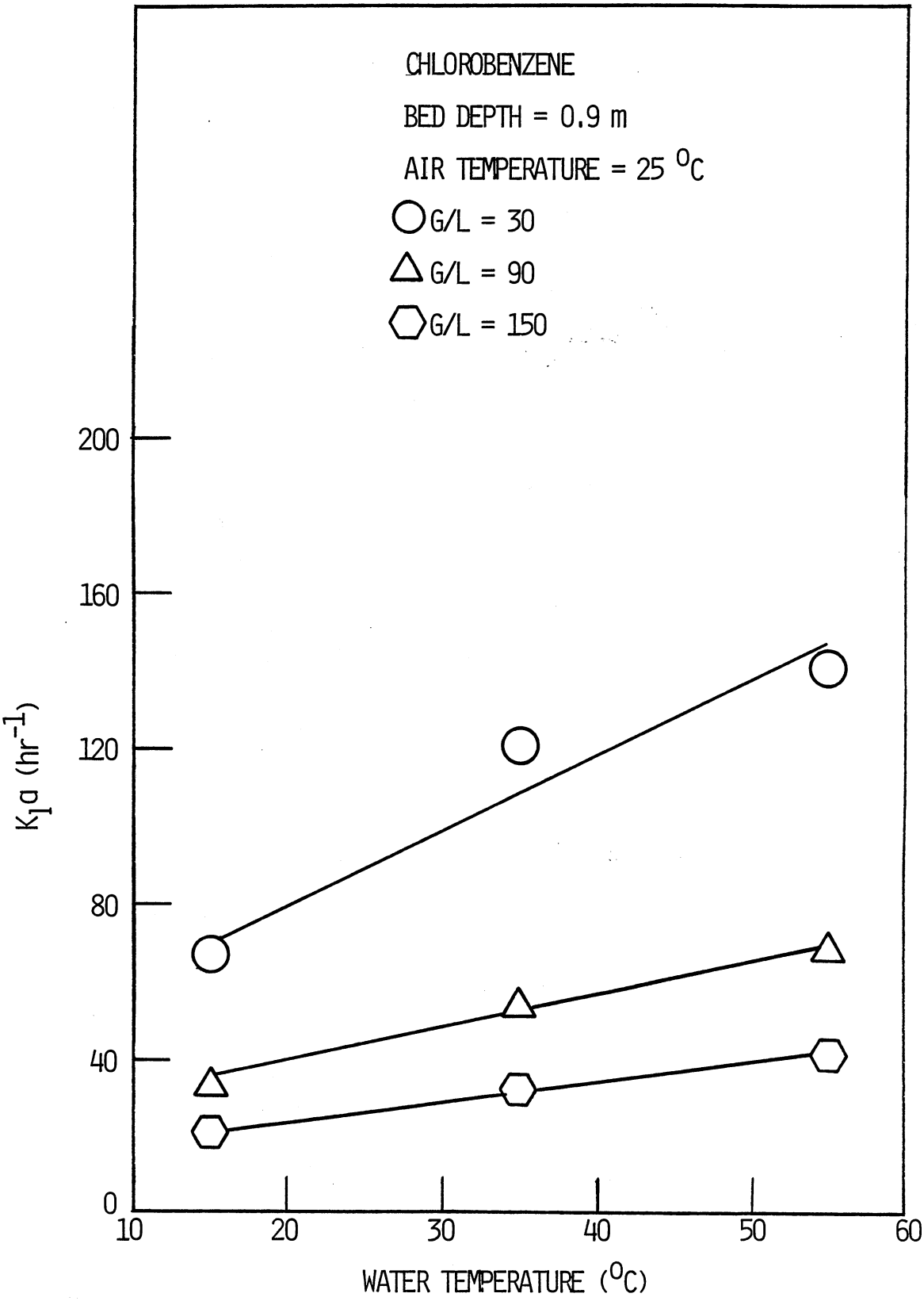


Figure 44. Measured Mass Transfer Coefficients Versus Influent Water Temperature

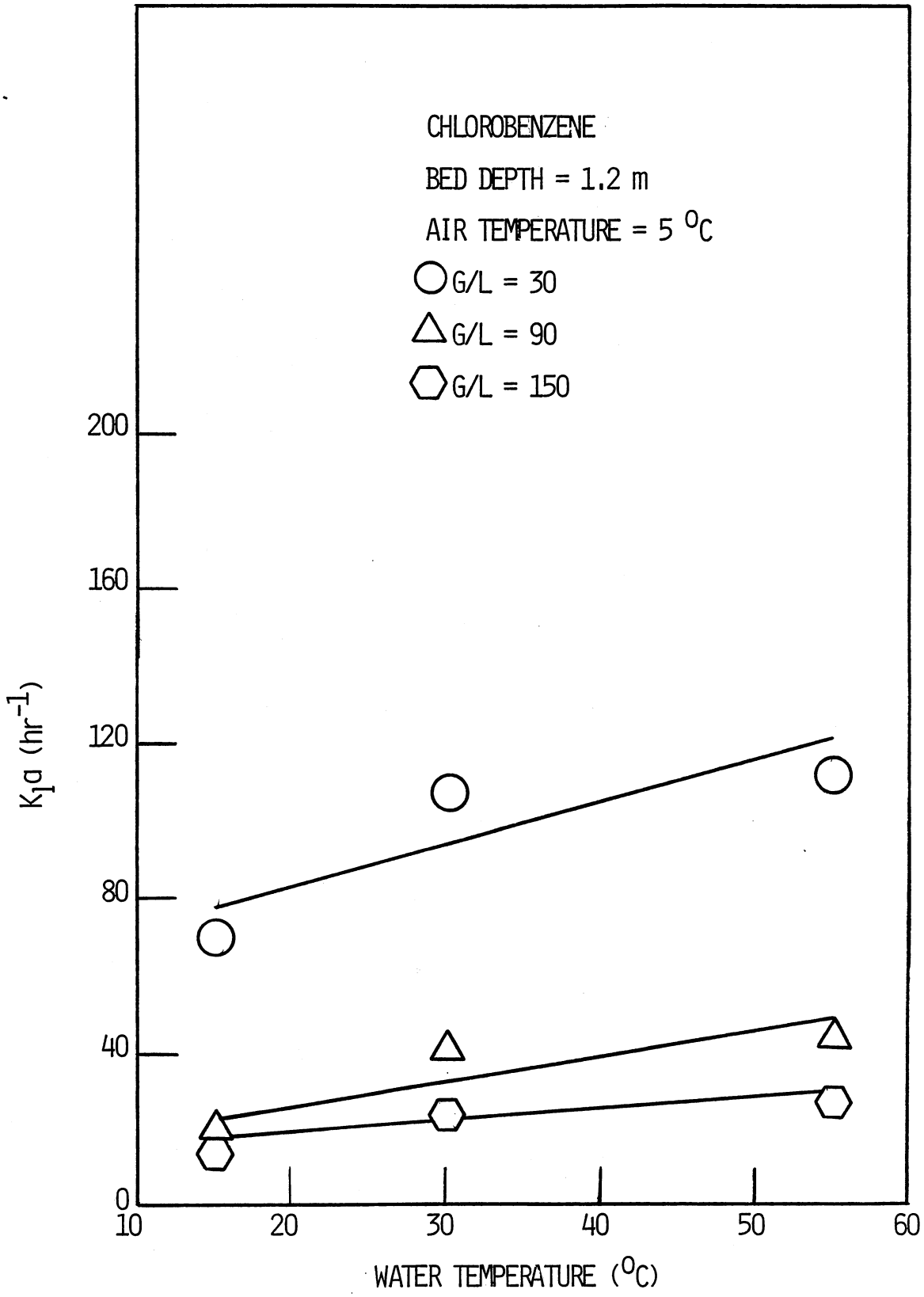


Figure 45. Measured Mass Tranfer Coefficients Versus Influent Water Temperature

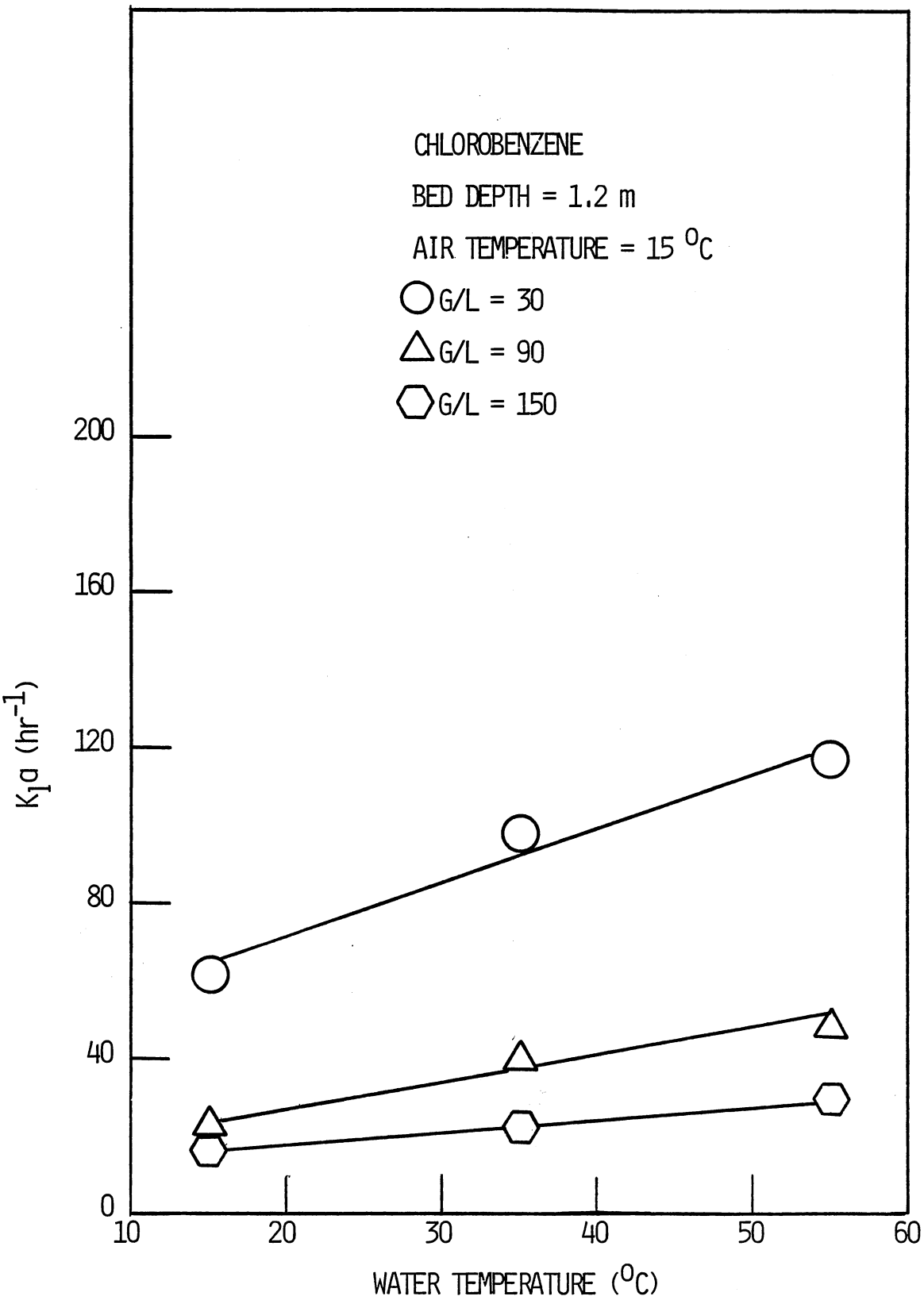


Figure 46. Measured Mass Transfer Coefficients Versus Influent Water Temperature

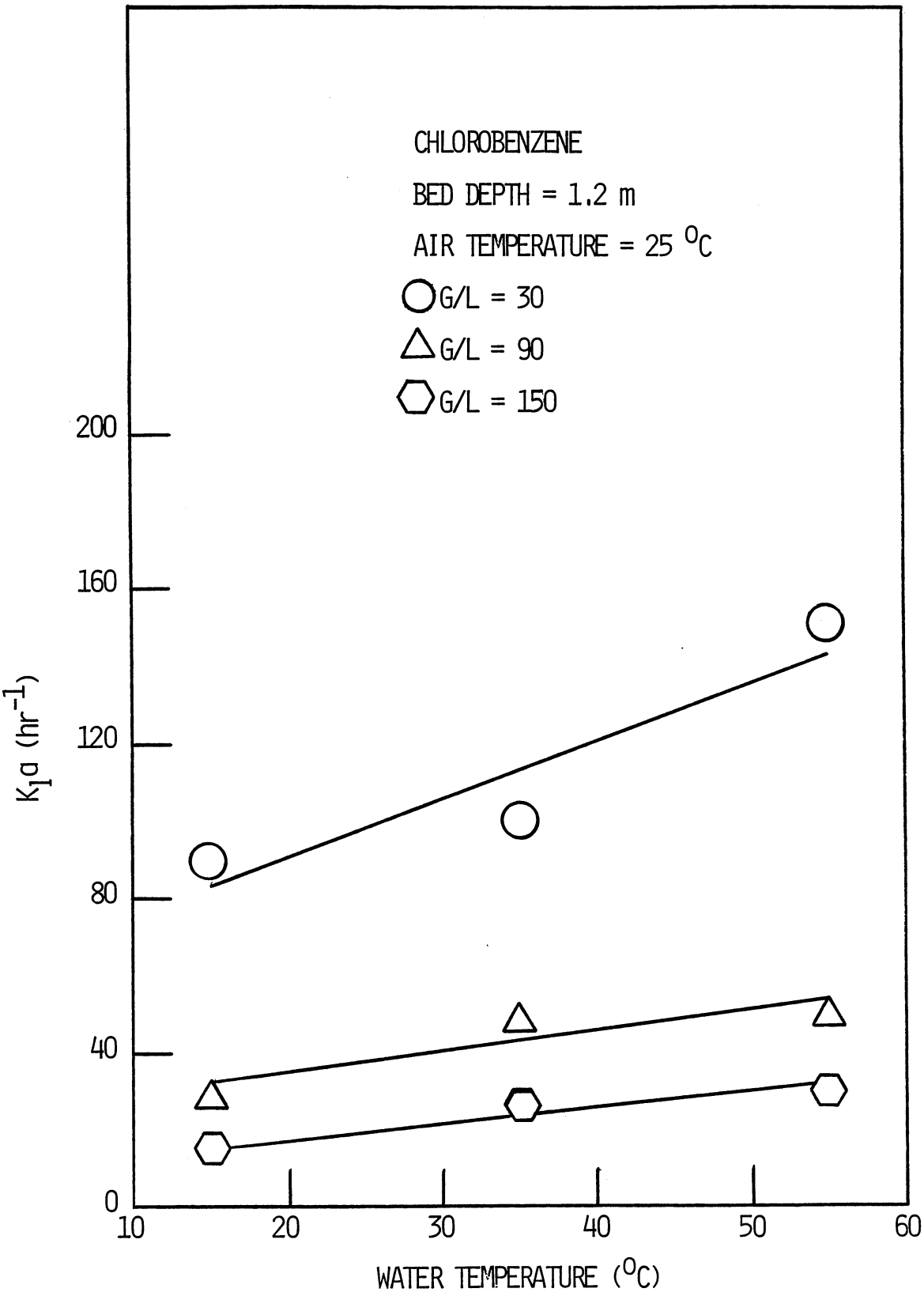


Figure 47. Measured Mass Transfer Coefficient Versus Influent Water Temperature

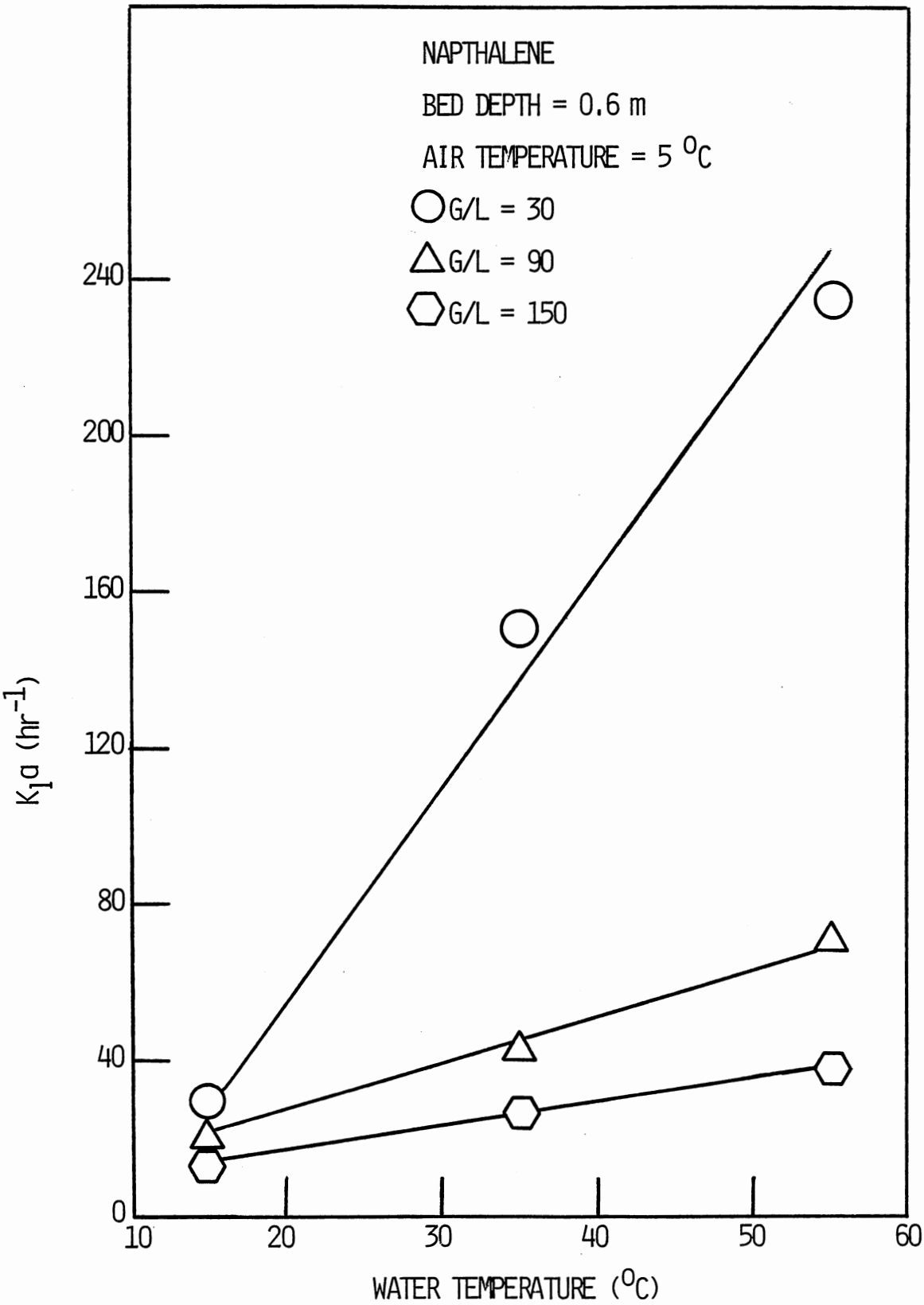


Figure 48. Measured Mass Transfer Coefficient Versus Influent Water Temperature

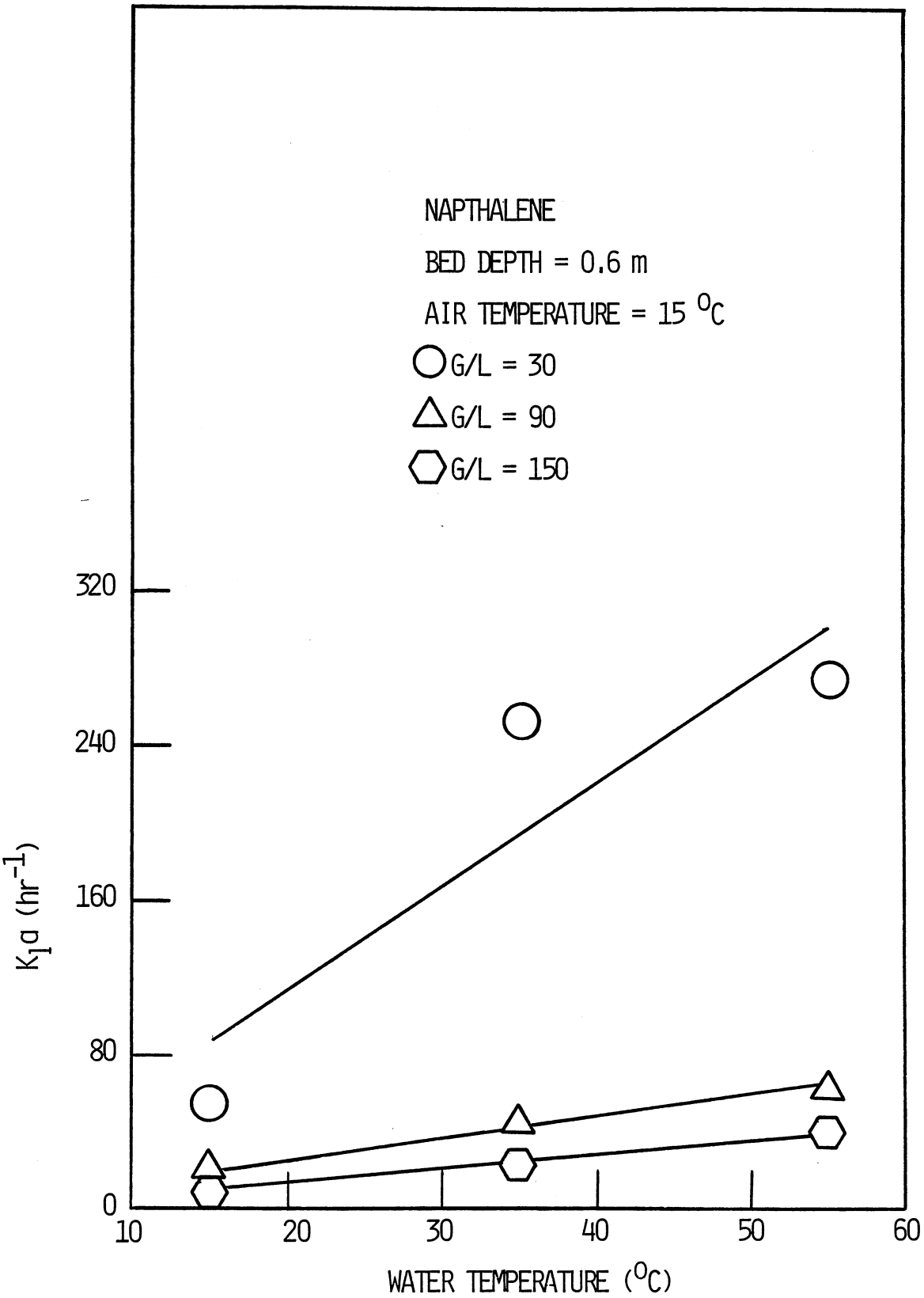


Figure 49. Measured Mass Transfer Coefficients Versus Influent Water Temperature

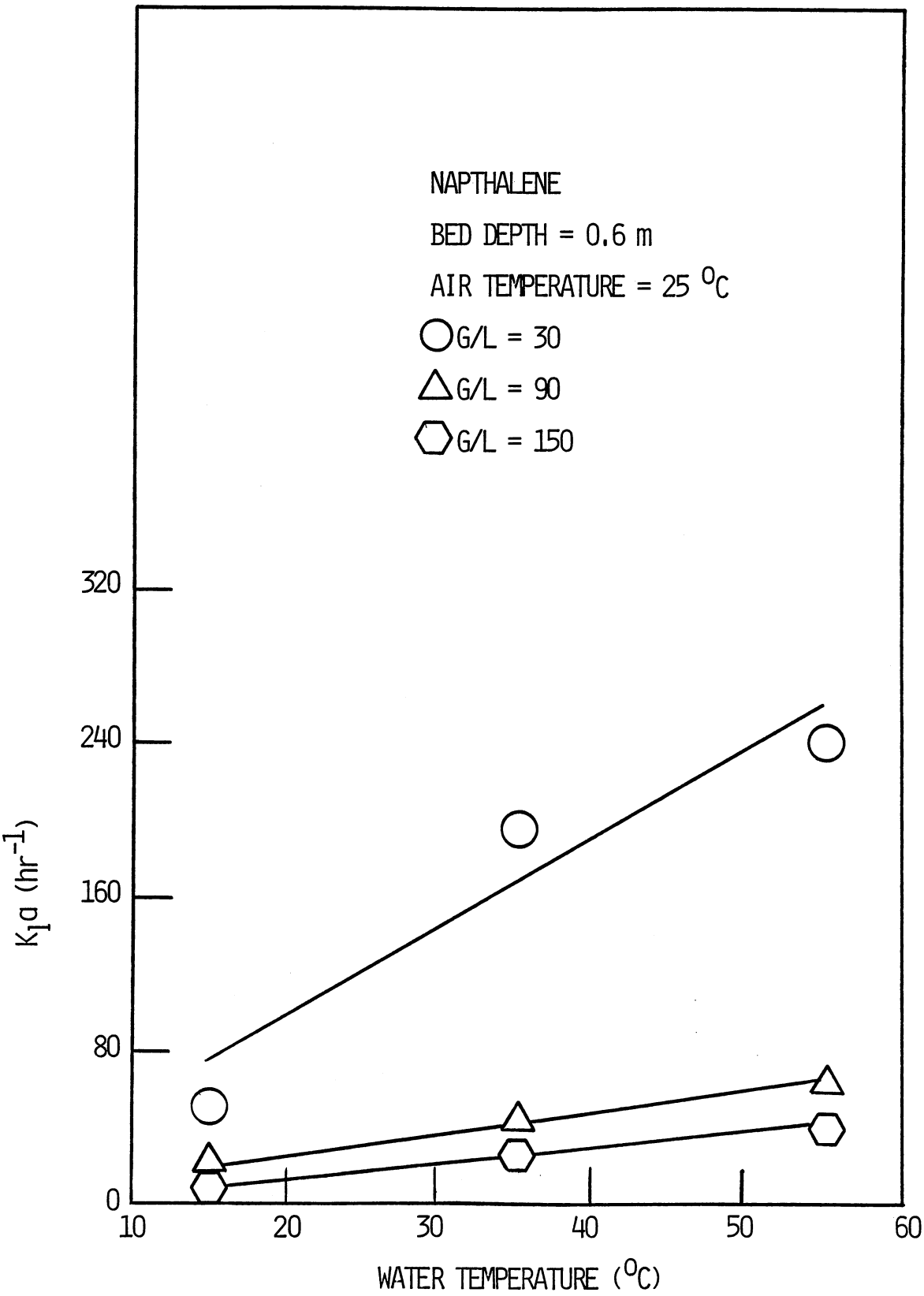


Figure 50. Measured Mass Transfer Coefficients Versus Influent Water Temperature

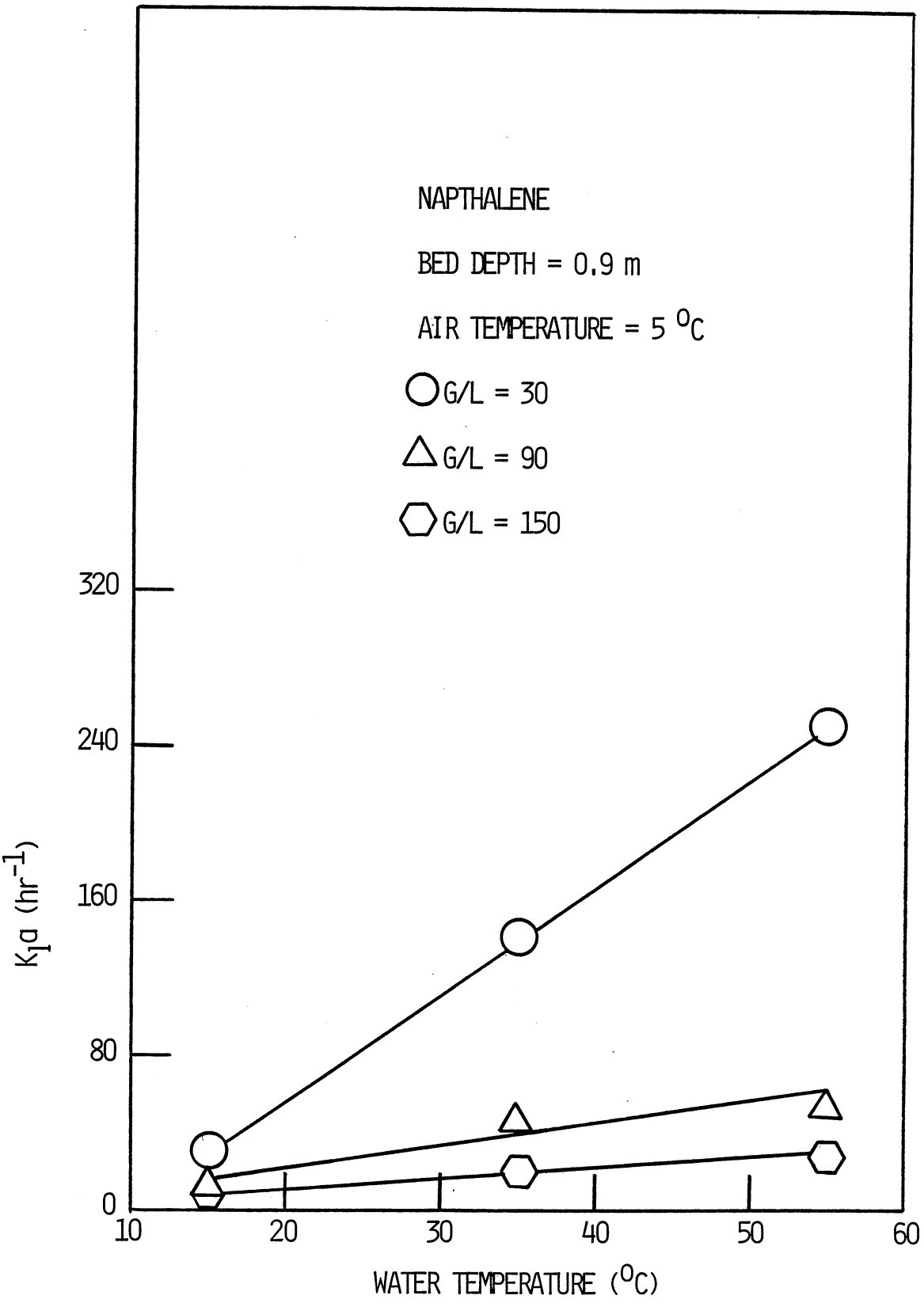


Figure 51. Measured Mass Transfer Coefficients Versus Influent Water Temperature

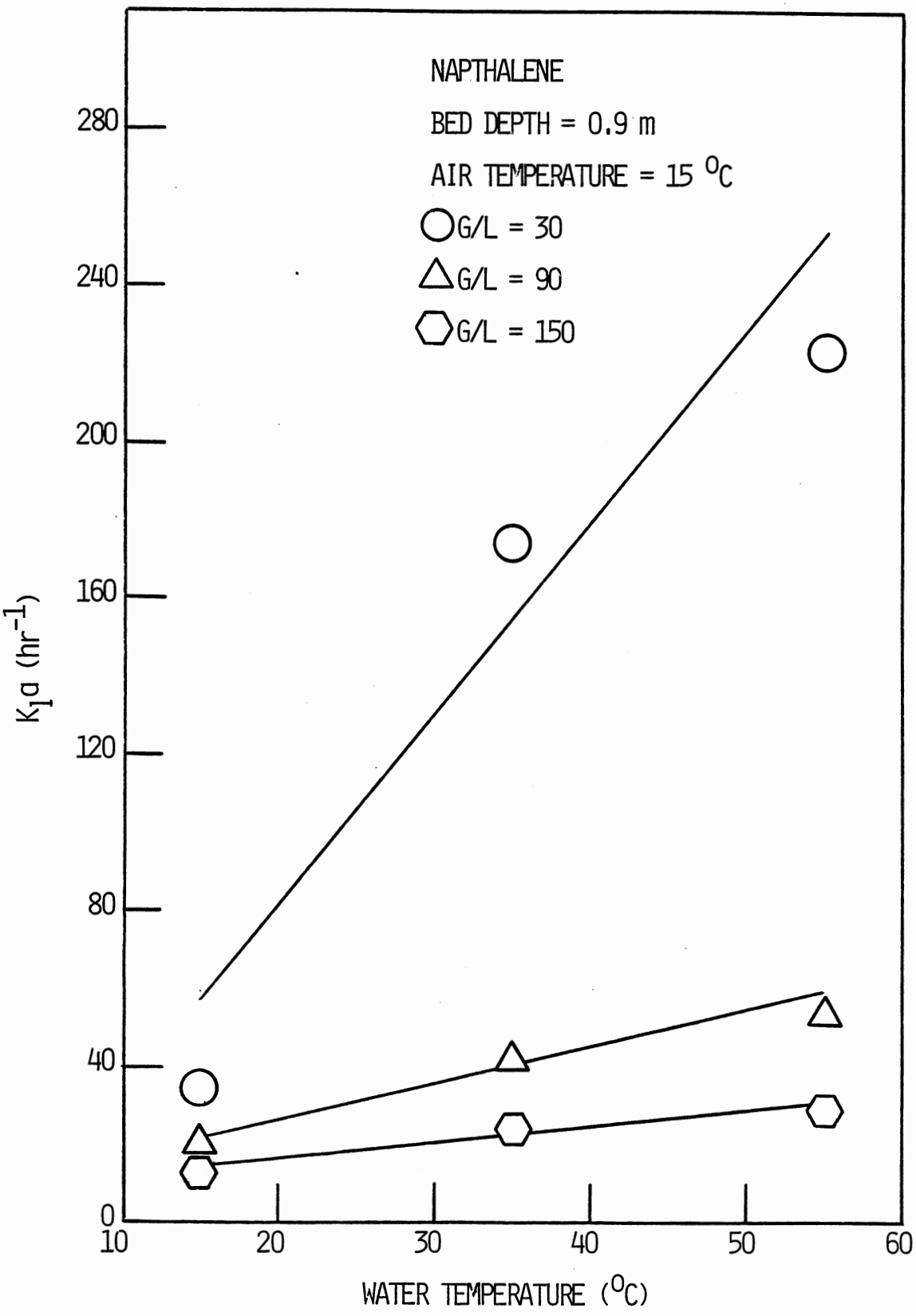


Figure 52. Measured Mass Transfer Coefficients Versus Influent Water Temperature

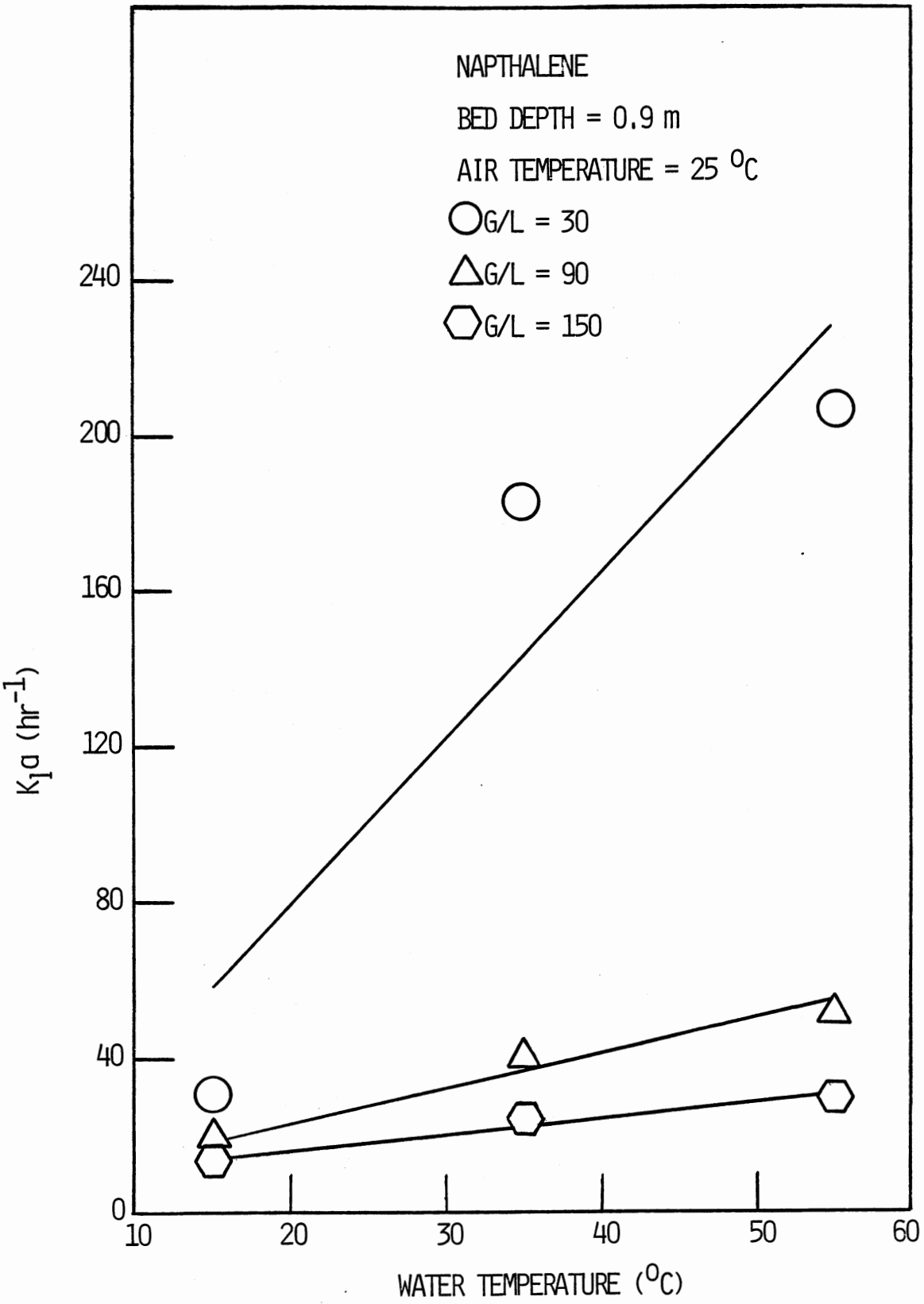


Figure 53. Measured Mass Transfer Coefficients Versus Influent Water Temperature

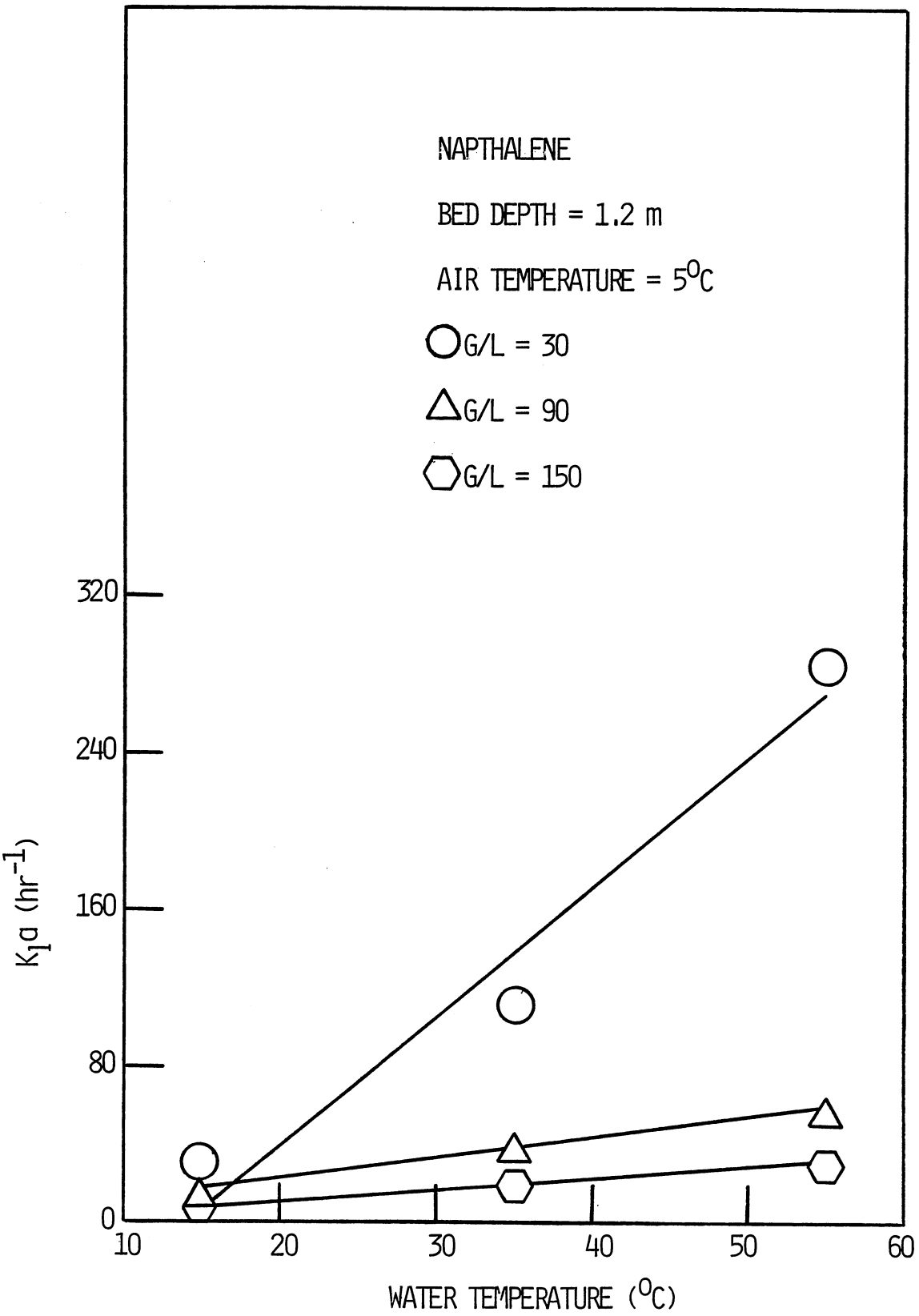


Figure 54. Measured Mass-Transfer Coefficients Versus Influent Water Temperature

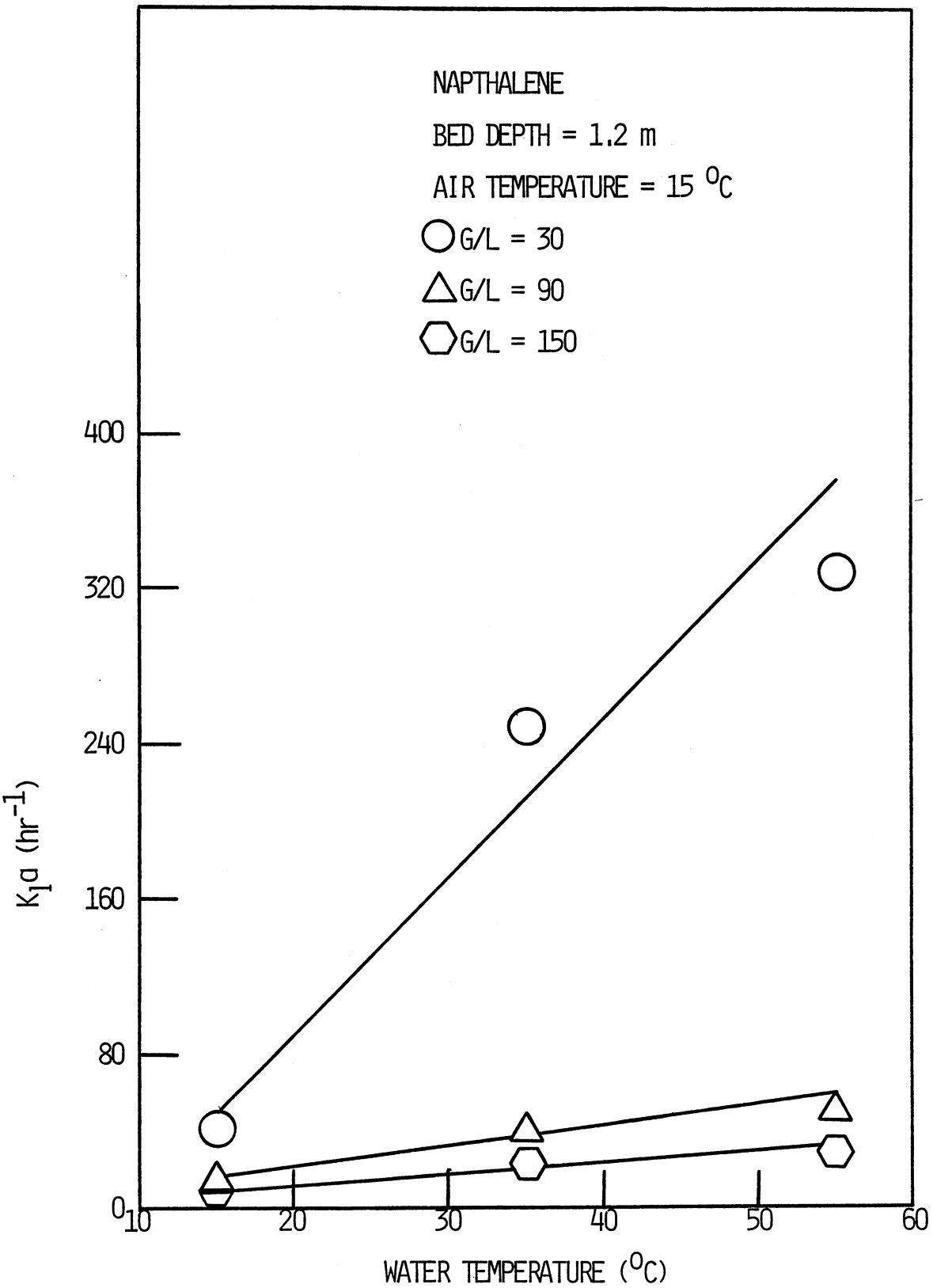


Figure 55. Measured Mass Transfer Coefficients Versus Influent Water Temperature

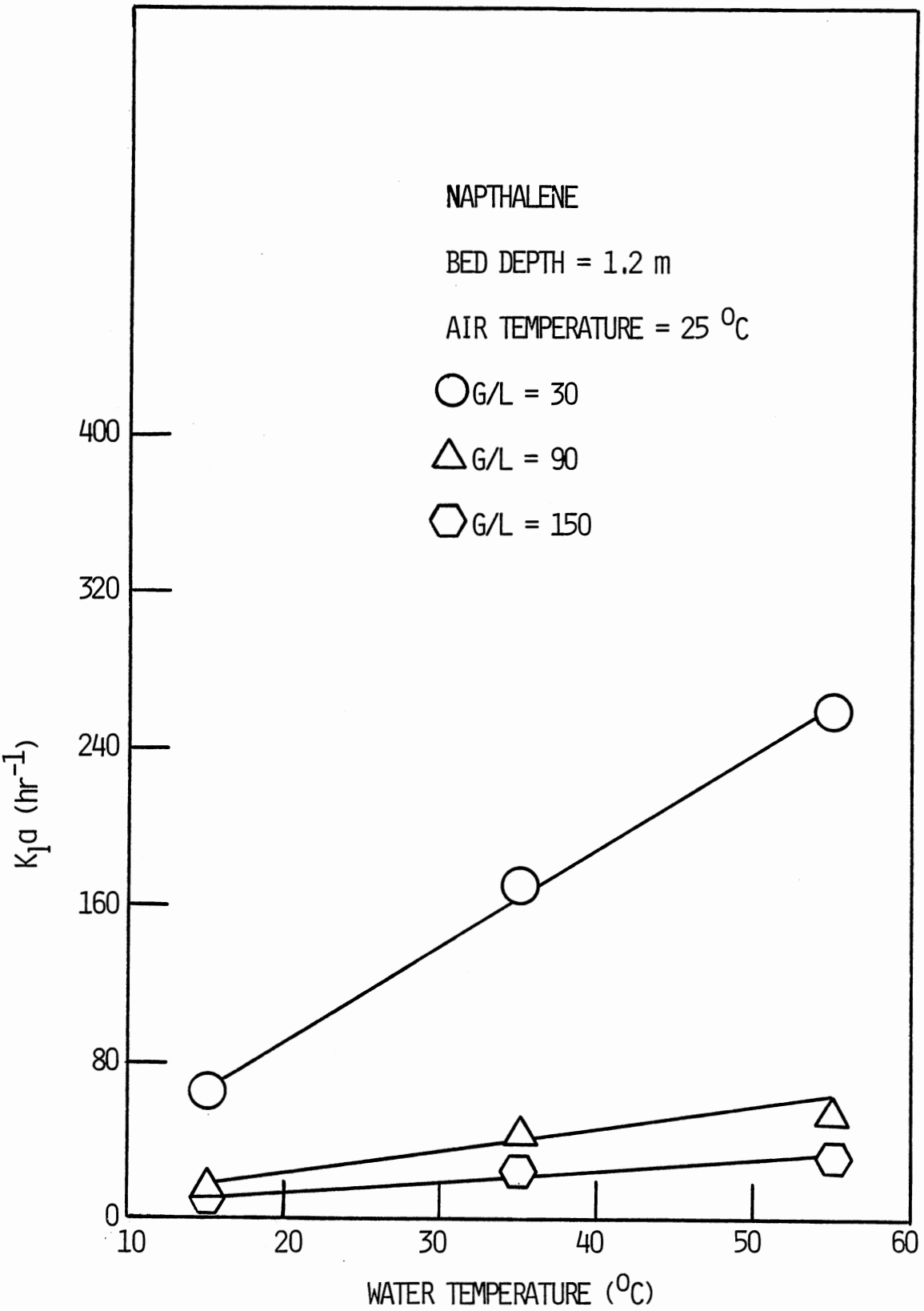


Figure 56. Measured Mass Transfer Coefficients Versus Influent Water Temperature

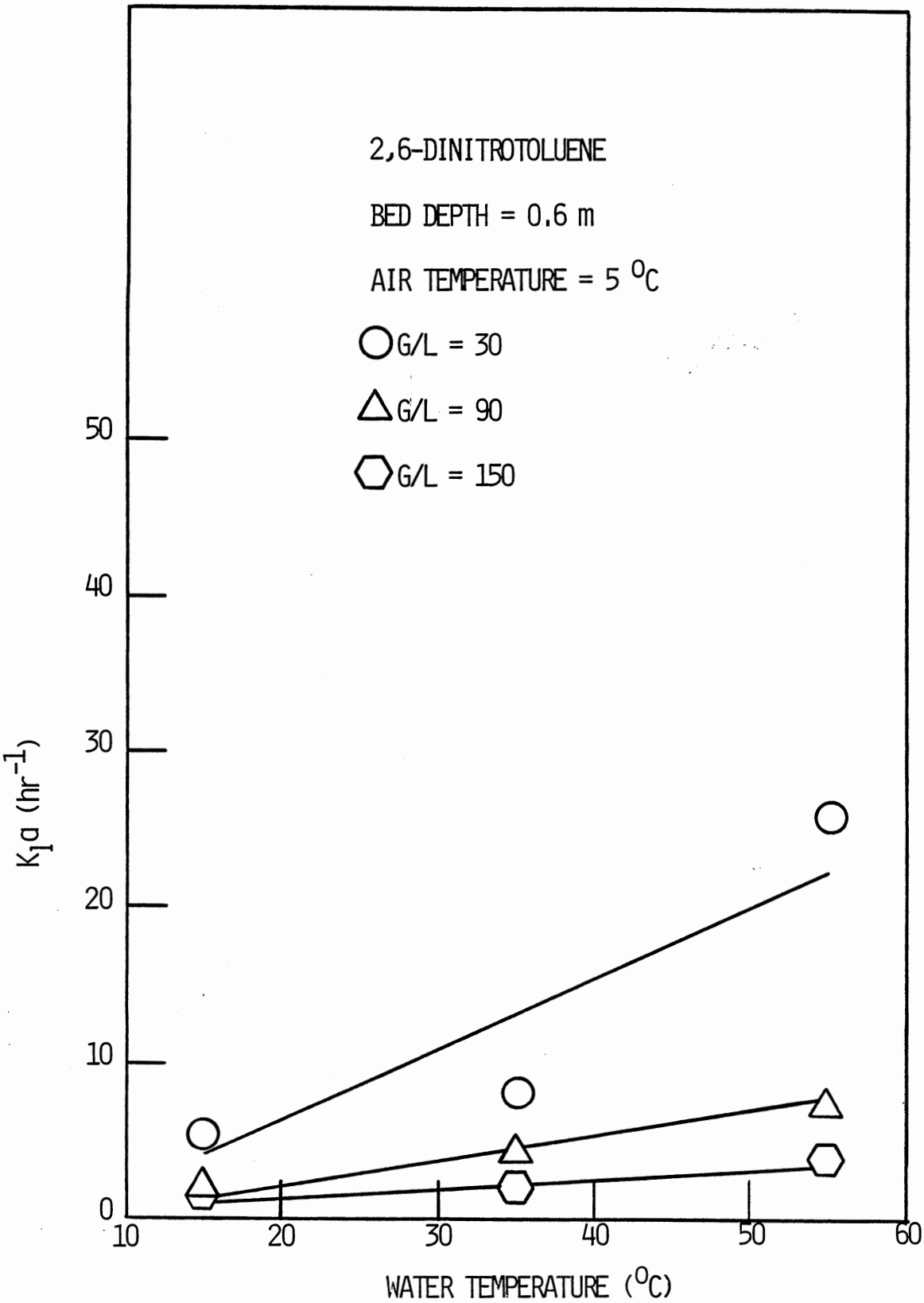


Figure 57. Measured Mass Transfer Coefficients Versus Influent Water Temperature

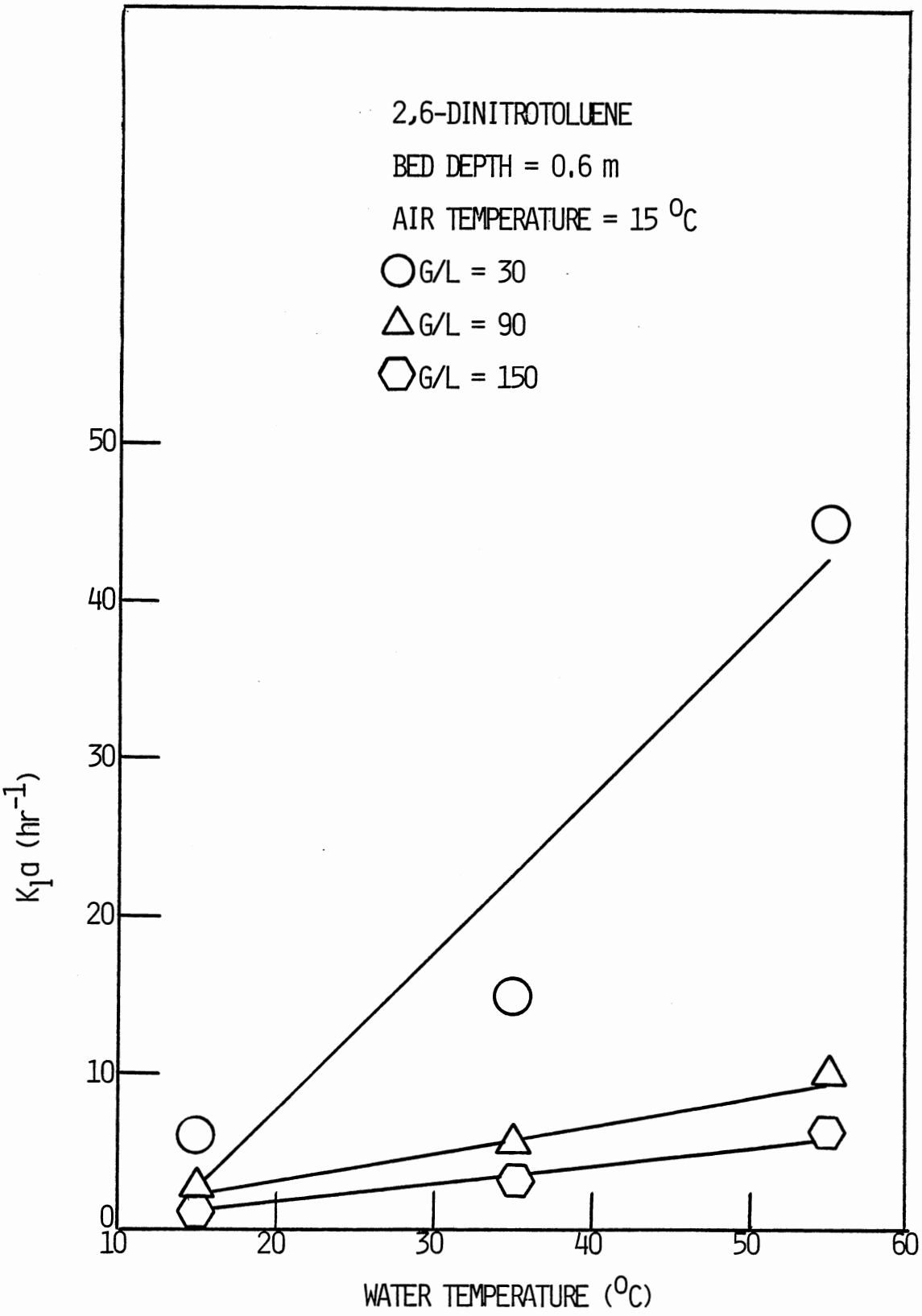


Figure 58. Measured Mass Transfer Coefficients Versus Influent Water Temperature

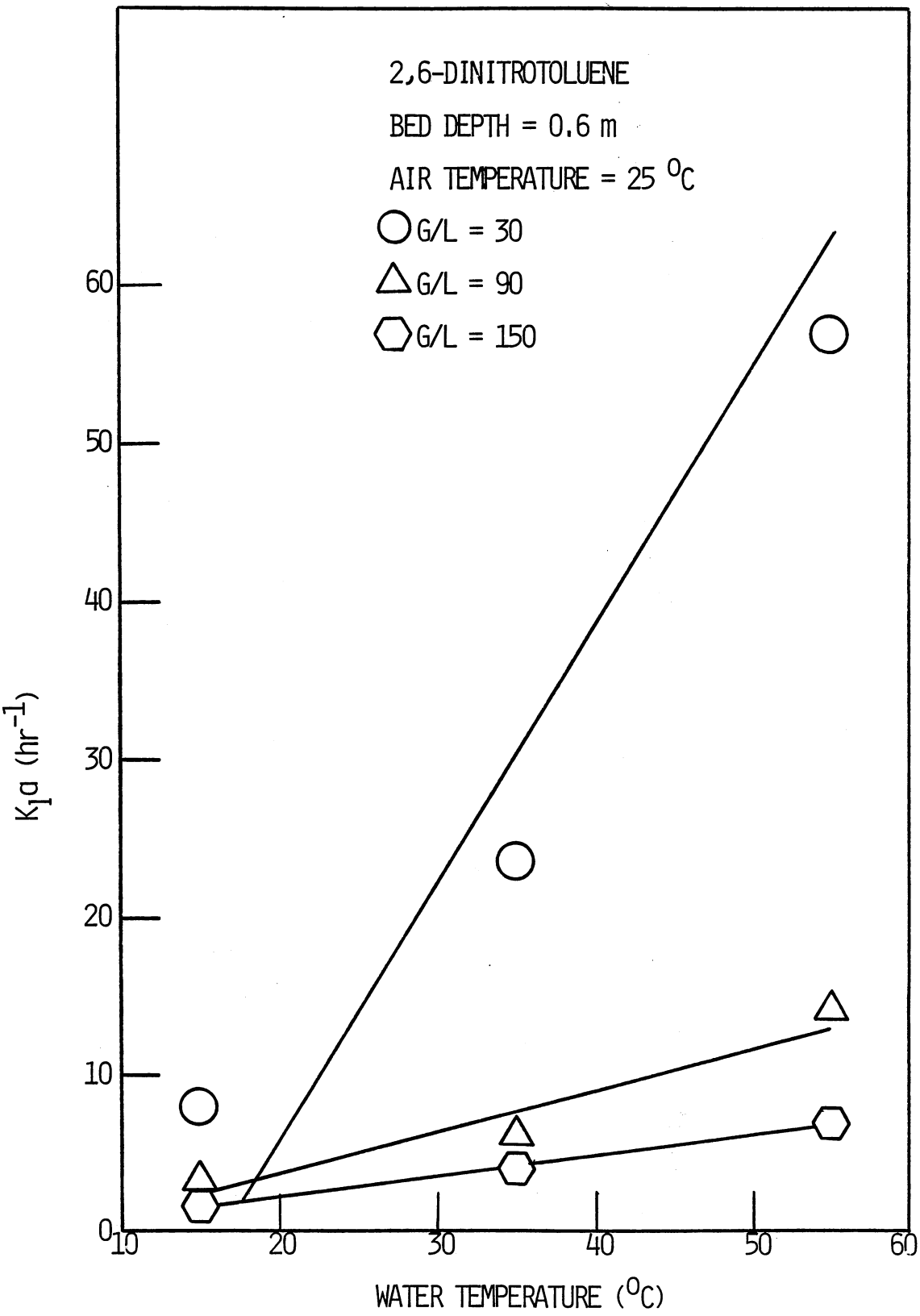


Figure 59. Measured Mass Transfer Coefficients Versus Influent Water Temperature

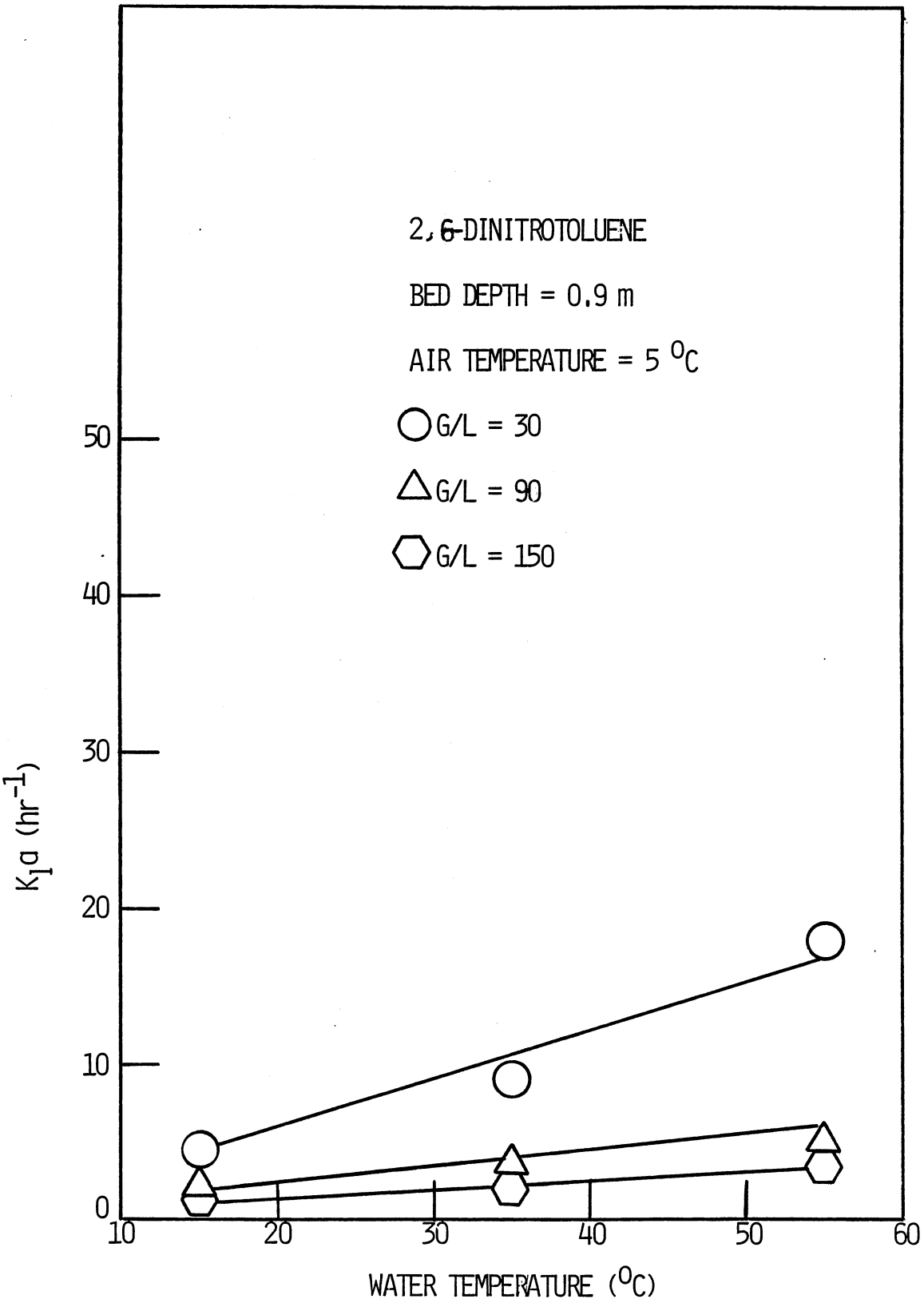


Figure 60. Measured Mass Transfer Coefficients Versus Influent Water Temperature

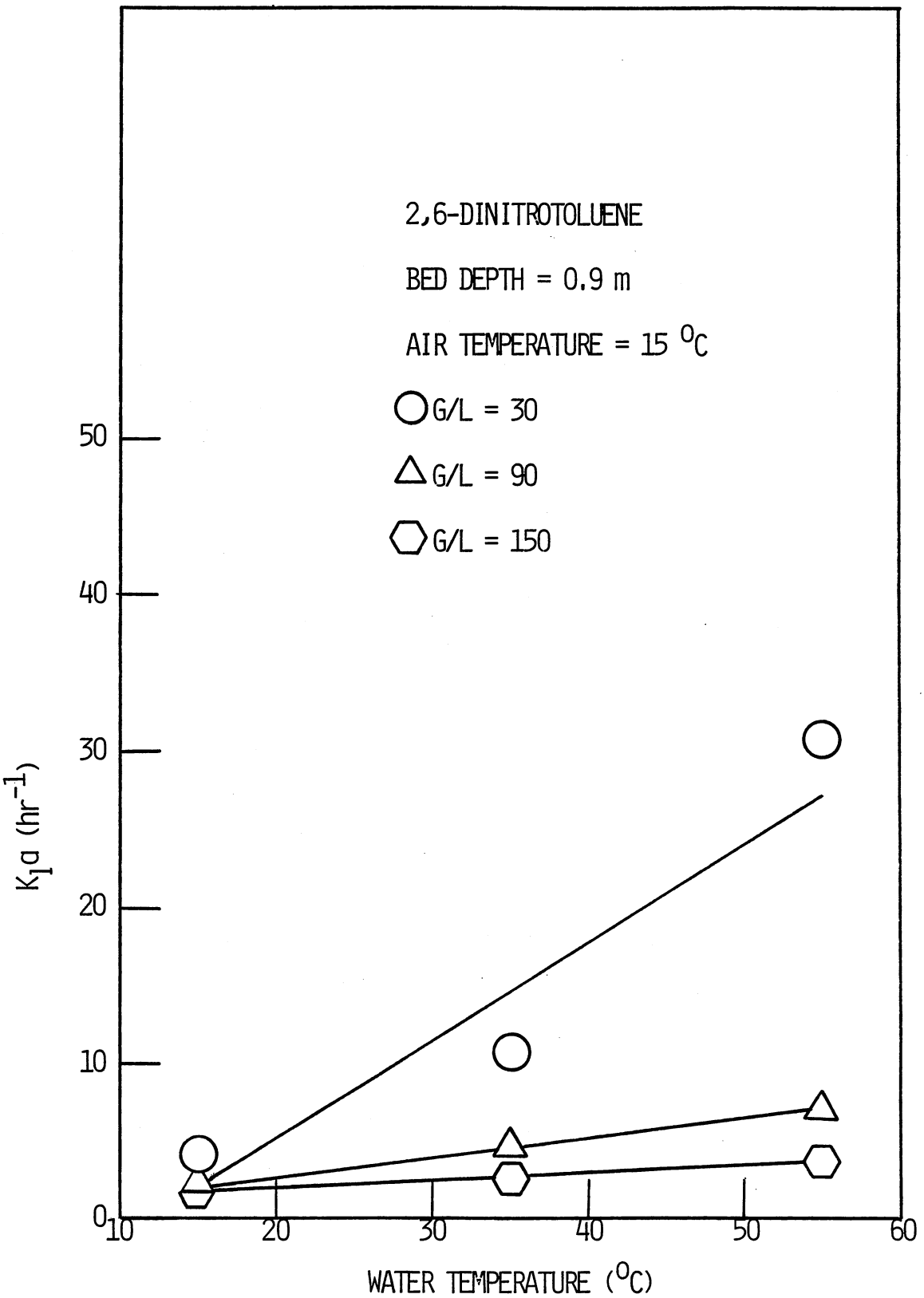


Figure 61. Measured Mass Transfer Coefficients Versus Influent Water Temperature

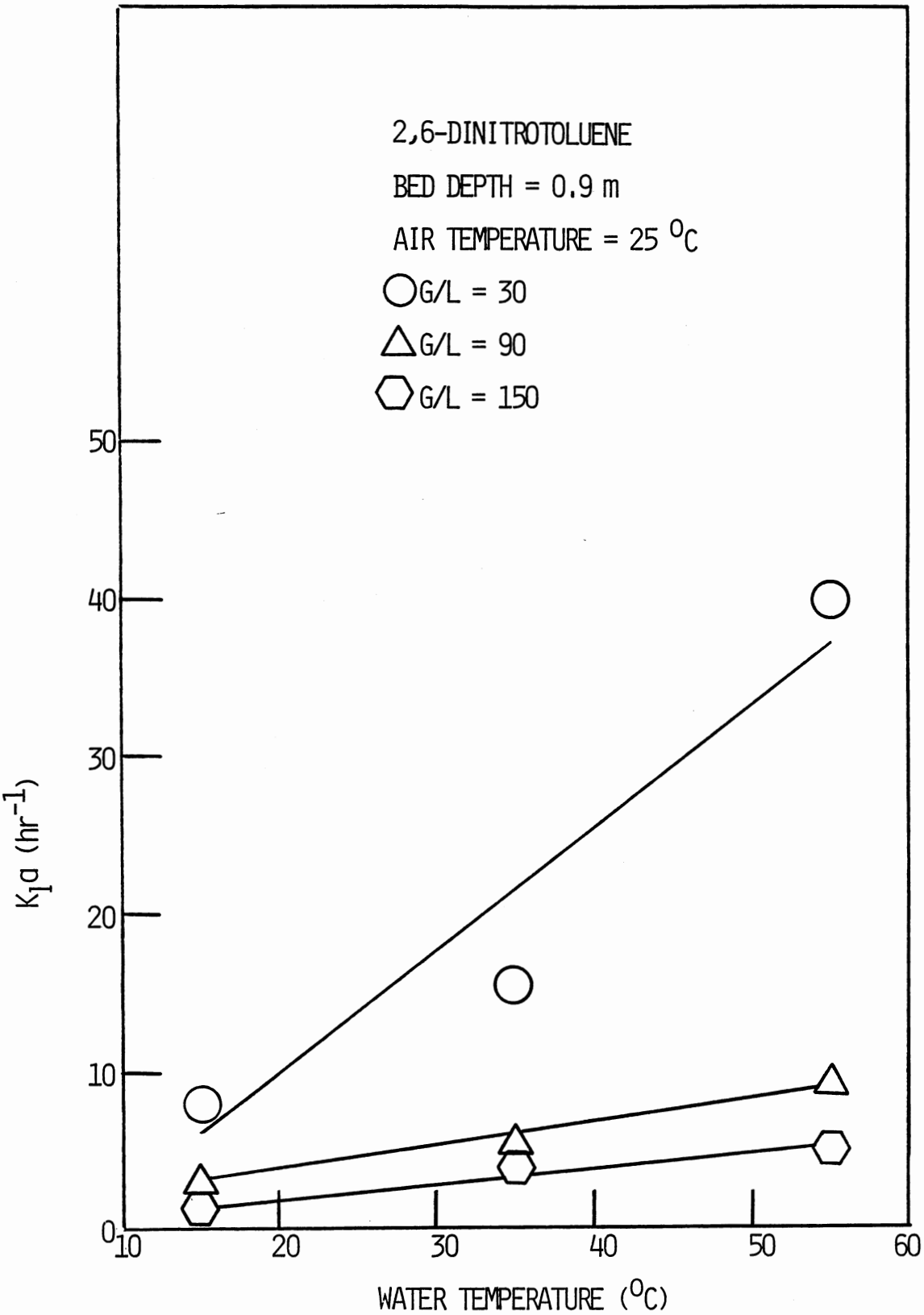


Figure 62. Measured Mass Transfer Coefficients Versus Influent Water Temperature

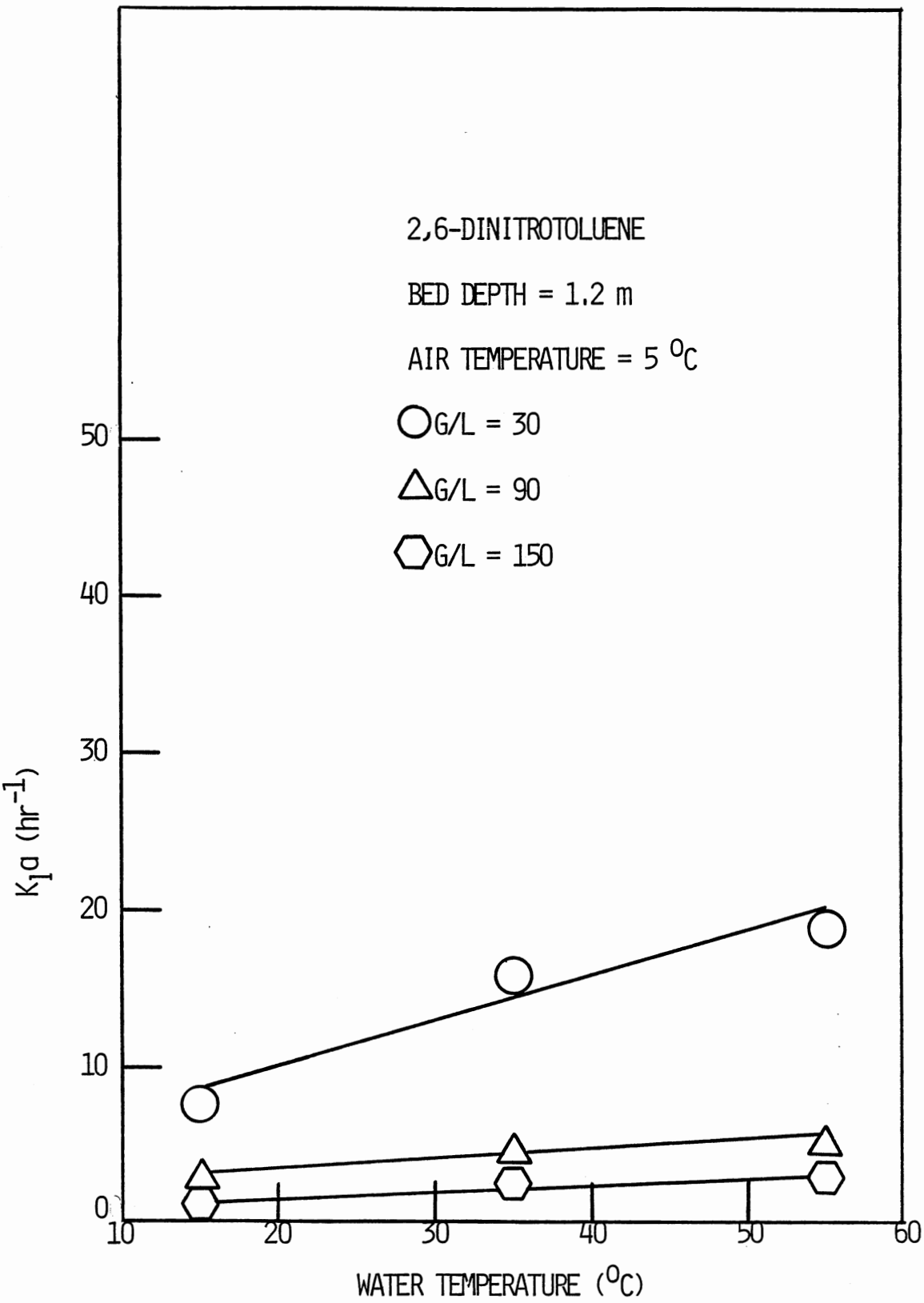


Figure 63. Measured Mass Transfer Coefficients Versus Influent Water Temperature

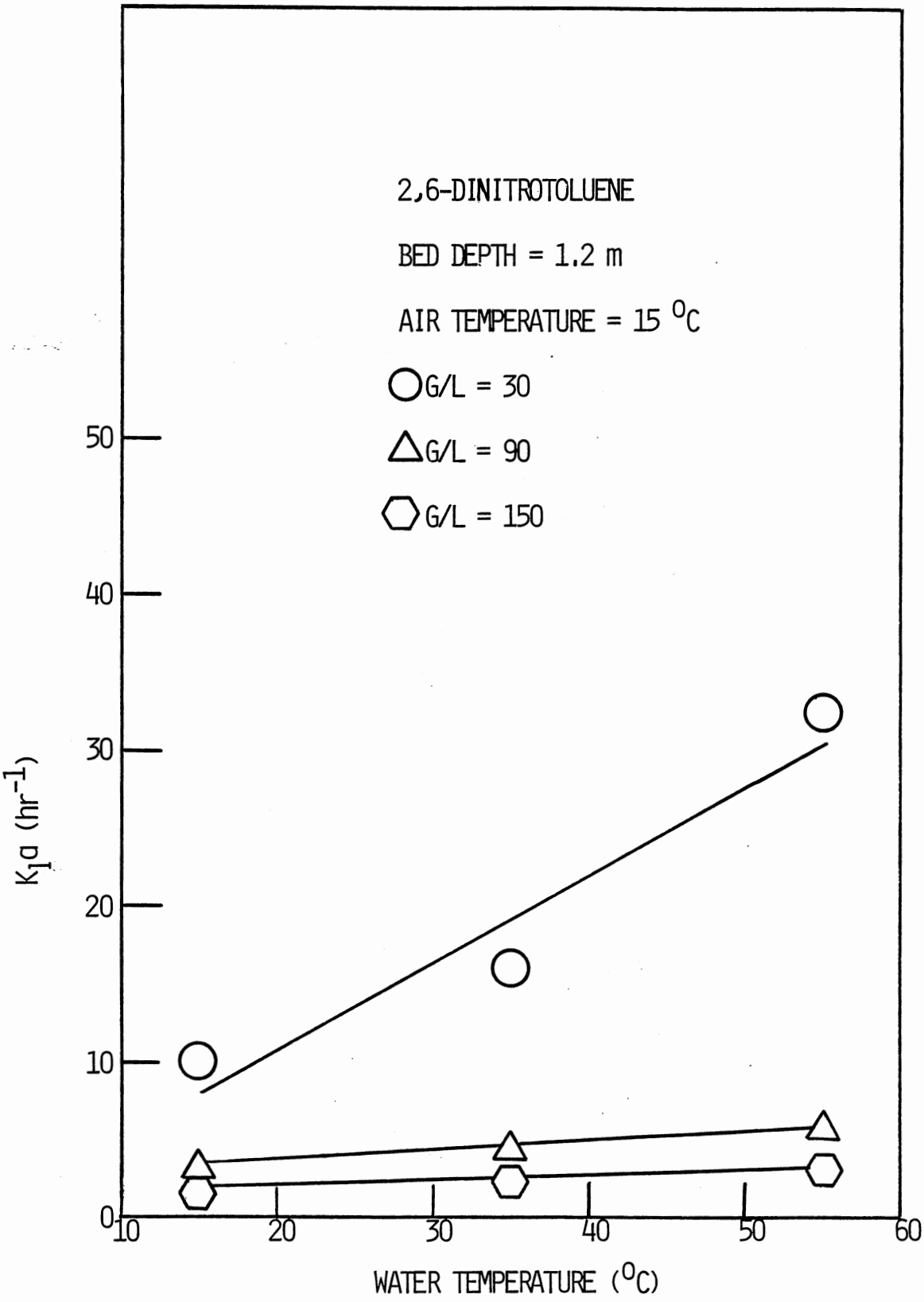


Figure 64. Measured Mass Transfer Coefficients Versus Influent Water Temperature

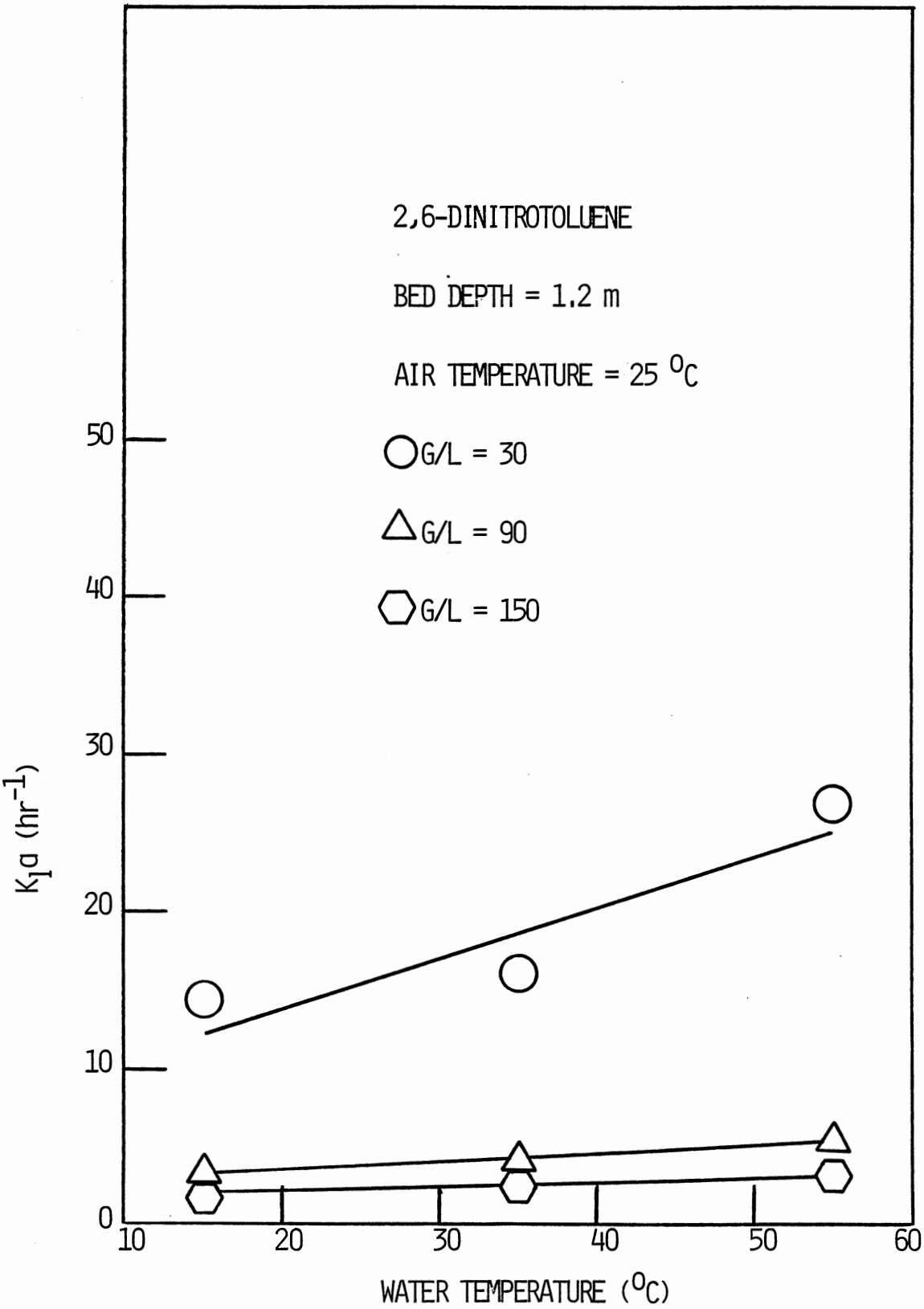


Figure 65. Measured Mass Transfer Coefficients Versus Influent Water Temperature

In Figures 39 through 65 it can be noted that compounds with higher Henry's constant (chlorobenzene), have higher mass transfer coefficients. These values are higher at higher temperatures and lower at lower temperatures. The results also show that as the gas-to-liquid ratio increases, the mass transfer coefficients for all compounds become similar. This is because of the turbulent conditions at higher gas-to-liquid ratios. At low gas-to-liquid ratios, the flows in the packed column are closer to the liminar conditions. Under these conditions, the mass transfer occurring is mostly due to molecular diffusion and, hence, the mass transfer rate will differ from compound to compound to a maximum extent (although not a large value). When turbulent conditions occur in the packed column (such as flooding or high gas-to-liquid ratios), the mass transfer is mainly caused by eddy diffusion and the mass transfer coefficients become similar for all compounds (11).

The resulting linear regression equations and correlation coefficients of overall mass transfer coefficients (K_1a) with water temperature at all combinations of bed depths, air temperatures, and gas-to-liquid ratios for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, 1-chloronapthalene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene are listed in Tables XXV, XXVI, XXVII, XXVIII, XXIX, XXX, XXXI, XXXII, XXXIII, XXXIV, XXXV, XXXVI, XXXVII, XXXVIII, AND XXXIX, respectively. Because all these expressions possess high correlation coefficients, the linear correlation between water temperatures and K_1a values measured at all combinations in this study seem applicable.

TABLE XXV

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR TOLUENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 60.17 + 2.559T$	0.9617
0.6	90	5	$K_1a = 23.57 + 0.7395T$	0.8934
0.6	150	5	$K_1a = 11.20 + 0.6958T$	0.9966
0.6	30	15	$K_1a = 63.44 + 3.140T$	0.8894
0.6	90	15	$K_1a = 29.48 + 0.8772T$	0.8351
0.6	150	15	$K_1a = 18.90 + 0.6102T$	0.9387
0.6	30	25	-	-
0.6	90	25	-	-
0.6	150	25	-	-
0.9	30	5	-	-
0.9	90	5	-	-
0.9	150	5	-	-
0.9	30	15	-	-
0.9	90	15	-	-
0.9	150	15	-	-
0.9	30	25	-	-
0.9	90	25	-	-
0.9	150	25	-	-
1.2	30	5	-	-
1.2	90	5	-	-
1.2	150	5	-	-
1.2	30	15	-	-
1.2	90	15	-	-
1.2	150	15	-	-
1.2	30	25	-	-
1.2	90	25	-	-
1.2	150	25	-	-

"-" is a symbol of percent removal greater than 99.5.

TABLE XXVI

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR CHLOROBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 33.66 + 2.6820T$	0.9873
0.6	90	5	$K_1a = 15.55 + 0.8315T$	0.9997
0.6	150	5	$K_1a = 13.88 + 0.4358T$	0.9994
0.6	30	15	$K_1a = 48.67 + 2.4455T$	0.9952
0.6	90	15	$K_1a = 15.18 + 0.9085T$	0.9972
0.6	150	15	$K_1a = 16.18 + 0.4212T$	0.9731
0.6	30	25	$K_1a = 56.64 + 2.1150T$	0.9953
0.6	90	25	$K_1a = 20.41 + 0.9392T$	0.9473
0.6	150	25	$K_1a = 15.18 + 0.4518T$	0.9593
0.9	30	5	$K_1a = 41.34 + 2.3268T$	0.9906
0.9	90	5	$K_1a = 19.77 + 0.7702T$	0.9822
0.9	150	5	$K_1a = 11.08 + 0.4535T$	0.8167
0.9	30	15	$K_1a = 42.99 + 2.9575T$	0.9999
0.9	90	15	$K_1a = 26.53 + 0.6685T$	0.9681
0.9	150	15	$K_1a = 16.95 + 0.3668T$	0.9793
0.9	30	25	$K_1a = 39.88 + 2.0883T$	0.9848
0.9	90	25	$K_1a = 23.07 + 0.8355T$	0.9947
0.9	150	25	$K_1a = 13.95 + 0.9715T$	0.9579
1.2	30	5	$K_1a = 60.49 + 1.0642T$	0.9064
1.2	90	5	$K_1a = 14.16 + 0.6108T$	0.9119
1.2	150	5	$K_1a = 17.10 + 0.1627T$	0.8248
1.2	30	15	$K_1a = 43.44 + 1.3925T$	0.9879
1.2	90	15	$K_1a = 15.87 + 0.6250T$	0.9721
1.2	150	15	$K_1a = 13.38 + 0.3170T$	0.9984
1.2	30	25	$K_1a = 60.27 + 1.541T$	0.9257
1.2	90	25	$K_1a = 26.13 + 0.4345T$	0.8413
1.2	150	25	$K_1a = 14.26 + 0.2875T$	0.8297

TABLE XXVII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR ETHYLBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 43.12 + 2.1755T$	0.9083
0.6	90	5	$K_1a = 18.95 + 0.7755T$	0.9831
0.6	150	5	$K_1a = 13.55 + 0.4085T$	0.9449
0.6	30	15	$K_1a = 54.29 + 1.9885T$	0.9040
0.6	90	15	$K_1a = 19.53 + 0.8092T$	0.9371
0.6	150	15	$K_1a = 13.96 + 0.4675T$	0.9761
0.6	30	25	$K_1a = 53.35 + 1.9708T$	0.9322
0.6	90	25	$K_1a = 13.76 + 1.2762T$	0.9594
0.6	150	25	$K_1a = 14.68 + 0.5042T$	0.8973
0.9	30	5	$K_1a = 39.81 + 1.6825T$	0.9837
0.9	90	5	$K_1a = 12.09 + 0.8408T$	0.9993
0.9	150	5	$K_1a = 5.725 + 0.5210T$	0.9078
0.9	30	15	$K_1a = 33.60 + 2.6345T$	0.9606
0.9	90	15	$K_1a = 12.92 + 0.9090T$	0.9965
0.9	150	15	$K_1a = 9.616 + 0.5005T$	0.9928
0.9	30	25	$K_1a = 34.75 + 2.0300T$	0.9780
0.9	90	25	$K_1a = 17.48 + 0.7755T$	0.9993
0.9	150	25	$K_1a = 15.09 + 0.2910T$	0.9849
1.2	30	5	$K_1a = 36.25 + 1.2628T$	0.9856
1.2	90	5	$K_1a = 13.84 + 0.622\ T$	0.9378
1.2	150	5	$K_1a = 9.744 + 0.3108T$	0.9203
1.2	30	15	$K_1a = 38.24 + 1.6285T$	0.9859
1.2	90	15	$K_1a = 17.63 + 0.5042T$	0.9686
1.2	150	15	$K_1a = 11.39 + 0.3015T$	0.9882
1.2	30	25	$K_1a = 96.15 + 0.6900T$	0.8660
1.2	90	25	$K_1a = 22.89 + 0.3798T$	0.9467
1.2	150	25	$K_1a = 13.74 + 0.2422T$	0.8229

TABLE XXVIII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR TETRACHLOROETHANE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -88.65 + 6.1908T$	0.9874
0.6	90	5	$K_1a = -7.310 + 1.1034T$	0.9785
0.6	150	5	$K_1a = -3.800 + 4.276\ T$	0.9759
0.6	30	15	$K_1a = -5.849 + 1.0883T$	0.8363
0.6	90	15	$K_1a = -5.450 + 0.7678T$	0.9838
0.6	150	15	$K_1a = -37.32 + 5.8632T$	0.9999
0.6	30	25	$K_1a = -28.61 + 2.6041T$	0.9687
0.6	90	25	$K_1a = -5.167 + 0.7881T$	0.9980
0.6	150	25	$K_1a = 5.609 + 1.8820T$	0.9999
0.9	30	5	$K_1a = -4.5785 + 0.8056T$	0.8312
0.9	90	5	$K_1a = -6.0691 + 0.5615T$	0.9766
0.9	150	5	$K_1a = -6.1075 + 3.5705T$	0.9724
0.9	30	15	$K_1a = -12.52 + 1.2099T$	0.8507
0.9	90	15	$K_1a = -3.7732 + 0.6011T$	0.9954
0.9	150	15	$K_1a = -38.83 + 5.3192T$	0.9776
0.9	30	25	$K_1a = -15.56 + 1.4481T$	0.9561
0.9	90	25	$K_1a = -7.3508 + 0.8025T$	0.9822
0.9	150	25	$K_1a = -39.27 + 3.7940T$	0.9702
1.2	30	5	$K_1a = -3.958 + 0.7533T$	0.9967
1.2	90	5	$K_1a = -1.4442 + 0.5010T$	0.9287
1.2	150	5	$K_1a = -20.27 + 3.8278T$	0.8890
1.2	30	15	$K_1a = 2.3725 + 0.7648T$	0.8900
1.2	90	15	$K_1a = 2.3725 + 0.7648T$	0.8313
1.2	150	15	$K_1a = -2.2834 + 0.5692T$	0.9845
1.2	30	25	$K_1a = -49.39 + 4.6252T$	0.9854
1.2	90	25	$K_1a = -0.1752 + 0.8536T$	0.9367
1.2	150	25	$K_1a = -3.1304 + 0.6410T$	0.9868

TABLE XXIX

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR 1,3-DICHLOROBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 43.65 + 2.2775T$	0.9653
0.6	90	5	$K_1a = 24.79 + 0.6455T$	0.9997
0.6	150	5	$K_1a = 12.56 + 0.4438T$	0.9999
0.6	30	15	$K_1a = 51.39 + 2.1837T$	0.9465
0.6	90	15	$K_1a = 19.18 + 0.8930T$	0.9910
0.6	150	15	$K_1a = 11.51 + 0.5550T$	0.9999
0.6	30	25	$K_1a = 31.08 + 3.1280T$	0.9987
0.6	90	25	$K_1a = 21.08 + 1.0105T$	0.9996
0.6	150	25	$K_1a = 9.5371 + 0.7348T$	0.9743
0.9	30	5	$K_1a = 34.03 + 2.6545T$	0.9910
0.9	90	5	$K_1a = 19.67 + 0.8645T$	0.9667
0.9	150	5	$K_1a = 17.00 + 0.2592T$	0.9498
0.9	30	15	$K_1a = 50.79 + 1.9698T$	0.9294
0.9	90	15	$K_1a = 24.25 + 0.7943T$	0.9808
0.9	150	15	$K_1a = 15.60 + 0.4425T$	0.9960
0.9	30	25	$K_1a = 26.23 + 2.3360T$	0.9768
0.9	90	25	$K_1a = 26.35 + 0.6760T$	0.9588
0.9	150	25	$K_1a = 18.39 + 0.3693T$	0.9637
1.2	30	5	$K_1a = 36.03 + 1.9690T$	0.9997
1.2	90	5	$K_1a = 16.12 + 0.6113T$	0.9430
1.2	150	5	$K_1a = 14.00 + 0.2760T$	0.9033
1.2	30	15	$K_1a = 23.76 + 2.3470T$	0.9981
1.2	90	15	$K_1a = 18.63 + 0.5010T$	0.9786
1.2	150	15	$K_1a = 13.36 + 0.3045T$	0.9843
1.2	30	25	$K_1a = 85.63 + 1.2800T$	0.8109
1.2	90	25	$K_1a = 21.15 + 0.4868T$	0.9930
1.2	150	25	$K_1a = 14.82 + 0.2170T$	0.9019

TABLE XXX

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR 1,2-DICHLOROBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 31.02 + 2.5830T$	0.9352
0.6	90	5	$K_1a = 18.29 + 0.7975T$	0.9873
0.6	150	5	$K_1a = 11.10 + 0.5200T$	0.9694
0.6	30	15	$K_1a = 53.49 + 2.152\ T$	0.9360
0.6	90	15	$K_1a = 16.01 + 0.8710T$	0.9684
0.6	150	15	$K_1a = 12.87 + 0.5385T$	0.9689
0.6	30	25	$K_1a = 17.45 + 3.1728T$	0.9689
0.6	90	25	$K_1a = 23.20 + 0.8400T$	0.9982
0.6	150	25	$K_1a = 14.94 + 0.4660T$	0.9997
0.9	30	5	$K_1a = 17.77 + 3.0908T$	0.9936
0.9	90	5	$K_1a = 25.82 + 0.5635T$	0.9078
0.9	150	5	$K_1a = 12.53 + 0.3690T$	0.9194
0.9	30	15	$K_1a = 39.95 + 2.1692T$	0.9416
0.9	90	15	$K_1a = 21.94 + 0.8030T$	0.9834
0.9	150	15	$K_1a = 11.79 + 0.5655T$	0.9971
0.9	30	25	$K_1a = 23.12 + 2.5575T$	0.9860
0.9	90	25	$K_1a = 25.07 + 0.6625T$	0.9633
0.9	150	25	$K_1a = 18.99 + 0.3340T$	0.8952
1.2	30	5	$K_1a = 26.80 + 2.2965T$	0.9932
1.2	90	5	$K_1a = 13.91 + 0.5985T$	0.9532
1.2	150	5	$K_1a = 13.46 + 0.2603T$	0.8918
1.2	30	15	$K_1a = 31.73 + 1.8540T$	0.9972
1.2	90	15	$K_1a = 17.86 + 0.4535T$	0.9715
1.2	150	15	$K_1a = 12.38 + 0.2938T$	0.9326
1.2	30	25	$K_1a = 54.30 + 1.6523T$	0.9852
1.2	90	25	$K_1a = 26.46 + 0.3970T$	0.8759
1.2	150	25	$K_1a = 15.04 + 0.2112T$	0.8892

TABLE XXXI

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR NITROBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -3.2774 + 0.7648T$	0.9467
0.6	90	5	$K_1a = -2.9638 + 0.3220T$	0.9985
0.6	150	5	$K_1a = -0.5982 + 0.1432T$	0.9887
0.6	30	15	$K_1a = 0.01125 + 0.7843T$	0.9973
0.6	90	15	$K_1a = -0.6887 + 0.2695T$	0.9942
0.6	150	15	$K_1a = -0.05180 + 0.1302T$	0.9965
0.6	30	25	$K_1a = 1.1042 + 0.9675T$	0.9911
0.6	90	25	$K_1a = 0.2213 + 0.2327T$	0.9994
0.6	150	25	$K_1a = 1.1677 + 0.125\ T$	0.9957
0.9	30	5	$K_1a = -2.6161 + 0.6196T$	0.9566
0.9	90	5	$K_1a = 0.7655 + 0.2302T$	0.8626
0.9	150	5	$K_1a = -1.9780 + 0.1896T$	0.9735
0.9	30	15	$K_1a = -2.0287 + 0.7345T$	0.9126
0.9	90	15	$K_1a = -3.4063 + 0.3315T$	0.9748
0.9	150	15	$K_1a = -1.9344 + 0.1988T$	0.9568
0.9	30	25	$K_1a = 0.2608 + 0.8655T$	0.9686
0.9	90	25	$K_1a = -0.9349 + 0.2262T$	0.9999
0.9	150	25	$K_1a = -1.0213 + 0.1626T$	0.9769
1.2	30	5	$K_1a = -1.9819 + 0.5574T$	0.9200
1.2	90	5	$K_1a = -4.5416 + 0.3485T$	0.9899
1.2	150	5	$K_1a = -1.3789 + 0.1635T$	0.9977
1.2	30	15	$K_1a = -2.8850 + 0.6692T$	0.9441
1.2	90	15	$K_1a = -3.1543 + 0.3507T$	0.9942
1.2	150	15	$K_1a = -1.4740 + 0.2118T$	0.9893
1.2	30	25	$K_1a = 10.324 + 0.4263T$	0.9409
1.2	90	25	$K_1a = -2.4354 + 0.3239T$	0.9993
1.2	150	25	$K_1a = -1.6608 + 0.2361T$	0.9996

TABLE XXXII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR NAPTHALENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -43.50 + 5.1820T$	0.9959
0.6	90	5	$K_1a = 0.9020 + 1.2378T$	0.9999
0.6	150	5	$K_1a = 5.4379 + 0.6022T$	0.9999
0.6	30	15	$K_1a = 2.7338 + 5.4428T$	0.9048
0.6	90	15	$K_1a = 4.5592 + 1.1345T$	0.9982
0.6	150	15	$K_1a = 6.8400 + 0.5980T$	0.9999
0.6	30	25	$K_1a = 1.5458 + 4.6625T$	0.9657
0.6	90	25	$K_1a = 7.7696 + 0.6418T$	0.9966
0.6	150	25	$K_1a = 5.4721 + 0.6418T$	0.9974
0.9	30	5	$K_1a = -49.37 + 5.4562T$	0.9999
0.9	90	5	$K_1a = 4.7312 + 0.9542T$	0.9145
0.9	150	5	$K_1a = 0.8095 + 0.5524T$	0.9999
0.9	30	15	$K_1a = -19.92 + 4.7170T$	0.9613
0.9	90	15	$K_1a = 8.6812 + 0.8678T$	0.9818
0.9	150	15	$K_1a = 8.3612 + 0.3983T$	0.9679
0.9	30	25	$K_1a = -7.0333 + 4.4000T$	0.8731
0.9	90	25	$K_1a = 8.7146 + 0.8303T$	0.9864
0.9	150	25	$K_1a = 9.1017 + 0.4150T$	0.9794
1.2	30	5	$K_1a = -90.15 + 6.8782T$	0.9724
1.2	90	5	$K_1a = -3.5304 + 1.0792T$	0.9899
1.2	150	5	$K_1a = 0.2208 + 0.5452T$	0.9949
1.2	30	15	$K_1a = -50.57 + 7.4118T$	0.9704
1.2	90	15	$K_1a = 1.6242 + 0.9375T$	0.9578
1.2	150	15	$K_1a = 1.8550 + 1.0690T$	0.9997
1.2	30	25	$K_1a = -4.5100 + 4.8140T$	0.9998
1.2	90	25	$K_1a = 7.3262 + 0.8412T$	0.9428
1.2	150	25	$K_1a = 3.4988 + 0.4978T$	0.9965

TABLE XXXIII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR 1-CHLORONAPTHALENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -28.48 + 4.9173T$	0.9648
0.6	90	5	$K_1a = -0.5442 + 1.2405T$	0.9968
0.6	150	5	$K_1a = 4.7746 + 0.59225T$	0.9998
0.6	30	15	$K_1a = -17.01 + 7.1285T$	0.9283
0.6	90	15	$K_1a = 5.4708 + 1.0755T$	0.9971
0.6	150	15	$K_1a = 5.4629 + 0.5813T$	0.9986
0.6	30	25	$K_1a = 15.12 + 3.4485T$	0.9722
0.6	90	25	$K_1a = 9.0383 + 0.9750T$	0.9997
0.6	150	25	$K_1a = 6.2833 + 0.5680T$	0.9898
0.9	30	5	$K_1a = -5.312 + 3.5202T$	0.9758
0.9	90	5	$K_1a = -0.5404 + 1.2273T$	0.9730
0.9	150	5	$K_1a = -6.7489 + 0.7392T$	0.9996
0.9	30	15	$K_1a = -11.85 + 4.9320T$	0.9338
0.9	90	15	$K_1a = 1.8517 + 1.0970T$	0.9954
0.9	150	15	$K_1a = 6.2725 + 1.4805T$	0.9958
0.9	30	25	$K_1a = -6.0700 + 4.1980T$	0.9160
0.9	90	25	$K_1a = 5.6425 + 0.9105T$	0.9720
0.9	150	25	$K_1a = 9.0741 + 0.4175T$	0.9469
1.2	30	5	$K_1a = -78.86 + 5.5723T$	0.9996
1.2	90	5	$K_1a = 4.8796 + 0.6412T$	0.9238
1.2	150	5	$K_1a = -0.1430 + 0.5442T$	0.9890
1.2	30	15	$K_1a = -41.71 + 6.4893T$	0.9765
1.2	90	15	$K_1a = -1.0679 + 0.9678T$	0.9979
1.2	150	15	$K_1a = -5.6117 + 1.3370T$	0.9587
1.2	30	25	$K_1a = 26.81 + 3.8480T$	0.9803
1.2	90	25	$K_1a = 4.5092 + 0.8445T$	0.9903
1.2	150	25	$K_1a = 5.5367 + 0.374\ T$	0.9921

TABLE XXXIV

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR 2,6-DINITROTOLUENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -4.9784 + 0.5227T$	0.9177
0.6	90	5	$K_1a = -0.1956 + 0.1229T$	0.9321
0.6	150	5	$K_1a = 0.8834 + 0.0563T$	0.9908
0.6	30	15	$K_1a = -12.86 + 1.0000T$	0.9553
0.6	90	15	$K_1a = -0.4226 + 0.1891T$	0.9911
0.6	150	15	$K_1a = -3.1220 + 0.1187T$	0.9619
0.6	30	25	$K_1a = -13.62 + 1.2394T$	0.9790
0.6	90	25	$K_1a = -1.4900 + 0.2643T$	0.9731
0.6	150	25	$K_1a = 0.7273 + 0.1131T$	0.9578
0.9	30	5	$K_1a = -1.7125 + 0.3476T$	0.9819
0.9	90	5	$K_1a = 0.8212 + 0.07765T$	0.9973
0.9	150	5	$K_1a = 0.9207 + 0.3828T$	0.9994
0.9	30	15	$K_1a = -8.9378 + 0.7066T$	0.9559
0.9	90	15	$K_1a = 0.0626 + 0.1199T$	0.9991
0.9	150	15	$K_1a = 0.6795 + 0.0615T$	0.9982
0.9	30	25	$K_1a = -6.4265 + 0.7908T$	0.9626
0.9	90	25	$K_1a = -0.5631 + 0.1756T$	0.9962
0.9	150	25	$K_1a = 0.2197 + 0.0910T$	0.9999
1.2	30	5	$K_1a = 4.0757 + 0.2837T$	0.9629
1.2	90	5	$K_1a = 0.9802 + 0.07554T$	0.9452
1.2	150	5	$K_1a = 1.0951 + 0.03522T$	0.9363
1.2	30	15	$K_1a = -1.9254 + 0.3342T$	0.9985
1.2	90	15	$K_1a = 1.5578 + 0.0731T$	0.9978
1.2	150	15	$K_1a = 1.1998 + 0.03918T$	0.9813
1.2	30	25	$K_1a = 7.8683 + 0.3170T$	0.9291
1.2	90	25	$K_1a = 2.1297 + 0.0610T$	0.9904
1.2	150	25	$K_1a = 2.423 + 0.01663T$	0.9104

TABLE XXXV

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR FLUORENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -10.13 + 1.3570T$	0.9879
0.6	90	5	$K_1a = 1.9580 + 0.2690T$	0.9512
0.6	150	5	$K_1a = 0.1805 + 0.3473T$	0.9774
0.6	30	15	$K_1a = -21.99 + 1.8426T$	0.9951
0.6	90	15	$K_1a = -6.6100 + 0.6586T$	0.9999
0.6	150	15	$K_1a = -7.545 + 0.6469T$	0.9351
0.6	30	25	$K_1a = 3.1749 + 2.1129T$	0.9744
0.6	90	25	$K_1a = 4.5033 + 0.3480T$	0.9659
0.6	150	25	$K_1a = 2.7426 + 0.25733T$	0.9885
0.9	30	5	$K_1a = -6.4510 + 0.9738T$	0.9175
0.9	90	5	$K_1a = 3.7226 + 0.2333T$	0.9999
0.9	150	5	$K_1a = 0.2222 + 0.2304T$	0.9254
0.9	30	15	$K_1a = -11.60 + 1.4465T$	0.9308
0.9	90	15	$K_1a = -1.4764 + 0.3854T$	0.9947
0.9	150	15	$K_1a = -0.9568 + 0.2469T$	0.9883
0.9	30	25	$K_1a = -10.59 + 1.5580T$	0.9539
0.9	90	25	$K_1a = 0.7228 + 0.3042T$	0.9959
0.9	150	25	$K_1a = 4.1987 + 0.1470T$	0.9012
1.2	30	5	$K_1a = 0.5058 + 0.6705T$	0.9213
1.2	90	5	$K_1a = -1.4698 + 0.4051T$	0.9711
1.2	150	5	$K_1a = -1.4191 + 0.2737T$	0.9398
1.2	30	15	$K_1a = 6.2838 + 0.4868T$	0.9999
1.2	90	15	$K_1a = -7.8968 + 0.5182T$	0.9186
1.2	150	15	$K_1a = -1.5183 + 0.2190T$	0.9861
1.2	30	25	$K_1a = -5.4296 + 1.5708T$	0.9224
1.2	90	25	$K_1a = 0.09908 + 0.3892T$	0.9210
1.2	150	25	$K_1a = 2.7608 + 0.1382T$	0.9288

TABLE XXXVI

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR 2,4-DINITROTOLUENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -0.8519 + 0.3238T$	0.9783
0.6	90	5	$K_1a = -10.82 + 0.6716T$	0.9005
0.6	150	5	$K_1a = 1.523 + 0.03795T$	0.9409
0.6	30	15	$K_1a = 0.5651 + 0.3756T$	0.9410
0.6	90	15	$K_1a = 1.8355 + 0.1051T$	0.9920
0.6	150	15	$K_1a = 0.8453 + 0.07993T$	0.9511
0.6	30	25	$K_1a = -1.5908 + 0.6865T$	0.9896
0.6	90	25	$K_1a = 0.3908 + 0.2088T$	0.9863
0.6	150	25	$K_1a = 4.6634 + 0.04095T$	0.9054
0.9	30	5	$K_1a = 13.42 + 0.0395T$	0.9721
0.9	90	5	$K_1a = 1.8711 + 0.07742T$	0.9615
0.9	150	5	$K_1a = 1.6205 + 0.2470T$	0.9998
0.9	30	15	$K_1a = 2.6000 + 0.3512T$	0.9940
0.9	90	15	$K_1a = 3.9426 + 0.04794T$	0.9830
0.9	150	15	$K_1a = 2.8540 + 0.02705T$	0.9733
0.9	30	25	$K_1a = 12.33 + 0.3040T$	0.9760
0.9	90	25	$K_1a = 2.7112 + 0.0959T$	0.9943
0.9	150	25	$K_1a = 2.4078 + 0.04015T$	0.9991
1.2	30	5	$K_1a = 2.8510 + 0.3349T$	0.9862
1.2	90	5	$K_1a = 2.1080 + 0.05213T$	0.9185
1.2	150	5	$K_1a = 1.5029 + 0.03478T$	0.9083
1.2	30	15	$K_1a = 11.86 + 0.06125T$	0.8853
1.2	90	15	$K_1a = -0.7378 + 0.4186T$	0.9490
1.2	150	15	$K_1a = -4.3881 + 0.3500T$	0.8705
1.2	30	25	$K_1a = 15.25 + 0.07925T$	0.8708
1.2	90	25	$K_1a = 3.1778 + 0.0518T$	0.9921
1.2	150	25	$K_1a = -2.1293 + 0.2171T$	0.90334

TABLE XXXVII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR HEXACHLOROBENZENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 7.858 + 0.3098T$	0.9999
0.6	90	5	$K_1a = 2.735 + 0.1114T$	0.9131
0.6	150	5	$K_1a = 1.615 + 0.1187T$	0.9920
0.6	30	15	$K_1a = 7.734 + 0.4115T$	0.9809
0.6	90	15	$K_1a = 4.023 + 0.1586T$	0.9992
0.6	150	15	$K_1a = 2.990 + 0.09945T$	0.9714
0.6	30	25	$K_1a = 12.72 + 0.3700T$	0.9657
0.6	90	25	$K_1a = -0.5790 + 0.4246T$	0.9295
0.6	150	25	$K_1a = 1.435 + 0.1353T$	0.9091
0.9	30	5	$K_1a = 12.42 + 0.1875T$	0.9674
0.9	90	5	$K_1a = 5.026 + 0.08798T$	0.9998
0.9	150	5	$K_1a = 2.728 + 0.05373T$	0.9163
0.9	30	15	$K_1a = 11.21 + 0.2560T$	0.9214
0.9	90	15	$K_1a = 4.934 + 0.09162T$	0.9242
0.9	150	15	$K_1a = 2.993 + 0.06022T$	0.9040
0.9	30	25	$K_1a = 13.76 + 0.3038T$	0.9918
0.9	90	25	$K_1a = 7.157 + 0.04473T$	0.9195
0.9	150	25	$K_1a = 3.677 + 0.0595T$	0.9953
1.2	30	5	$K_1a = 14.26 + 0.1445T$	0.9874
1.2	90	5	$K_1a = 4.283 + 0.09438T$	0.8977
1.2	150	5	$K_1a = 1.1826 + 1.09492T$	0.9854
1.2	30	15	$K_1a = 14.21 + 0.2002T$	0.9971
1.2	90	15	$K_1a = 4.951 + 0.06402T$	0.9650
1.2	150	15	$K_1a = 2.383 + 0.09185T$	0.9017
1.2	30	25	$K_1a = 17.69 + 0.1605T$	0.8814
1.2	90	25	$K_1a = 5.5384 + 0.0763T$	1.0000
1.2	150	25	$K_1a = 3.6465 + 0.0763T$	0.9197

TABLE XXXVIII

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR PHENANTHRENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = -7.353 + 0.3172T$	0.9494
0.6	90	5	$K_1a = 3.360 + 0.1547T$	0.9994
0.6	150	5	$K_1a = 2.138 + 0.09867T$	0.9992
0.6	30	15	$K_1a = 3.000 + 0.7988T$	0.9109
0.6	90	15	$K_1a = 5.3308 + 0.07922T$	0.9596
0.6	150	15	$K_1a = 3.434 + 0.07678T$	0.9526
0.6	30	25	$K_1a = 18.92 + 0.5898T$	0.9980
0.6	90	25	$K_1a = 3.102 + 0.2093T$	0.9680
0.6	150	25	$K_1a = 3.105 + 0.08053T$	0.9870
0.9	30	5	$K_1a = 5.539 + 0.5794T$	0.9978
0.9	90	5	$K_1a = 6.371 + 0.03090T$	0.9809
0.9	150	5	$K_1a = 2.263 + 0.05830T$	0.9861
0.9	30	15	$K_1a = 6.549 + 0.5338T$	0.8730
0.9	90	15	$K_1a = 6.102 + 0.05732T$	0.9959
0.9	150	15	$K_1a = 3.253 + 0.06935T$	0.8916
0.9	30	25	$K_1a = 27.45 + 0.1670T$	0.9191
0.9	90	25	$K_1a = 6.457 + 0.06733T$	0.9652
0.9	150	25	$K_1a = 3.664 + 0.04510T$	0.9113
1.2	30	5	$K_1a = 0.2400 + 0.8340T$	0.9215
1.2	90	5	$K_1a = 4.824 + 0.02958T$	0.9154
1.2	150	5	$K_1a = 3.135 + 0.02552T$	0.9885
1.2	30	15	$K_1a = 9.646 + 0.58135T$	0.9060
1.2	90	15	$K_1a = 5.790 + 0.01450T$	0.9989
1.2	150	15	$K_1a = 2.856 + 0.04190T$	0.9929
1.2	30	25	$K_1a = 10.61 + 0.8268T$	0.9952
1.2	90	25	$K_1a = 5.669 + 0.02325T$	0.9078
1.2	150	25	$K_1a = 3.019 + 0.04475T$	0.9999

TABLE XXXIX

LINEAR CORRELATION OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH INFLUENT WATER TEMPERATURE FOR FLUORANTHENE

Bed Depth (m)	G/L	Influent Air Temperature (°C)	Water Temperature Dependence Linear Regression Equation (1/hr)	Correlation Coefficient (r)
0.6	30	5	$K_1a = 20.38 + 0.06975T$	0.9339
0.6	90	5	$K_1a = 3.126 + 0.1033\ T$	0.9439
0.6	150	5	$K_1a = 1.584 + 0.08820T$	0.9764
0.6	30	15	$K_1a = 22.24 + 0.1845\ T$	0.9565
0.6	90	15	$K_1a = 5.299 + 0.07595T$	0.9211
0.6	150	15	$K_1a = 2.763 + 0.06998T$	0.9014
0.6	30	25	$K_1a = 29.78 + 0.1362\ T$	0.9617
0.6	90	25	$K_1a = 5.632 + 0.08822T$	0.9926
0.6	150	25	$K_1a = 2.075 + 0.09572T$	0.9514
0.9	30	5	$K_1a = 22.69 + 0.08425T$	0.9394
0.9	90	5	$K_1a = 6.680 + 0.04232T$	0.9654
0.9	150	5	$K_1a = 2.385 + 0.05132T$	0.9912
0.9	30	15	$K_1a = 20.81 + 0.1905\ T$	0.9558
0.9	90	15	$K_1a = 7.919 + 0.01850T$	0.9932
0.9	150	15	$K_1a = 3.693 + 0.03805T$	0.9600
0.9	30	25	$K_1a = 16.86 + 0.61325T$	0.9854
0.9	90	25	$K_1a = 7.055 + 0.04680T$	0.9346
0.9	150	25	$K_1a = 3.924 + 0.03340T$	0.9947
1.2	30	5	$K_1a = -1.372 + 0.9490\ T$	0.9853
1.2	90	5	$K_1a = 5.602 + 0.01948T$	0.9505
1.2	150	5	$K_1a = 3.146 + 0.01868T$	0.9766
1.2	30	15	$K_1a = 8.565 + 0.8398\ T$	0.9548
1.2	90	15	$K_1a = 4.976 + 0.05590T$	0.9630
1.2	150	15	$K_1a = 4.206 + 0.0009275T$	0.8753
1.2	30	25	$K_1a = -1.0804 + 1.875\ T$	0.9990
1.2	90	25	$K_1a = 4.996 + 0.06902T$	0.9958
1.2	150	25	$K_1a = 4.259 + 0.008450T$	0.9139

In Chapter II, the Onda correlation (55) expressions for both liquid and gas phase mass transfer coefficients were presented to design a packed column. Using these equations (2.36, 2.37, and 2.38), the solute properties in Appendix A, and the temperature profiles around the tower in the stripping studies at the three bed depths (Tables XXXX, XXXXI, and XXXXII) the overall mass transfer coefficients (K_1a) were calculated. In this study, the experiment was designed to mimic actual field conditions that a stripping tower would be exposed to. This included non-isothermal operation. Therefore, the question arose as to which temperatures would be used in the calculations to try to predict column operation. It was decided to use the average influent and effluent water and air temperature. Due to the large volume of data in this study, the K_1a values computed using Onda correlations were rounded off by a maximum of 2.5°C from the average of the influent and effluent water and air temperatures (i.e., water temperature 32°C rounded to 30°C). An example of the percent difference in the K_1a values between the actual and the rounded off water and air temperatures are presented in Table XXXXIII. Table XXXXIII shows the maximum percent difference between the actual and rounded K_1a values was greatest for fluoranthene (i.e., -4.08% difference compared to that of toluene -0.35%), under the conditions specified in the table (liquid loading = 6.4 m/hr, gas loading = 960 m/hr, and the average actual water and air temperatures were 32.5° and 22.5°C respectively). Due to the small percent differences between the actual and the rounded off K_1a values, the rounded off average influent and effluent water and air temperatures by a maximum of 2.5°C seem to be reasonable. The K_1a values along with interfacial area per unit bed volume and both the liquid and gas phase mass transfer

TABLE XXXX

TEMPERATURE PROFILE OF STRIPPING STUDY
FOR 0.6 M BED DEPTH

G/L	Influent Air Temp. (°C)	Effluent Air Temp. (°C)	Average Air Temp. (°C)	Influent Water Temp. (°C)	Effluent Water Temp. (°C)	Average Water Temp. (°C)
30	5	15	10	15	15	15
90	5	15	10	15	15	15
150	5	14	9	15	15	15
30	15	15	15	15	15	15
90	15	15	15	15	15	15
150	15	15	15	15	15	15
30	25	15	20	15	17	16
90	25	15	20	15	15	15
150	25	15	20	15	15	15
30	5	33	19	35	33	34
90	5	32	18	35	33	34
150	5	32	18	35	32	33
30	15	34	24	35	33	34
90	15	34	24	35	32	33
150	15	29	22	35	31	32
30	25	34	29	35	33	34
90	25	34	29	35	33	34
150	25	32	28	35	33	34
30	5	53	29	55	53	54
90	5	47	26	55	45	50
150	5	39	22	55	37	46
30	15	55	35	55	53	54
90	15	45	30	55	45	50
150	15	45	30	55	37	46
30	25	53	39	55	53	54
90	25	47	36	55	45	50
150	25	45	35	55	37	46

TABLE XXXXI

TEMPERATURE PROFILE OF STRIPPING STUDY
FOR 0.9 M BED DEPTH

G/L	Influent Air Temp. (°C)	Effluent Air Temp. (°C)	Average Air Temp. (°C)	Influent Water Temp. (°C)	Effluent Water Temp. (°C)	Average Water Temp. (°C)
30	5	15	10	15	15	15
90	5	15	10	15	15	15
150	5	14	9	15	15	14
30	15	15	15	15	15	15
90	15	15	15	15	15	15
150	15	15	15	15	15	15
30	25	15	20	15	17	16
90	25	15	20	15	15	15
150	25	15	20	15	15	15
30	5	33	19	35	33	34
90	5	32	18	35	31	33
150	5	32	18	35	31	33
30	15	34	24	35	32	33
90	15	34	24	35	33	34
150	15	31	23	35	32	33
30	25	34	29	35	33	34
90	25	34	29	35	33	34
150	25	32	28	35	32	33
30	5	47	26	55	41	48
90	5	43	24	55	45	50
150	5	37	21	55	45	49
30	15	53	34	55	45	50
90	15	47	31	55	45	50
150	15	43	29	55	45	49
30	25	51	38	55	49	52
90	25	47	36	55	47	51
150	25	53	39	55	49	52

TABLE XXXXII

TEMPERATURE PROFILE OF STRIPPING STUDY
FOR 1.2 M BED DEPTH

G/L	Influent Air Temp. (°C)	Effluent Air Temp. (°C)	Average Air Temp. (°C)	Influent Water Temp. (°C)	Effluent Water Temp. (°C)	Average Water Temp. (°C)
30	5	15	10	15	15	14
90	5	15	10	15	15	15
150	5	14	9	15	15	14
30	15	15	15	15	15	15
90	15	15	15	15	15	15
150	15	15	15	15	15	15
30	25	15	20	15	17	16
90	25	15	20	15	17	16
150	25	15	20	15	15	15
30	5	33	19	35	33	34
90	5	32	18	35	32	33
150	5	32	18	35	32	33
30	15	34	24	35	33	34
90	15	34	24	35	32	33
150	15	31	23	35	32	33
30	25	34	29	35	33	34
90	25	32	28	35	33	34
150	25	32	28	35	33	34
30	5	47	26	55	45	50
90	5	45	25	55	44	49
150	5	37	21	55	43	48
30	15	53	34	55	50	52
90	15	43	29	55	45	50
150	15	41	28	55	45	50
30	25	55	40	55	49	52
90	25	47	36	55	47	51
150	25	53	39	55	49	52

TABLE XXXXIII

PERCENTAGE DIFFERENCE IN OVERALL MASS TRANSFER COEFFICIENTS (K_1a), COMPUTED USING ONDA CORRELATIONS CAUSED BY ROUNDING THE ACTUAL AVERAGE WATER AND AIR TEMPERATURES OFF BY A MAXIMUM OF 2.5°C LIQUID LOADING = 6.4 M/HR AND GAS LOADING = 960 M/HR)

Compound	Rounded* K_1a (1/hr)	Actual** K_1a (1/hr)	% Difference
Toluene	33.83	33.95	-0.35
Chlorobenzene	33.46	33.63	-0.49
Ethylbenzene	32.27	32.38	-0.32
Tetrachloroethane	24.24	24.77	-2.13
1,3-Dichlorobenzene	31.09	31.29	-0.64
1,2-Dichlorobenzene	30.80	31.02	-0.69
Nitrobenzene	16.82	17.33	-2.91
Napthalene	25.24	25.64	-1.56
1-Chloronapthalene	23.43	23.86	-1.80
2,6-Dinitrotoluene	20.07	20.44	-1.83
Fluorene	25.91	26.18	-1.01
2,4-Dinitrotoluene	20.17	20.55	-1.82
Hexachlorobenzene	25.07	25.35	-1.10
Phenanthrene	17.81	18.47	-3.54
Fluoranthene	16.59	17.29	-4.08

*Average rounded water temperature = 30°C, Average rounded air temperature = 20°C.

**Average actual water temperature = 32.5°C, Average actual air temperature = 22.5°C.

coefficients are presented in Appendix D. In general, in this study, the K_1a values decreased with increasing gas-to-liquid ratio. With the operating flow rates employed in this work (Table XX) the gas-to-liquid ratio was increased, by decreasing liquid flow rate, and leaving the gas flow rate the same (Table XX). Under this set of conditions, the liquid phase resistance increased but the gas phase resistance decreased (Appendix D).

Effect of Water Temperature, Gas-to-Liquid Ratio, Air Temperature, and Bed Depth on Predicted Overall Mass Transfer Coefficients (K_1a) Using Onda Correlation

The range of K_1a values of volatile and slightly-volatile organic compounds at constant gas-to-liquid ratios 30, 90, and 150 measured at all combinations of water temperatures (15°, 35°, and 55°C), air temperatures (5°, 15°, and 25°C), and bed depths (0.6, 0.9, and 1.2 M) is listed in Table XXXXIV. All of the compounds in this study show the range of K_1a values decreasing with increasing gas-to-liquid ratios. This behavior of the decreasing range of the K_1a values with increasing gas-to-liquid ratio, is similar to that seen for the K_1a values obtained from this experimental study. A comparison of the K_1a values with the experimental ones is presented in Appendix E. It is can be seen that the average of the predicted K_1a values for chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, and 1,2-dichlorobenzene are about 83% of the experimental values.

In Chapter II, the mass transfer coefficients for the compounds are also estimated using the equations from the Reference Method. Individual

TABLE XXXXIV

THE RANGE OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) VALUES FOR ORGANIC COMPOUNDS AT CONSTANT GAS-TO-LIQUID RATIOS 30, 90, AND 150 ESTIMATED BY USING ONDA CORRELATIONS AT ALL COMBINATIONS OF WATER TEMPERATURES, BED DEPTHS, AND AIR TEMPERATURES

Compounds	The Range of K_1a Values Estimated at a Constant G/L = 30 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Estimated at a Constant G/L = 90 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Estimated at a Constant G/L = 150 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures
Toluene	57.76 - 160.0	25.87 - 70.17	17.52 - 47.06
Chlorobenzene	57.48 - 158.2	25.47 - 69.58	17.35 - 47.30
Ethylbenzene	65.18 - 153.0	24.68 - 66.96	16.69 - 45.40
Tetrachloroethane	36.18 - 102.7	18.78 - 49.72	13.36 - 35.62
1,3-Dichlorobenzene	52.84 - 145.1	23.77 - 64.54	16.22 - 44.14
1,2-Dichlorobenzene	51.94 - 143.2	23.57 - 64.06	16.09 - 43.90
Nitrobenzene	24.34 - 58.0	13.88 - 31.34	10.34 - 24.25
Napthalene	40.22 - 106.6	19.70 - 51.15	13.86 - 36.37
1-Chloronapthalene	36.30 - 98.02	18.12 - 49.05	12.82 - 33.39
2,6-Dinitrotoluene	32.04 - 71.15	16.65 - 38.15	11.97 - 28.19
Fluorene	43.07 - 113.1	20.16 - 52.68	13.93 - 36.78
2,4-Dinitrotoluene	31.49 - 73.16	16.44 - 38.37	11.84 - 38.32
Hexachlorobenzene	41.44 - 113.50	19.34 - 51.69	13.36 - 36.90
Phenanthrene	24.86 - 75.09	13.51 - 37.49	9.90 - 27.51
Fluoranthene	12.65 - 71.11	12.50 - 35.54	9.21 - 26.09

phase mass transfer coefficients were calculated according to Liss and Slater (51) using the measured transfer ratios of reference compounds and the following expression:

$$k_c = k_r\left[\frac{M_c}{M_r}\right]^{0.5} \tag{4.3}$$

where: k_c = mass transfer coefficient of compound of interest, m/sec
k_r = mass transfer coefficient of reference substance, m/sec
M_r = molecular weight of reference substance, gm/mole
M_c = molecular weight of compound of interest, gm/mole

Using field data measurements of total resistance for transfer from sea to air, values of k_g = 0.5 m/min for water and k_l = 0.00333 m/min for the oxygen were established. Since the k values vary with temperature, it is appropriate that k_g and k_l of the reference compound be corrected (11). The k_l of oxygen was corrected according to:

$$k_{l(T)} = k_{l\ (20)}^{1.024^{(T-20)}} \tag{4.4}$$

The k_g of water at 20°C was used throughout without any correction, because information on its variation with temperature was not available. Then, the overall mass transfer coefficient (K_l) was calculated according to:

$$\frac{1}{K_l} = \frac{1}{k_l} + \frac{1}{H_c k_g} \tag{4.5}$$

where: K_l = overall mass transfer coefficient, m/sec
k_l = liquid phase mass transfer coefficient, m/sec
k_g = gas phase mass transfer coefficient, m/sec
H_c = Henry's constant dimensionless unit

Using the estimated mass transfer rate of the compound interest and the reference compound along with the measured K_1a of the reference (oxygen), the overall mass transfer coefficients of the compounds were calculated according to the following expression (44) and are presented in Appendix E.

$$(K_1a)_c = (K_1a)_r \frac{(K_1)_c}{(K_1)_r} \tag{4.6}$$

where: $(K_1a)_c$ = overall mass transfer coefficient of compound of interest, 1/sec
$(K_1a)_r$ = overall mass transfer coefficient of reference, 1/sec
$(K_1)_c$ = mass transfer rate of compound of interest, m/sec
$(K_1)_r$ = mass transfer rate of reference, m/sec

Effect of Water Temperature, Gas-to-Liquid Ratio, Air Temperature, and Bed Depth on Estimated Overall Mass Transfer Coefficients (K_1a) Using Reference Method

The range of K_1a values of volatile and slightly-volatile organic compounds at constant gas-to-liquid ratio 30, 90, and 150 measured at all combinations of water temperatures, air temperatures, and bed depths are listed in Table XXXXV. All of the compounds in this study show the range of K_1a values decreasing with increasing gas-to-liquid ratios. This behavior, of the decreasing range of the K_1a values with increasing gas-to-liquid ratio, is similar to that seen for the K_1a values obtained from this experimental study. A comparison of the K_1a values with experimental ones are presented in Appendix E. This tabulation shows that the estimated values are about half the measured values for all the compounds used in this study.

TABLE XXXXV

THE RANGE OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) VALUES FOR ORGANIC COMPOUNDS AT CONSTANT GAS-TO-LIQUID RATIOS 30, 90, AND 150 ESTIMATED BY USING REFERENCE METHOD AT ALL COMBINATIONS OF WATER TEMPERATURES, BED DEPTHS, AND AIR TEMPERATURES

Compounds	The Range of K_1a Values Measured at a Constant G/L = 30 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Measured at a Constant G/L = 90 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures	The Range of K_1a Values Measured at a Constant G/L = 150 and All Combinations of Water Temperatures, Bed Depths, and Air Temperatures
Toluene	NA	NA	NA
Chlorobenzene	17.94 - 43.61	6.12 - 16.06	4.91 - 9.46
Ethylbenzene	18.98 - 46.36	6.48 - 17.00	5.21 - 10.52
Tetrachloroethane	13.25 - 30.42	4.52 - 11.87	3.57 - 7.35
1,3-Dichlorobenzene	15.86 - 38.39	5.41 - 14.21	4.34 - 8.80
1,2-Dichlorobenzene	15.81 - 38.17	5.39 - 14.15	4.32 - 8.76
Nitrobenzene	12.00 - 26.54	4.10 - 10.75	3.19 - 6.66
Napthalene	15.56 - 36.46	5.31 - 13.93	4.22 - 8.62
1-Chloronapthalene	13.64 - 31.73	4.65 - 12.21	3.69 - 7.56
2,6-Dinitrotoluene	11.48 - 26.87	3.92 - 10.28	3.11 - 6.36
Fluorene	14.31 - 34.28	4.88 - 12.81	3.90 - 7.93
2,4-Dinitrotoluene	11.59 - 26.86	3.96 - 10.38	3.13 - 6.43
Hexachlorobenzene	11.09 - 26.51	3.78 - 9.93	3.02 - 6.15
Phenanthrene	12.01 - 26.63	4.10 - 10.75	3.19 - 6.66
Fluoranthene	11.15 - 23.97	3.80 - 9.98	2.95 - 6.18

NA = Not Applicable.

CHAPTER V

DISCUSSION

The procedure for designing stripping tower systems requires a knowledge of Henry's constant and the overall mass transfer coefficient for the compound being stripped. Henry's constants for organic compounds can be computed from solubility and vapor pressure data. However, the solubility data are not readily available for all compounds. The Henry's constant can be measured by a batch-air stripping method (12).

Proper design of packed tower stripping systems requires the ability to predict the overall mass transfer coefficients of the specific organic compounds for the various of packing material, water and air temperatures, and liquid and gas loading rates. The use of empirical correlations to estimate the mass transfer coefficient were suggested by Kavanaugh and Trussell (41), Singley and Billeo (74), Gosset et al. (12), and Robert et al. (72). Many of these correlations are available in the Chemical Engineering Handbook by Perry and Chilton (71). However, the Onda correlations (56) seem to be the most promising for evaluating the mass transfer coefficients of volatile organic compounds (12).

Effect of Henry's Constant on Mass Transfer Coefficients

The results previously presented indicate that the batch air stripping experiments demonstrate the temperature dependency of Henry's

constant (H). Henry's constant obtained from the solubility and vapor pressure data (81, 71) for toluene, chlorobenzene, 1,3-dichlorobenzene, 1,2-dichlorobenzene, and tetrachloroethane were close (65%) to the experimental H from the batch air stripping study. Table XXXXVI shows percentage difference of Henry's constant for organic compounds between the batch air stripping experiment and Goldstein's equation at 35°C (represent the maximum effluent air temperature which was obtained using the maximum water temperature of 55°C and the maximum influent air temperature of 25°C). The results of Henry's constant for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, 1-chloronapthalene, and hexachlorobenzene showed small differences between the batch air stripping from this study and that calculated from Goldstein's equation. The range in the percent difference for H of these compounds was 3.75 to 22.3. However, the Henry's constant calculated from Goldstein's equation for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene tended to be lower, ranging from 84.6 to 96.4%, than those measured by the batch air stripping experiments.

The Henry's constant is an important factor in the design of packed tower stripping, it is used to calculate the number of transfer units (NTU), height transfer units (HTU), and overall mass transfer coefficients (Equations 2.85, 2.86, and 2.87). The percent difference of measured mass transfer coefficients (K_1a) using Henry's constant (H) from this study and Henry's constant from Goldstein's equation at an average air temperature of 35°C is presented in Table XXXXVII. The results of K_1a for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, 1-

TABLE XXXXVI

COMPARISON OF HENRY'S CONSTANT (H) FROM BATCH AIR STRIPPING STUDY AND GOLDSTEIN'S EQUATION AT 35°C

Compound	Experimental H from Batch Air Stripping Study ($atm-m^3/mole$)	H from Goldstein's Equation ($atm-m^3/mole$)	% Difference between Henry's Constant
Toluene	0.005818	0.007036	20.93
Chlorobenzene	0.004828	0.005009	3.75
Ethylbenzene	0.006563	0.007635	16.33
Tetrachloroethane	0.0007458	0.0005954	-20.17
1,3-Dichlorobenzene	0.003430	0.003693	- 7.12
1,2-Dichlorobenzene	0.003080	0.003540	17.53
Nitrobenzene	0.0002392	0.00003395	-85.83
Napthalene	0.0009120	0.0007088	22.29
1-Chloronapthalene	0.0008199	0.0009264	12.99
2,6-Dinitrotoluene	0.0004145	0.00006384	-84.61
Fluorene	0.001504	0.001623	-89.15
2,4-Dinitrotoluene	0.0004335	0.00006384	-85.28
Hexachlorobenzene	0.001870	0.002045	9.36
Phenanthrene	0.004895	0.0001760	-96.40
Fluoranthene	0.0004637	NA	NA

NA = Not Available.

TABLE XXXXVII

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING HENRY'S CONSTANT (H) FROM THIS STUDY AND HENRY'S CONSTANT FROM GOLDSTEIN'S EQUATION (LIQUID LOADING = 6.4 M/HR, GAS LOADING = 960 M/HR, AVERAGE AIR TEMPERATURE = 35°C, AVERAGE WATER TEMPERATURE = 46°C, AND 0.6 M BED DEPTH)

Compound	% Removal	Experimental H From This Study ($atm.m^3/mole$)	Number of Transfer Unit (NTU) From Experiment	Experimental K_1a Using H From This Study (1/hr)	H From Goldstein's Equation ($atm.m^3/mole$)	Number of Transfer Unit (NTU) Using H From Goldstein's Equation	K_1a Calculated Using H From Goldstein's Equation	% Difference Between K_1a's
Toluene	---	0.005818	---	---	0.007036	---	---	--
Chlorobenzene	97.03	0.004828	3.608	38.49	0.005009	3.605	38.45	-0.10
Ethylbenzene	97.37	0.006563	3.708	39.55	0.007635	3.698	39.44	-0.28
Tetrachloroethane	95.08	0.0007458	3.578	38.17	0.0005954	3.763	40.14	5.16
1,3-Dichlorobenzene	90.07	0.003430	4.867	51.19	0.004693	4.814	51.35	-1.08
1,2-Dichlorobenzene	97.43	0.003080	3.815	40.70	0.002540	3.850	41.06	0.88
Nitrobenzene	45.29	0.002392	0.7415	7.907	0.00003395	0.0	0.0	--
Napthalene	96.20	0.0009120	3.772	40.23	0.0007088	3.449	42.13	4.72
1-Chloronapthalene	94.72	0.0008199	3.430	36.58	0.0009264	3.364	35.88	-1.92
2,6-Dinitrotoluene	45.96	0.0004145	0.6882	7.341	0.00006384	0.0	0.0	--
Fluorene	73.58	0.001504	0.6276	17.35	0.0001632	2.944	31.41	-81.04
2,4-Dinitrotoluene	45.65	0.0004335	1.626	6.694	0.00006384	0.0	0.0	--
Hexachlorobenzene	58.19	0.001870	0.8993	9.593	0.002045	0.8969	9.567	-0.27
Phenanthrene	47.94	0.004895	0.7205	7.685	0.0001960	0.9035	9.637	-25.40
Fluoranthene	44.82	0.0004637	0.6545	6.982	NA	NA	---	--

NA = Not Available.

chloronapthalene, and hexachlorobenzene showed small differences between using H from this study and H from Goldstein's equation. The range in the percent difference for K_1a of these compounds was -0.10 to 5.16. However, the calculated K_1a values using H from Goldstein's equation for fluorene and phenanthrene tended to be higher than those K_1a using H from the batch air stripping study. It should be noted that the Henry's constant obtained from Goldstein's equation for nitrobenzene, 2,6-dinitrotoluene, and 2.4-dinitrotoluene are not applicable to calculate the K_1a values, even though the percent removal of these compounds are 45.96%, 45.65%, and 47.94% respectively. This is because of the H from Goldstein's equation of these compounds are severely underestimated when compared to the H from the batch air stripper in this study. Thus, under the conditions specified in Table XXXXVII, values for the number transfer units and K_1a for nitrobenzene, 2,6-dinitrotoluene, and 2,4-dinitrotoluene were not able to be calculated.

Table XXXXVIII also shows percent difference of Henry's constant for organic compounds between the batch air stripping experiment and Goldstein's equation at air 10°C (represent the minimum effluent air temperature which was obtained using the minimum water temperature of 15°C and the minimum influent air temperature of 5°C). The results of Henry's constant for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, 1-chloronapthalene, and hexachlorobenzene showed some differences between the batch air stripping study and Goldstein's equation. The range of percent difference for H of these compounds was -37.24 to 48.87. However, the Henry's constant from Goldstein's equation for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene tended to be

TABLE XXXXVIII

COMPARISON OF HENRY'S CONSTANT (H) FROM THIS STUDY AND GOLDSTEIN'S EQUATION AT 10°C

Compound	Experimental H from Batch Air Stripping Study ($atm\text{-}m^3/mole$)	H from Goldstein's Equation ($atm\text{-}m^3/mole$)	% Difference between Henry's Constant
Toluene	0.002959	0.004061	37.24
Chlorobenzene	0.002085	0.002786	33.62
Ethylbenzene	0.003094	0.004011	29.64
Tetrachloroethane	0.0003526	0.0002544	27.85
1,3-Dichlorobenzene	0.001552	0.001664	7.22
1,2-Dichlorobenzene	0.001396	0.001167	16.40
Nitrobenzene	0.0001411	0.000009480	-93.33
Napthalene	0.0004752	0.0002571	45.87
1-Chloronapthalene	0.0004820	0.0003128	35.10
2,6-Dinitrotoluene	0.0002859	0.00002817	-90.17
Fluorene	0.0008329	0.00006875	-91.76
2,4-Dinitrotoluene	0.0002758	0.00002817	-89.18
Hexachlorobenzene	0.0008912	0.001303	46.20
Phenanthrene	0.0002033	0.00004590	-77.42
Fluoranthene	0.0001809	NA	--

NA = Not Available.

lower in the range of 77.4 to 91.8% than those measured by the batch air stripping experiment.

Table XXXXIX presents the percent difference of the measured mass transfer coefficients (K_1a) using Henry's constant (H) from batch air stripping in this study and Henry's constant from Goldstein's equation at 10°C of the average air temperature. The results of K_1a for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, 1-chloronapthalene, and hexachlorobenzene showed small differences between using H from the batch air stripping from this study and the H from Goldstein's equation. The range in the percent difference for the K_1a of these compounds was -1.91 to 9.43. However the calculated K_1a values using H from Goldstein's equation for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene are not applicable to calculate the K_1a values, even though the percent removal of these compounds are 7.98%, 11.68%, 37.75%, 14.00%, and 22.89% respectively. This is because of the H from Goldstein's equation of these compounds are underestimated when compared to the H from this study. Therefore, under the conditions specified in Table XXXXIX, values for the number transfer units and K_1a for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene were not able to be calculated.

In this study, the correlation coefficients of the linear regression equations between Henry constants and temperatures were all greater than 0.82, an indication of good precision. Furthermore, Tables XXXXVII and XXXXIX indicates that the difference between the values of Henry's constants measured by batch air stripping and from Goldstein's equation showed a smaller difference than the K_1a values for toluene,

TABLE XXXXIX

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING HENRY'S CONSTANT (H) FROM THIS STUDY AND HENRY'S CONSTANT FROM GOLDSTEIN'S EQUATION (LIQUID LOADING = 11.09 M/HR, GAS LOADING = 960 M/HR, AVERAGE AIR TEMPERATURE = 10°C, AVERAGE WATER TEMPERATURE = 15°C, AND 0.6 M BED DEPTH)

Compound	% Removal	Experimental H From This Study ($atm.m^3/mole$)	Number of Transfer Unit (NTU) From Experiment	Experimental K_1a Using H From This Study (1/hr)	H From Goldstein's Equation ($atm.m^3/mole$)	Number of Transfer Unit (NTU) Using H From Goldstein's Equation	K_1a Calculated Using H From Goldstein's Equation	% Difference Between K_1a's
Toluene	79.12	0.002959	1.643	30.37	0.004061	1.612	27.79	-1.91
Chlorobenzene	75.75	0.002085	1.504	27.81	0.002786	1.481	27.38	-1.51
Ethylbenzene	77.73	0.003094	1.565	28.93	0.004011	1.538	28.43	-1.73
Tetrachloroethane	27.14	0.0003526	0.3546	6.554	0.0002544	0.3612	6.676	1.861
1,3-Dichlorobenzene	81.84	0.001552	1.871	34.58	0.001664	1.859	34.35	-0.66
1,2-Dichlorobenzene	79.07	0.001396	1.725	31.73	0.001167	1.761	32.56	2.62
Nitrobenzene	7.98	0.0001411	0.0903	1.661	0.00000948	0.0	---	--
Napthalene	57.87	0.0004752	1.066	19.662	0.0002571	1.377	21.47	9.43
1-Chloronapthalene	53.27	0.0004820	0.9149	16.91	0.0003128	1.040	18.21	8.98
2,6-Dinitrotoluene	11.68	0.0002859	0.1311	2.424	0.00002817	0.0	---	--
Fluorene	37.75	0.0008329	0.5063	9.358	0.00006075	0.0	---	--
2,4-Dinitrotoluene	14.00	0.0002758	0.1622	2.997	0.00002817	0.0	---	--
Hexachlorobenzene	22.89	0.0008912	0.2694	4.981	0.001303	0.2664	4.924	-1.14
Phenanthrene	22.61	0.0002033	0.3041	5.621	0.00004590	0.0	---	--
Fluoranthene	20.66	0.0001809	0.2756	5.094	NA	NA	---	--

NA = Not Available.

chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, and 1-chloronapthalene. There were significant differences between both the H and K_1a values for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene. The cause of these large differences in the H and K_1a values might be that the H from Goldstein's equation for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene were severely underestimated when compared to the H from the batch air stripping in this study. Due to the underestimated H of these compounds, it was impossible to calculate the number of transfer units and the K_1a values. However, the Henry's constant obtained from the batch air stripping study for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene were able to be used to calculate the number of transfer unit and K_1a. Therefore, the temperature dependency equation determined by batch air stripping should be used to calculate Henry's constant throughout this study.

Effect of High Water Temperature on Removal of Volatile and Slightly-Volatile Organic Compounds

The results presented in Appendix C indicated that at a constant gas-to-liquid ratio, water at higher temperature had a higher removal of the contaminant. When the gas-to-liquid ratio, air temperature, and bed depth were increased, higher removals were obtained. A further increase in these variables would have resulted in a closer approach to 100% removal for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, and

1-chloronapthalene (98.1%). In the case of nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene, the maximum percent removal percentage in this study was 73.87%, 39.97%, 80.03%, 47.43%, 73.70%, 46.33%, and 53.29% respectively. This suggests that it is necessary to increase the water temperature, gas-to-liquid ratio, air temperature, and bed depth separately or in combinations to remove these compounds more efficiently. From the regression equations developed in this study, the author predicts that increasing the water temperature from 55°C to 100°C and the bed depth from 1.2 to 6.0 m at an air temperature 25°C and gas-to-liquid ratio at 150, these slightly-volatile organic compounds (nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene) should be removed close to 100%. The prediction was based on extrapolation of the equations developed in this work. This is a first attempt to predict the condition needed to almost completely strip slightly-volatile organic compounds.

Table XXXXX is a summary of the procedure used to predict the percentage removal of nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene. Table XXXXXI shows the predicted percent removal of nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene at a water temperature of 100°C, air temperature 25°C, gas-to-liquid ratio 150, and 6.0 m bed depth. The predicted removal are found to be close to 100% for all of these compounds. Hence, high water temperature has significant effect on removal of volatile and slightly-volatile organic compounds.

TABLE XXXXX

SUMMARY OF PROCEDURE USED TO PREDICT PERCENT REMOVAL OF NITROBENZENE, 2,6-DINITROTOLUENE, FLUORENE, 2,4-DINITROTOLUENE, HEXACHLOROBENZENE, PHENANTHRENE, AND FLUORANTHENE AT WATER TEMPERATURE 100°C, AIR TEMPERATURE 25°C, GAS-TO-LIQUID RATIO 150, AND BED DEPTH 6.0 M

Calculate overall mass transfer coefficient (K_1a), the equations presented in previous section to determine the experimental K_1a with water at various temperatures at air temperature 25°C, gas-to-liquid ratio 150, and bed depth 6.0 m.
These equations are listed below:

Nitrobenzene:	$K_1a = -1.6608 + 0.2361T$
2,6-Dinitrotoluene:	$K_1a = 2.423 + 0.01663T$
Fluorene:	$K_1a = 2.7608 + 0.1382T$
2,4-Dinitrotoluene:	$K_1a = -2.1293 + 0.2171T$
Hexachlorobenzene:	$K_1a = 3.6465 + 0.0763T$
Phenanthrene:	$K_1a = 3.019 + 0.04475T$
Fluoranthene:	$K_1a = 4.259 + 0.008450T$

where: T = temperature in °C = 100°C

Estimate HTU, using estimated K_1a

$$HTU = \frac{Lm}{K_1a}$$

where: Lm = 6.4 m/hr

Calculate NTU as

$$NTU = \frac{Z}{HTU}$$

where: Z = 6.0 m

Calculate the expected fraction (F) of influent contaminant remaining:

$$F = \frac{C_1^1}{C_1^2} = \frac{\frac{HG}{RTL} - 1}{\frac{HG}{RTL} \cdot e^{NTU\left(\frac{HG-1}{RTL}\right)/\left(\frac{HG}{RTL}\right)} - 1}$$

Calculate predicted percentage removed:

Percent removed = (1 - F) x 100

TABLE XXXXXI

PREDICTED PERCENT REMOVAL OF NITROBENZENE, 2,6-DINITROTOLUENE, FLUORENE, 2,4-DINITROTOLUENE, HEXACHLOROBENZENE, PHENANTHRENE, AND FLUORANTHENE AT WATER TEMPERATURE 100°C, AIR TEMPERATURE 25°C, GAS-TO-LIQUID RATIO 150, AND BED DEPTH 6.0 M

Compound	Predicted Percent Removal at Water Temperature 100°C, Air Temperature 25°C, Gas-to-Liquid Ratio 150, and Bed Depth 6.0 m
Nitrobenzene	99.9
2,6-Dinitrotoluene	97.7
Fluorene	94.8
2,4-Dinitrotoluene	99.9
Hexachlorobenzene	99.9
Phenanthrene	99.9
Fluoranthene	98.9

The results from the batch air stripping and packed column studies demonstrate the significance of water temperatures dependency of Henry's constant and percent removal of volatile and slightly-volatile organic compounds (Tables XVII, XXI, XXII, and Appendix C). The results of Henry's constant (H) in this study for toluene, chlorobenzene, ethylbenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, napthalene, 1-chloronapthalene, and hexachlorobenzene seem to be close (3.75 to 22.3%) to those calculated for Goldstein's equations (Table XXXXVI). However, the H for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, and phenanthrene tend to be higher than those predicted by Goldstein's equations. Under prediction of the H values by the Goldstein's equation caused problems in the calculation of the NTU values. These low values of H lead to negative values for the NTU. The equations developed from this data in this study were able to calculate NTU values for all the compounds under all conditions studied. Examples of the data fit are contained in Figures 20 through 34 for the volatile and slightly volatile organic compounds.

The results of the packed tower study showed that at a constant water temperature of 55°C at all combinations of air temperatures, gas-to-liquid ratios, and bed depths, toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, and 1-chloronapthalene were close to 100% removed. However, at this water temperature and all of the possible combinations of the other experimental variables, nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene were removed in the range of 35-80%. A prediction concerning the close to 100% removal of these compounds concluded that the required conditions

were met by increasing the water temperature from 55°C to 100°C and bed depth from 1.2 to 6.0 m with constant to gas-to-liquid ratio of 150, and an air temperature 25°C.

At a constant 35°C water temperature with all combinations of air temperatures, gas-to-liquid ratios, and bed depths for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, and 1-chloronapthalene removals were in the range of 70-95%. However, at this same constant water temperature and all combinations of air temperatures, gas-to-liquid ratios, and bed depths for nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene were removed in a range of 30-70%. At a constant 15°C water temperature with all combinations of air temperatures, gas-to-liquid ratios, and bed depths toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, and chloronapthalene were removed in a range of 65-90%. At this constant water temperature and all combinations of air temperatures, gas-to-liquid ratios, and bed depths, nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene removal were in the range of 5-45%. This indicates that elevated water temperature has a significant effect on removal of both volatile and slightly-volatile organic compounds.

Comparison Measured Overall Mass Transfer Coefficients With Both Onda and Reference Method

As mentioned previously, two methods were used to predict the mass transfer coefficients. The single phase Reference Method by Mumford and

Schnoor (48) and the Onda Method (56). It is interesting to compare the results of this study to both Onda and Reference Methods. The values of the percent differences between the experimental K_1a and both the Onda and Reference Methods are presented in Appendix E. Table XXXXXII shows the average percent difference between the measured K_1a's and both the Onda and Reference Methods. The average percent difference between the measured K_1a's and predicted K_1a's by Onda correlations for chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, and 1,2-dichlorobenzene is within 20%. The average percent difference between the measured K_1a's and predicted K_1a's by Onda Method for toluene, napthalene, and 1-chloronapthalene is within 30%. The average percent difference between the measured K_1a's and predicted K_1a's by Onda correlations for tetrachloroethane, nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene is from by 78.6 to 457%. This represents an overestimation of the K_1a's by these percentages. Table XXXXXII also shows the average percent difference between the measured K_1a's and predicted K_1a's by Reference Method for all the compounds in this study is underestimated by 32.5 to 91.3%. Figures 66 through 80 show the relationship between K_1a measured and K_1a predicted by the Onda and Reference Methods. The middle solid line (45° angle line) in the figure represents perfect agreement between measured K_1a's and predicted K_1a's; the upper and lower lines represent the percentage deviations of predicted values from those observed. It appears that the Onda correlations are generally capable of fitting the data for chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, and 1,2-dichlorobenzene within 20%. This percent deviation is approximately the accuracy claimed by Onda for his k_1 correlation (12, 56). In the case of toluene,

TABLE XXXXXII

COMPARISON OF THE AVERAGE PERCENT DIFFERENCE OF MEASURED AND PREDICTED OVERALL MASS TRANSFER COEFFICIENTS

Compound	Average Percent Difference Measured and Onda	Average Percent Difference Measured and Reference Method
Toluene	- 28.25	- 70.63
Chlorobenzene	18.38	- 74.02
Ethylbenzene	20.37	- 70.42
Tetrachloroethane	78.59	- 57.05
1,3-Dichlorobenzene	18.12	- 77.54
1,2-Dichlorobenzene	16.20	- 75.63
Nitrobenzene	246.5	- 91.25
Napthalene	- 26.98	- 71.65
1-Chloronapthalene	- 29.88	- 74.65
2,6-Dinitrotoluene	457.2	- 84.27
Fluorene	162.4	- 34.51
2,4-Dinitrotoluene	392.6	- 47.06
Hexachlorobenzene	311.5	- 32.10
Phenanthrene	199.3	- 35.20
Fluoranthene	183.3	- 37.20

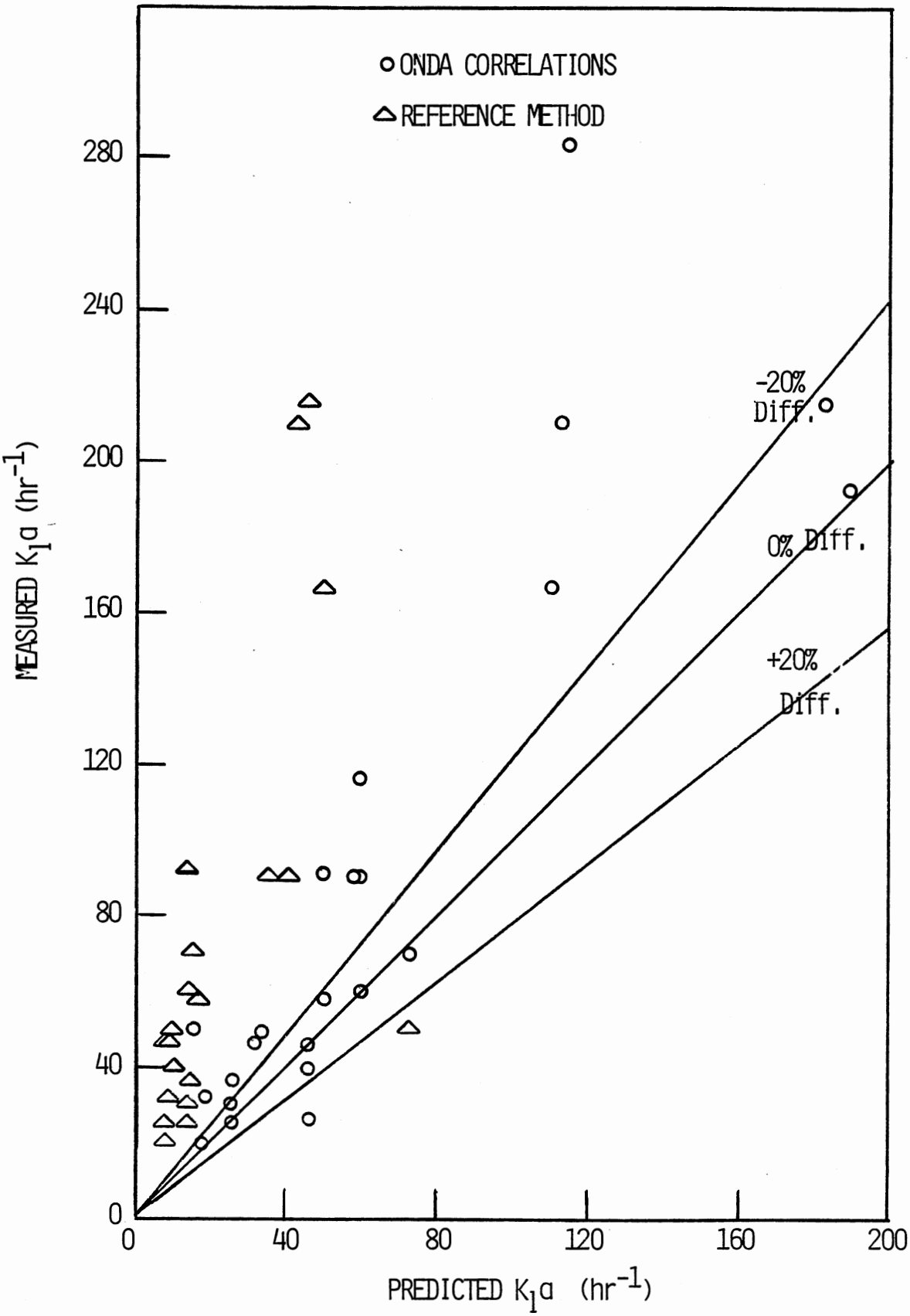


Figure 66. Measured Versus Predicted Mass Transfer Coefficients for Toluene

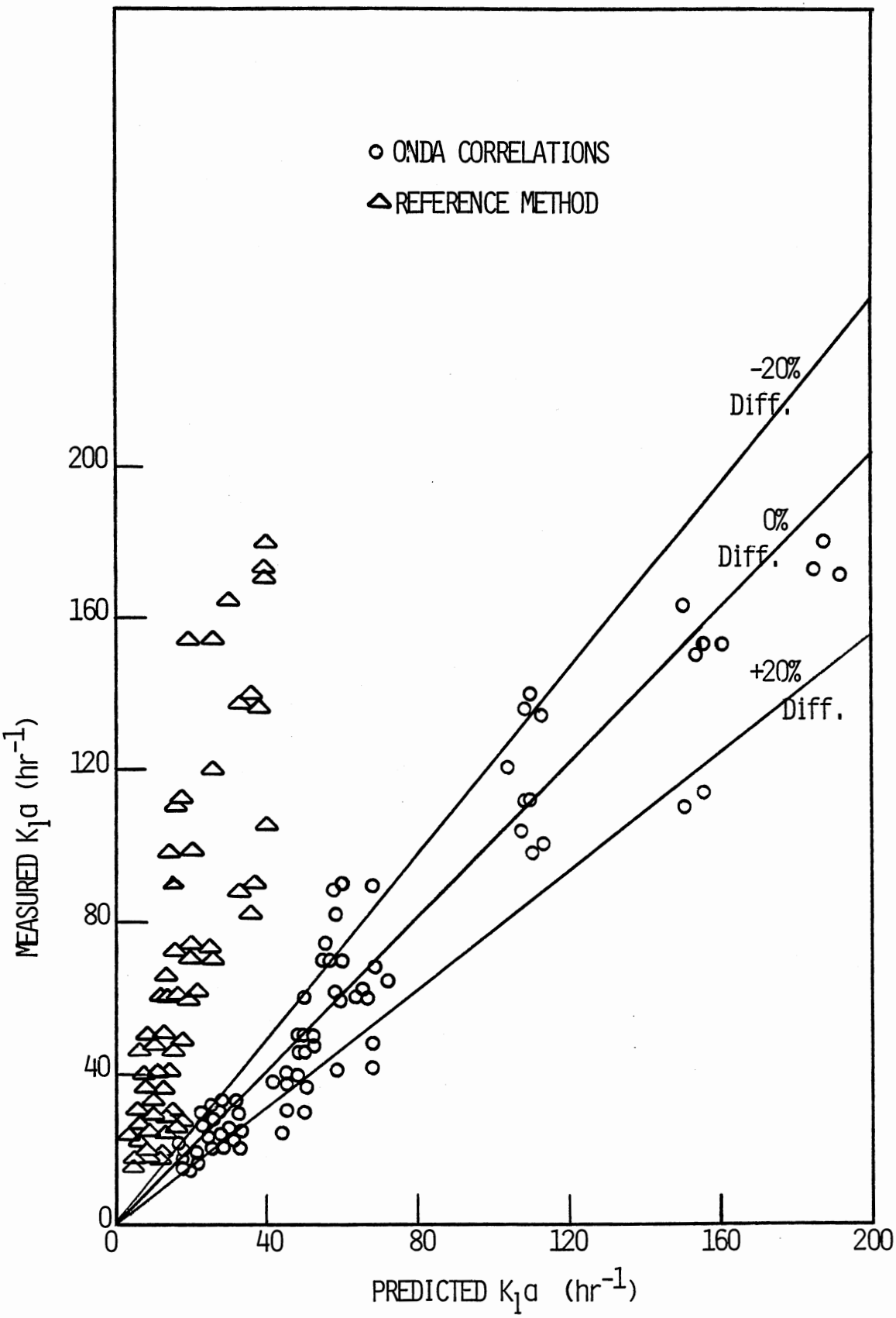


Figure 67. Measured Versus Predicted Mass Transfer Coefficients for Chlorobenzene

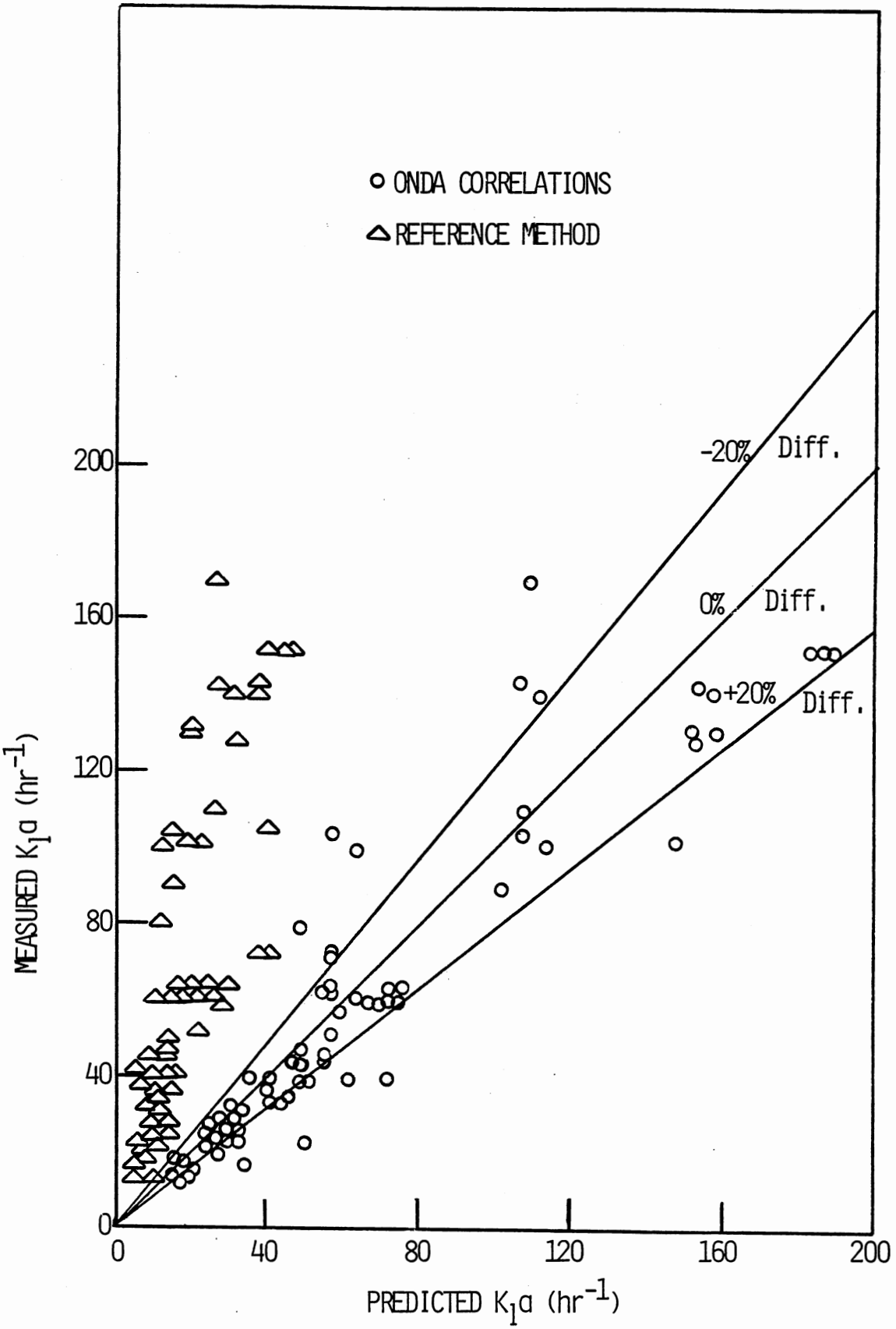


Figure 68. Measured Versus Predicted Mass Transfer Coefficients for Ethylbenzene

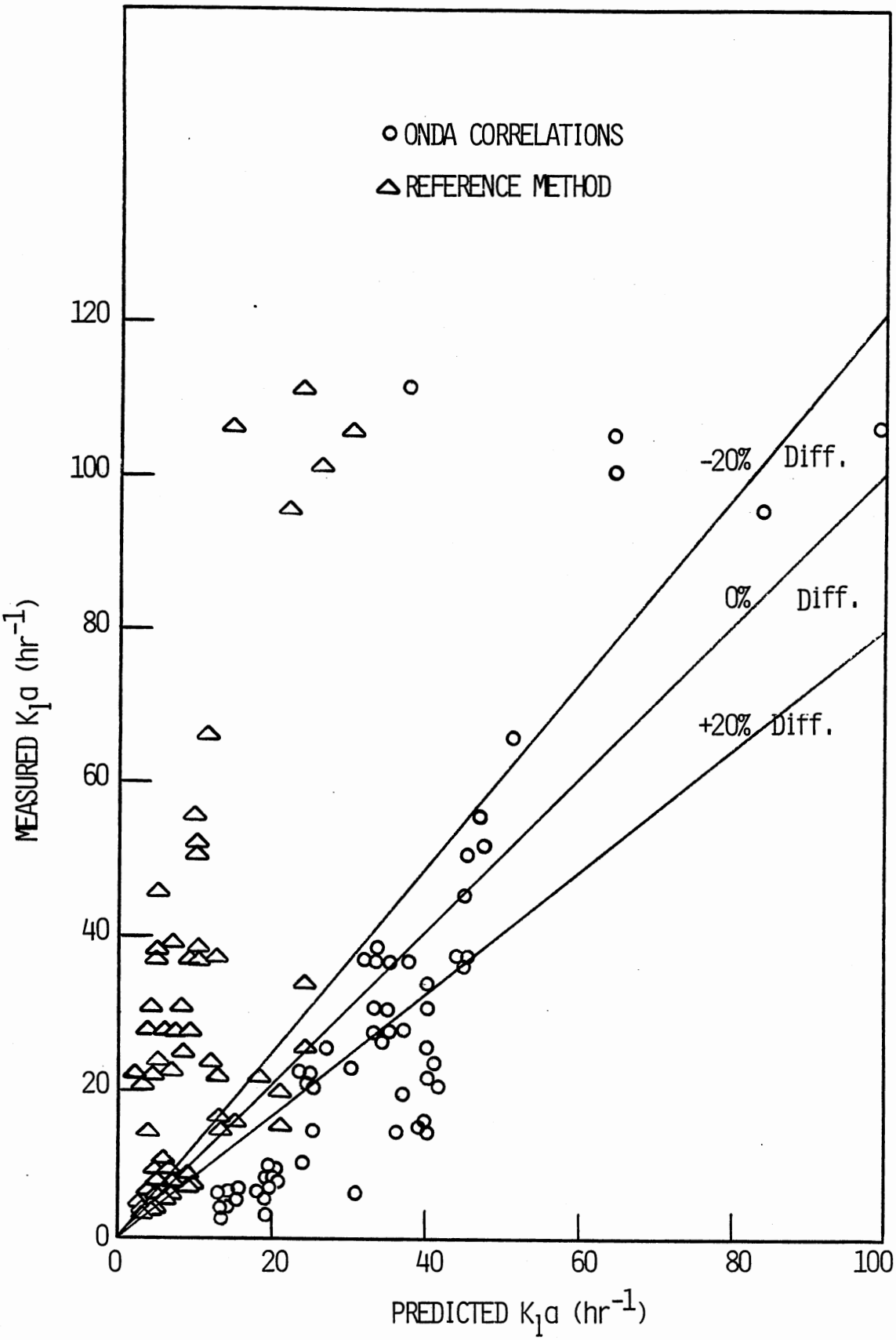


Figure 69. Measured Versus Predicted Mass Transfer Coefficients for Tetrachlorobenzene

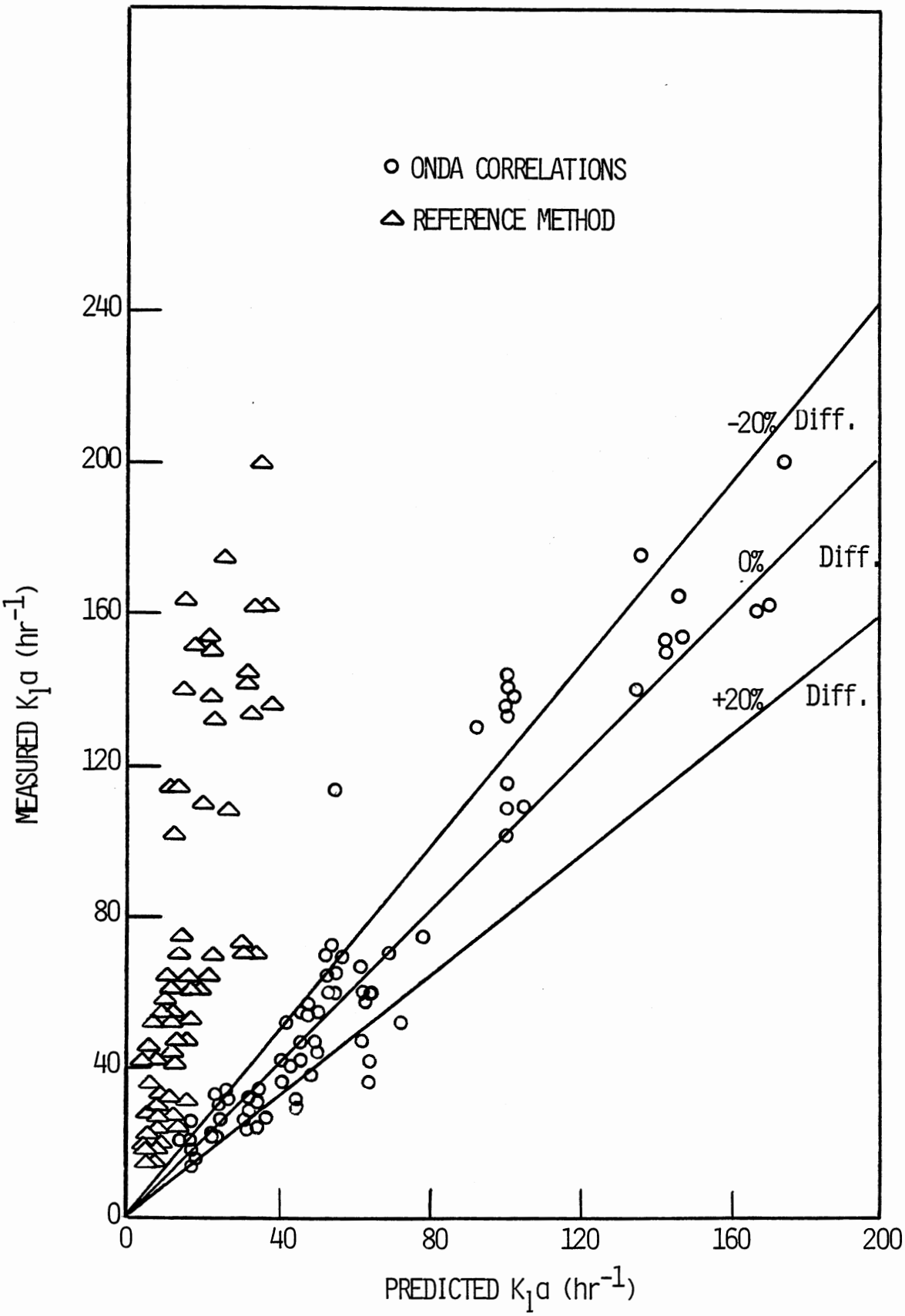


Figure 70. Measured Versus Predicted Mass Transfer Coefficients for 1,3-Dichlorobenzene

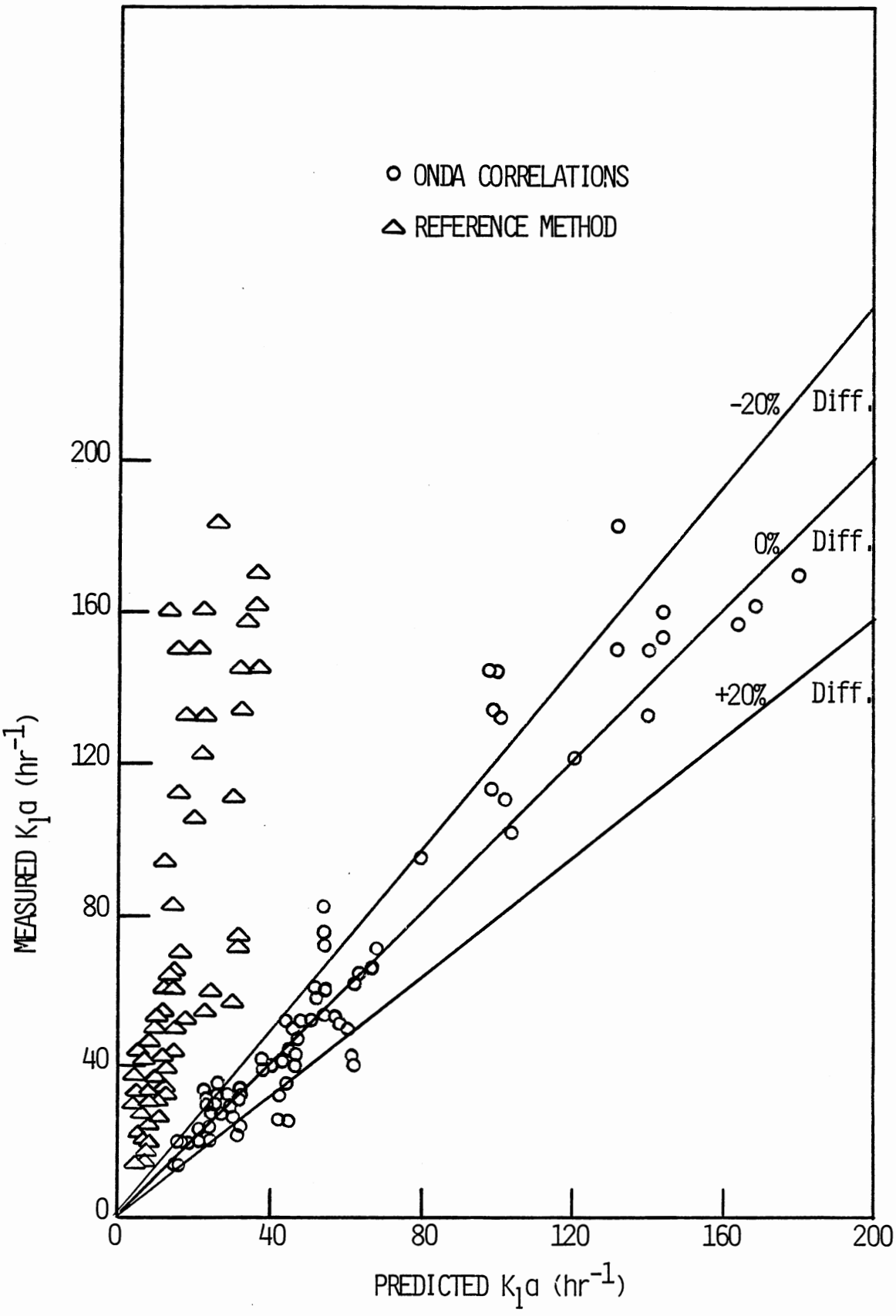


Figure 71. Measured Versus Predicted Mass Transfer Coefficients for 1,2-Dichlorobenzene

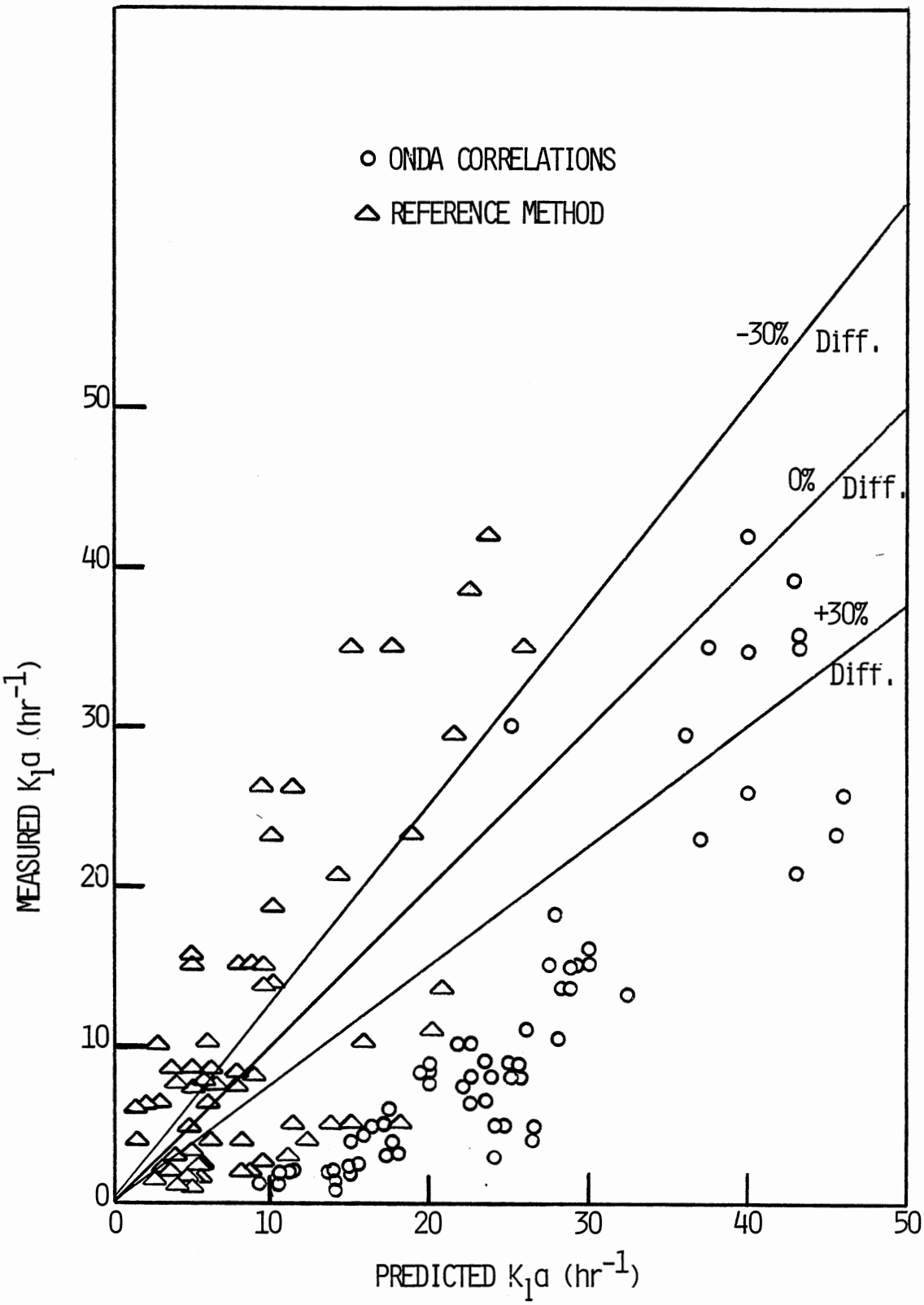


Figure 72. Measured Versus Predicted Mass Transfer Coefficients for Nitrobenzene

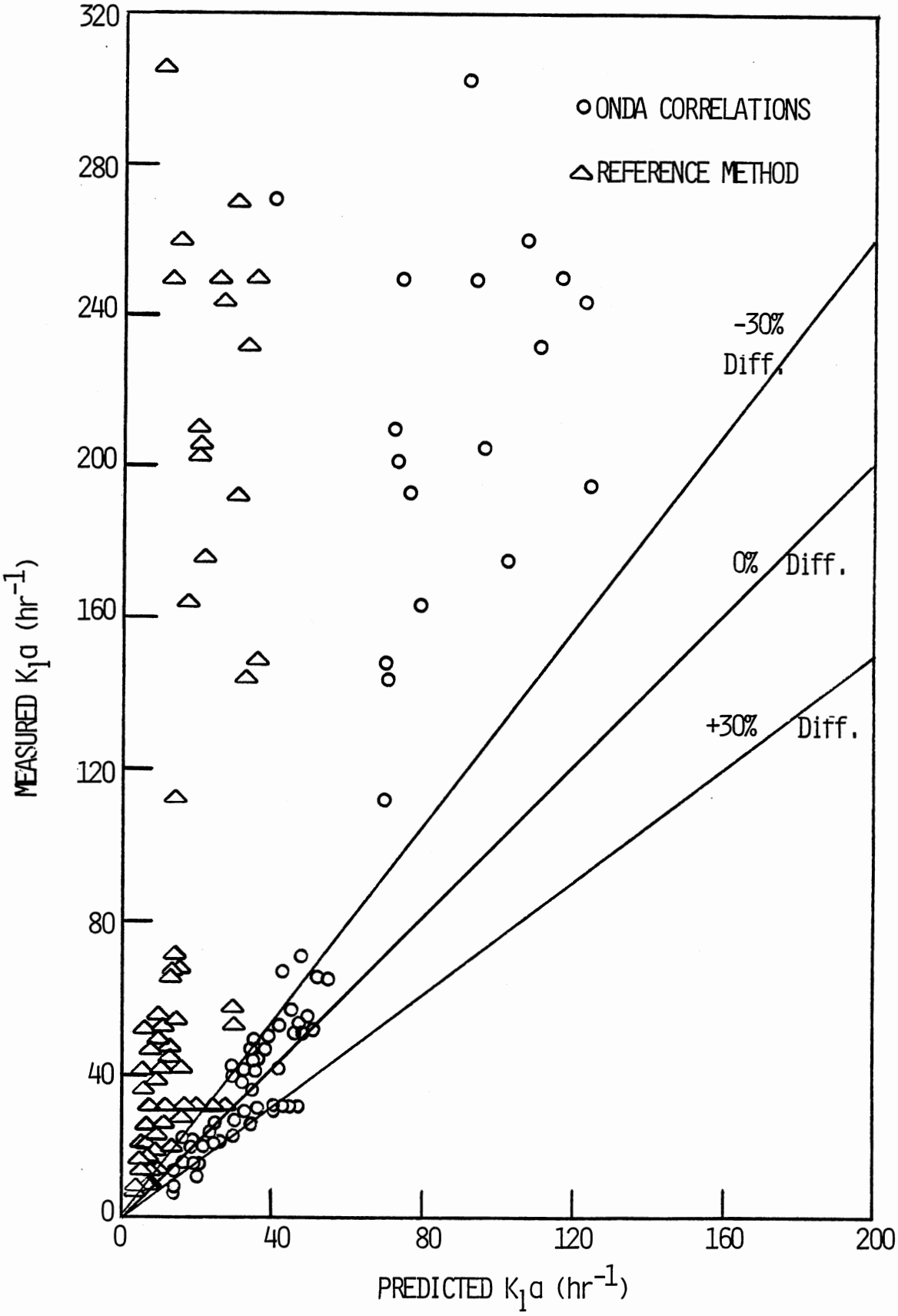


Figure 73. Measured Versus Predicted Mass Transfer Coefficients for Napthalene

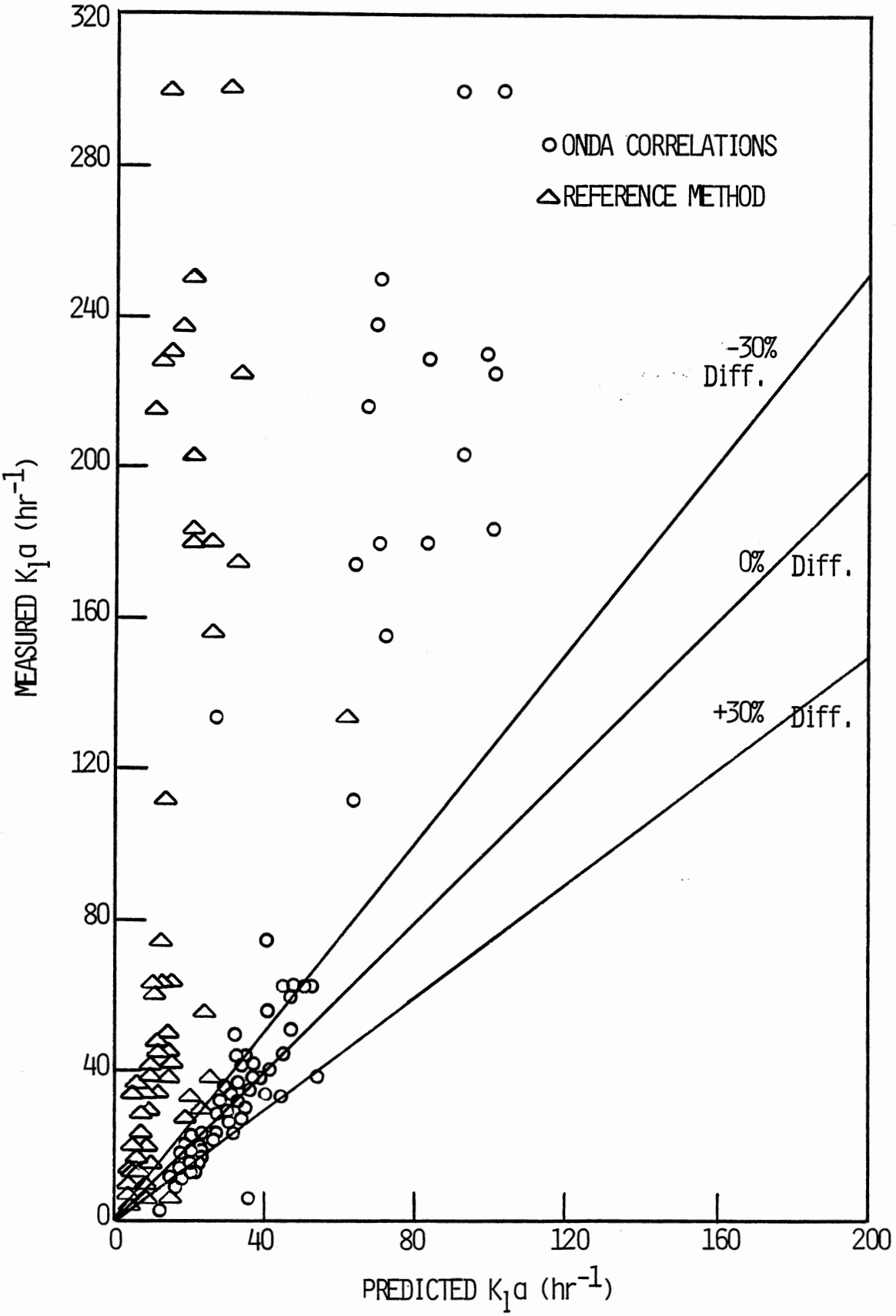


Figure 74. Measured Versus Predicted Mass Transfer Coefficients for 1-Chloronapthalene

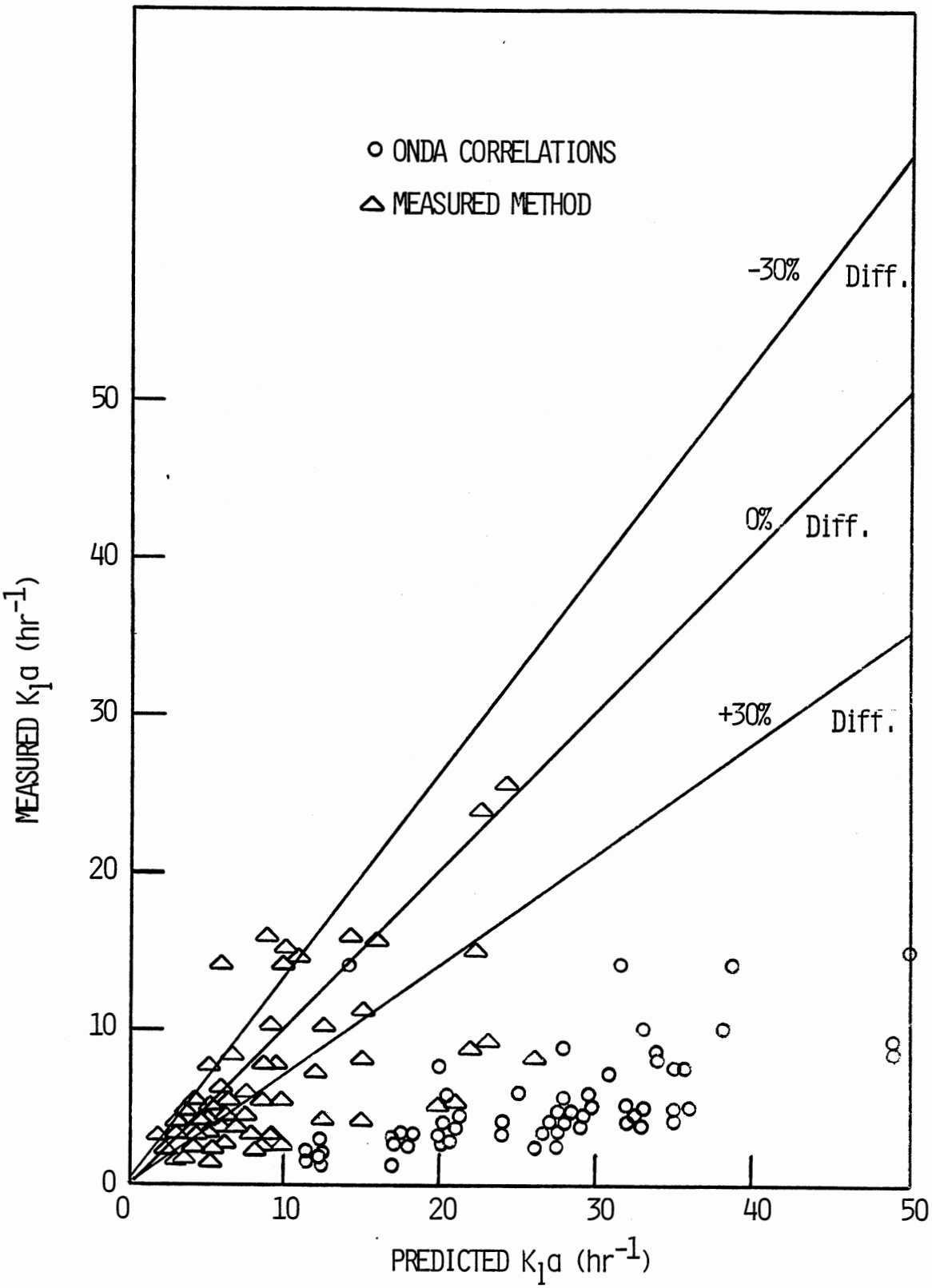


Figure 75. Measured Versus Predicted Mass Transfer Coefficients for 2,6-Dinitrotoluene

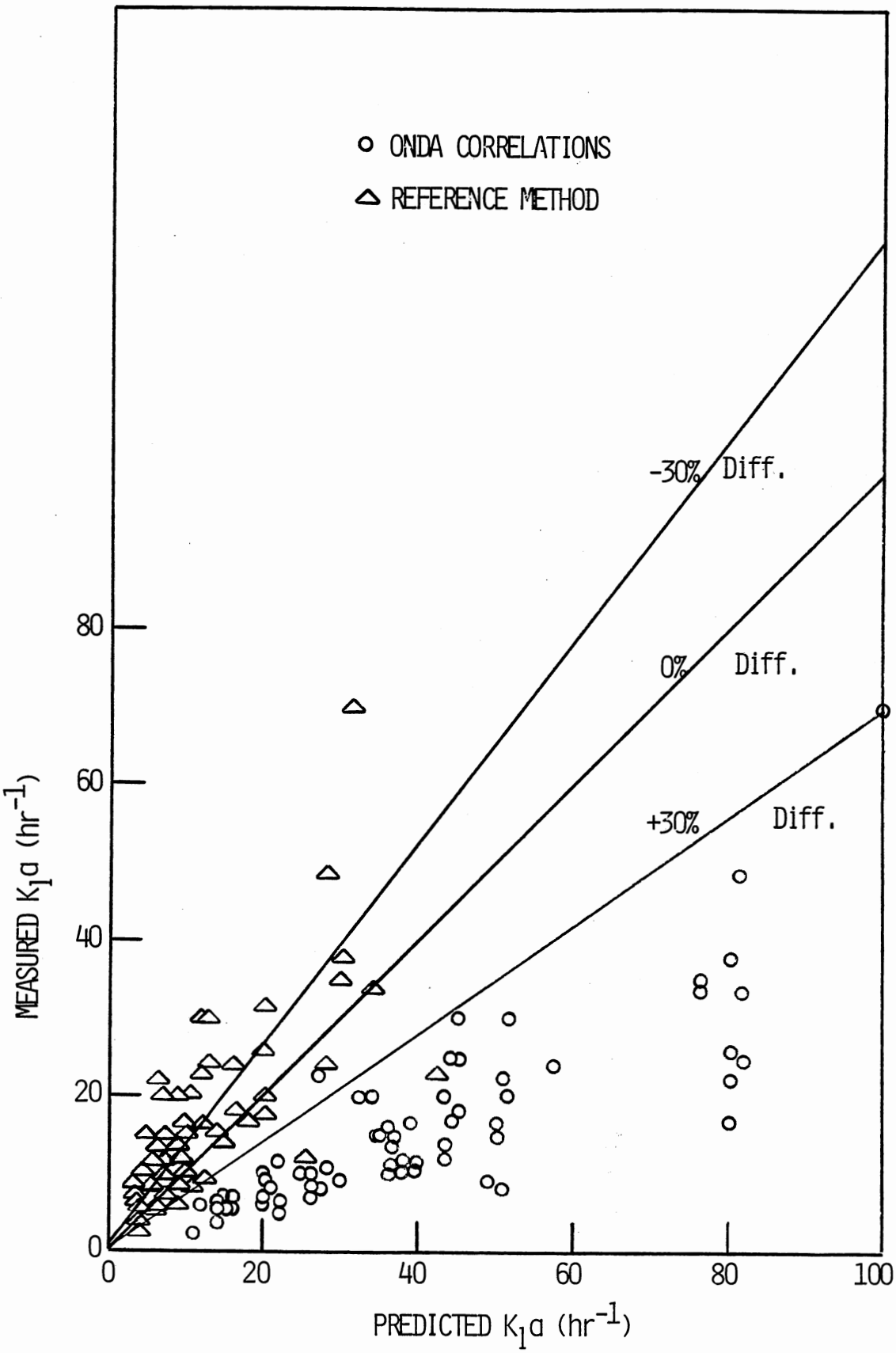


Figure 76. Measured Versus Predicted Mass Transfer Coefficients for Fluorene

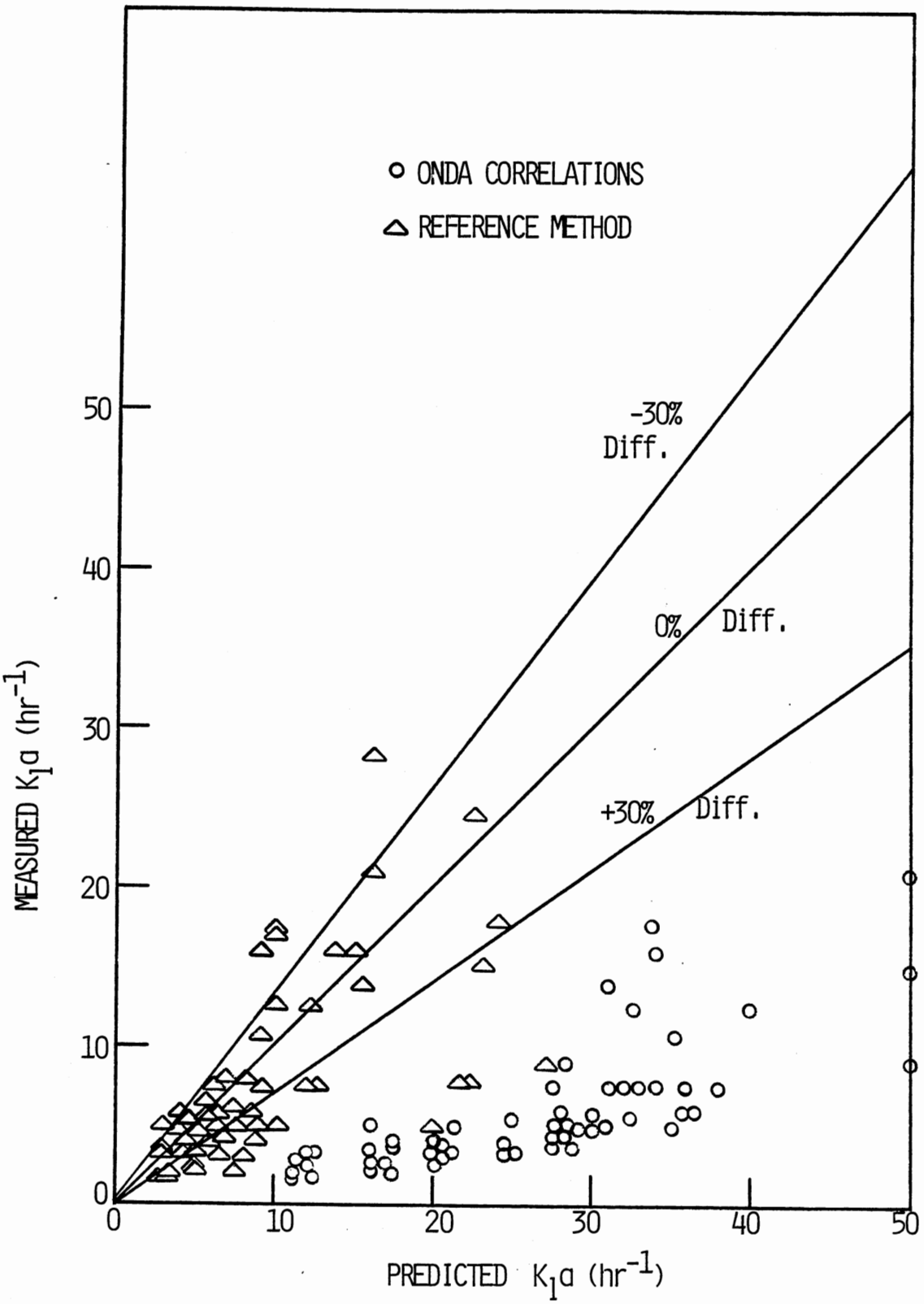


Figure 77. Measured Versus Predicted Mass Transfer Coefficients for 2,4-Dinitrotoluene

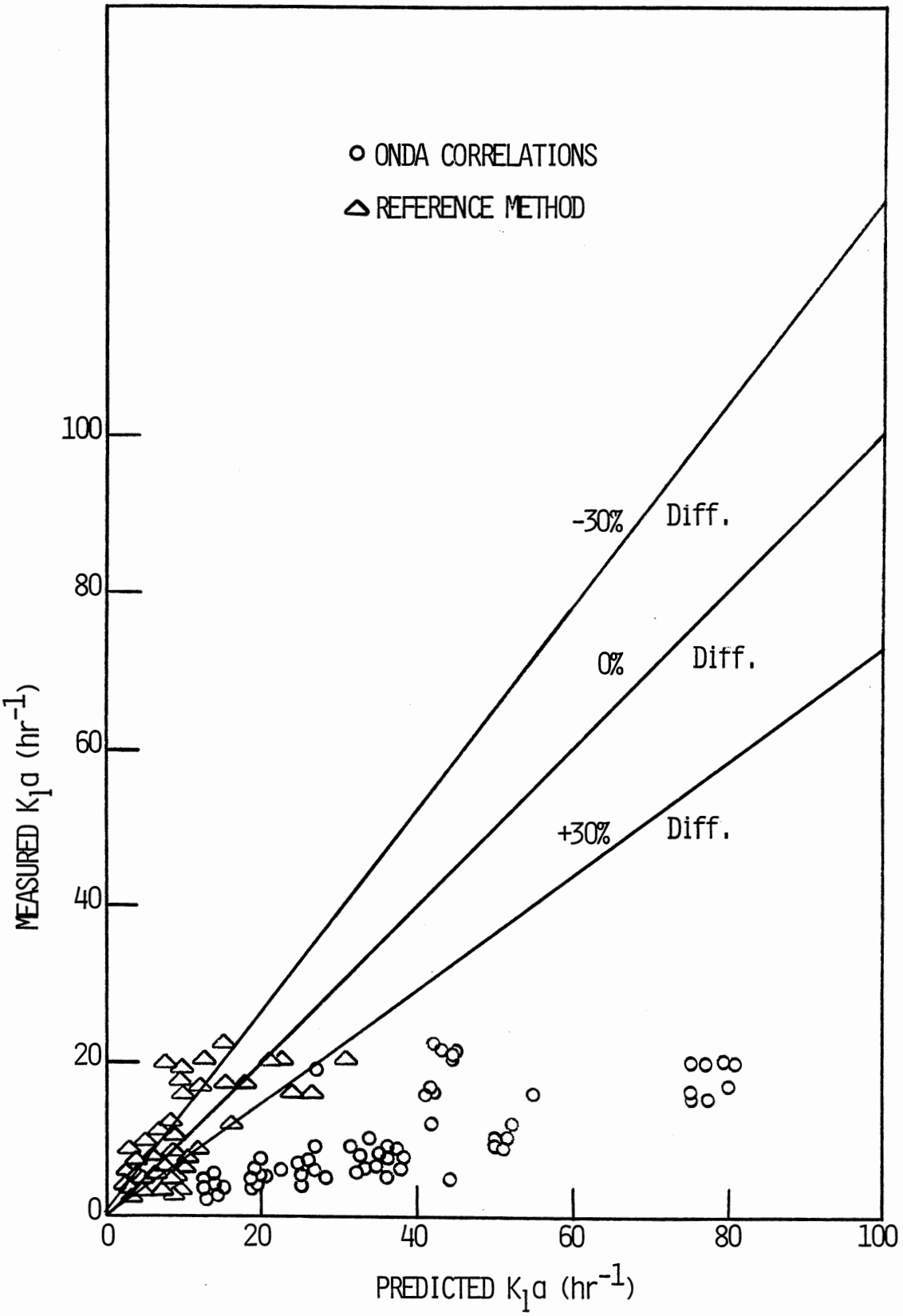


Figure 78. Measured Versus Predicted Mass Transfer Coefficients for Hexachlorobenzene

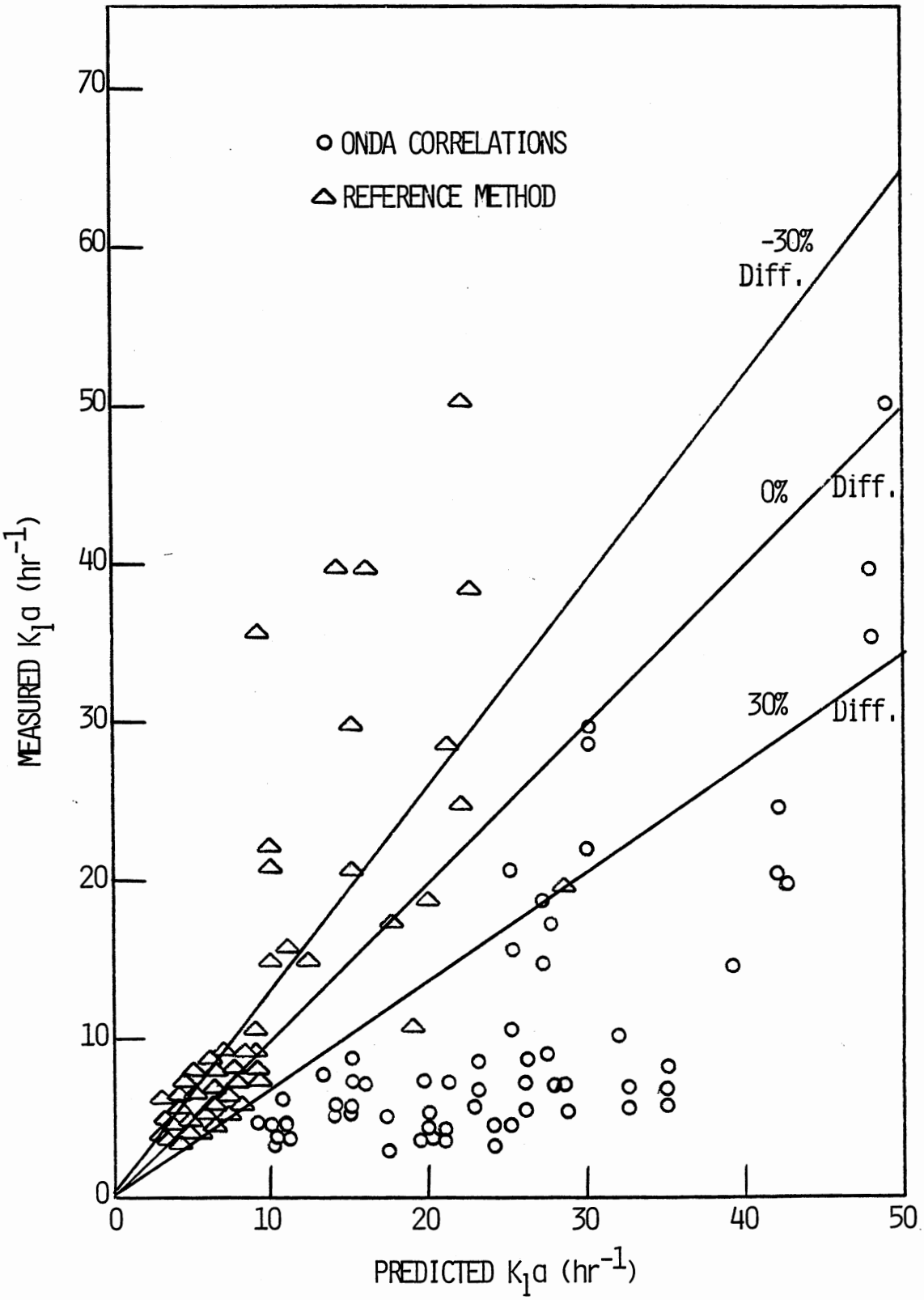


Figure 79. Measured Versus Predicted Mass Transfer Coefficients for Phenanthrene

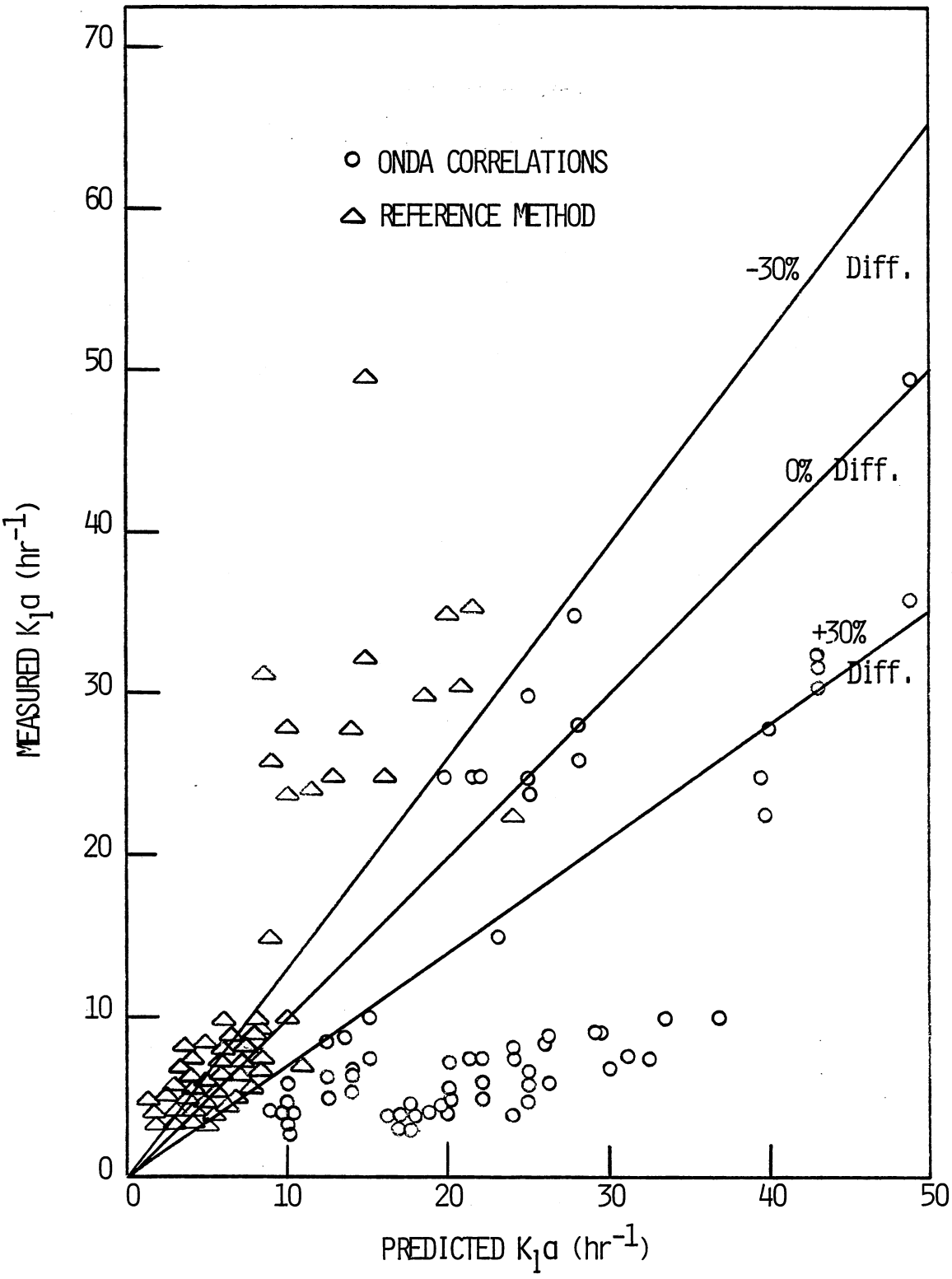


Figure 80. Measured Versus Predicted Mass Transfer Coefficients for Fluoranthene

napthalene and 1-chloronapthalene, the Onda correlation is capable of fitting the data within 30%. The plots of toluene, chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene and 1-chloronapthalene showed that the Onda correlations were much closer to the line of no difference than the Reference Method. An interesting point to note is that for tetrachloroethane, nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene the single phase Reference Method actually predicted closer to the line of no difference than Onda Method.

The effect of gas phase resistance was also noted in the packed tower experiments, although it has rarely been investigated (12). The magnitude of the gas phase resistance effect depends on the characteristics of the compound being stripped. The gas phase resistance increases with decreasing Henry's constant. This can be explained by the two film theory which relates the gas phase resistance to Henry's constant. Pakanati (11) reported that nitrobenzene (slightly-volatile organic compound) with a very low H has more than 70% of its total resistance in the gas phase. Gosset et al. (12) observed that the increased percent difference of his measured K_1a's and those predicted by the Onda correction (56) increased as a function of gas phase resistance. The same trend also occurred in this study. Chlorobenzene (most volatile) showed an 8.4% average difference between the measured K_1a's and the ones predicted by the Onda Method. Its average gas phase resistance was 7.0%. However, 2,6-dinitrotoluene (least volatile) showed a 457% average difference in the K_1a's between measured and predicted by the Onda Method when the average gas phase resistance was 69.2%. This indicates that chlorobenzene possessed smaller values in both the percent

differences of the K_1a's and the gas phase resistance than 2,6-dinitrotoluene. Thus, the increased percent difference between the measured K_1a's and those predicted by the Onda Method also increased as a function of gas phase resistance. It would appear that for the Onda correlation to be used to predict the K_1a of slightly-volatile compounds a modification of the Onda equation is needed.

The differences between the values of K_1a measured and K_1a from the Reference Method were significant. It may be caused by the gas phase mass transfer (k_g) of water at 20°C which was used throughout in this study, without any correction, because information on its variation with temperature was not available. If the changes due to variation of temperature are not considered in predicting gas phase mass transfer coefficients (k_g), errors can result. It is necessary to take into account the variation in the k_g of water when using it to predict the K_1a of the volatile and slightly-volatile organic compounds. Thus, any error in the calculation of K_1a in the Reference Method for all compounds in this study may be caused from not accounting for the change in gas phase mass transfer coefficients (k_g).

CHAPTER VI

CONCLUSIONS

Batch air stripping for measuring Henry's constant of volatile and slightly-volatile organic compounds in dilute aqueous systems were proposed and evaluated. Based on the experimental evidence presented, the following conclusions may be drawn:

1. Henry's constants (H) were measured for 15 organic compounds in the water temperature range from 10°C to 55°C. The 15 compounds employed were: toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, nitrobenzene, napthalene, 1-chloronapthalene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene. For each compound a regression equation for H as a function of water temperature was calculated. The results obtained possessed high correlation coefficients (-0.93 to -0.99).

2. The results of the comparison of Henry's constants between the measured values by batch air stripping and the constants calculated from Goldstein's equation for toluene, chlorobenzene, ethylbenzene, tetrachloroethane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, napthalene, 1-chloronapthalene, and hexachlorobenzene showed little significant (3.75 to 22.3%) differences (Table XXXXVI). These compounds also showed little effect of the H on overall mass transfer coefficients (K_1a) (Table XXXXVII). However, the results for nitrobenzene, 2,6-dinitrotoluene,

fluorene, 2,4-dinitrotolulene, and phenanthrene showed large differences (-84.6 to -96.4%) in Henry's constant (Table XXXXVI). These compounds also showed a large effect of H on the K_1a values (Table XXXXVII).

Measuring the percent removal and the overall mass transfer coefficients (K_1a) of volatile and slightly-volatile organic compounds using a stripping tower was proposed and evaluated. Based on the experimental evidence presented, the following conclusions may be described:

1. In this study, volatile and slightly-volatile organic compounds with Henry's constant of 0.0004 to 0.0025 atm.m^3/mole at 20°C achieved close to 100% removal by air stripping (water temperature = 55°C, air temperature = 25°C, gas-to-liquid ratio = 150, and bed depth = 1.2 m).

2. The influent water and air temperatures effect the removal of both volatile and slightly-volatile organic compounds. Higher removals are obtained at higher water and air temperatures (under equal conditions of gas-to-liquid ratio, air temperature, and bed depth) (Appendix C, Tables XXI, XXII). However, in this study water temperature was shown to have a greater effect on the removal of the organic compounds than did air temperature (Appendix C, Tables XXI, XXII).

3. An increase in water temperature caused an increase in the removal efficiency of all compounds. The effect was more pronounced on volatile organic compounds than on the slightly-volatile organic compounds. The same trend occurred in Pakanati's (11) study.

4. Overall mass transfer coefficients were measured for 15 organic compounds at the water temperatures 15°C, 35°C, 55°C; air temperatures 5°C, 15°C, 25°C; gas-to-liquid ratios 30, 90, 150; and bed depths 0.6 m, 0.9 m, 1.2 m. For each compound the overall mass transfer coefficients (K_1a) regressions equation was calculated as a function of the water

temperature at all combinations of air temperatures, gas-to-liquid ratios, and bed depths. The results obtained possessed high correlation coefficients (0.82 to 0.99).

5. For chlorobenzene, ethylbenzene, 1,3-dichlorobenzene, and 1,2-dichlorobenzene, the Onda correlations predicted the K_1a values within 20% of the measured K_1a values. The Onda estimations of the K_1a's for these compounds were better than the Reference Method.

6. For toluene, napthalene and 1-chloronapthalene, the Onda correlations predicted the K_1a value within 30% of the measured K_1a values. The Onda estimations of the K_1a's for these compounds were better than the Reference Method.

7. For nitrobenzene, 2,6-dinitrotoluene, fluorene, 2,4-dinitrotoluene, hexachlorobenzene, phenanthrene, and fluoranthene, the Onda estimation overestimated the K_1a values. However, the Reference Method underestimated the K_1a values for all of these compounds. The Reference Method estimation of the K_1a's for these compounds were better than the Onda Method.

The microextraction technique was a useful method to analyze the 15 organic compounds used in this study. The precision of a method can be quantified in terms of standard deviation and range. The standard deviation for the microextraction technique was 8.4 ng while the range was 2.5 to 25 ng. The accuracy with reference to an USEPA standard was in the range of 86.6% to 98.4%.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

The following studies are suggested for future work.

1. To remove slightly-volatile organic compounds close to 100%, suggest that the water temperature and the bed depth needs to be increased to value larger than used in this study. A prediction of the condition required to achieve close to 100% removal of this slightly-volatile compound was made. Future study should attempt to verify the accuracy of this prediction.

2. The use of steam stripping is suggested in order to remove the slightly-volatile organic compounds close to 100%.

3. In Reference Method, the relationship between gas phase mass transfer coefficients (k_g) values with temperature needs to be developed.

4. The expenditure to remove the organic compounds in this study needs to be compared with the other treatment methods (i.e., activated carbon absorption, synthetic resin absorbents).

5. The change of gas phase resistance for volatile and slightly-volatile organic compounds for all temperatures should be determined.

REFERENCES

1. McCarty, P.L., Reinhard, M., and Rittman, B.E., "Trace Organic in Groundwater," Envi. Sci. and Tech., 15, 40-51 (1981).

2. Houg, G.E., and Marley, M.C., "Gasoline Residual Saturation in Unsaturated Uniform Aquifer Material," Jour. Envi. Eng. Div. ASCE., 112, 3, 586-604 (1986).

3. Salo, J.E., Harrison, D., and Archibab E.M., "Removing Contaminants by Groundwater Recharge Basins," Jour. AWWA, 59, 76-81 (1986).

4. Hand, D.E., Crittenden, J.C., Gehin, J.L., and Lykins, B.W., "Design and Evaluation of an Air-Stripping Tower for Removing VOC's from Groundwater," Jour. AWWA, 59, 87-99 (1986).

5. Altohof, W.F., et al., "Aquifer Decontamination for Volatile Organics: A Case History," Groundwater, 19, 5, 495-504 (1981).

6. Guerrera, A.A., "Chemical Contamination of Aquifers on Long Island, New York," Jour. AWWA, 4, 190-191 (1981).

7. Engineering Times, May 1985, p. 3.

8. Kelleher, D.L., Stover, E.L., and Sullivan, M., "Investigation of Volatile Organics Removal," presented at New England Water Works Association Meeting, Randolph, Massachusetts, Jan. 17, 1980.

9. Symons, J.M., et al., Removal of Organic Contaminants From Drinking Water Using Techniques Other Than GAC Alone, progress report submitted to USEPA, Cincinnati, Ohio, May, 1979.

10. Woodhull, R.S., "Groundwater Contamination in Connecticut," Jour. AWWA, 4, 188-189 (1981).

11. Pakanati, R.R., "Study of Temperature Effects on Air Stripping of Volatile Organics from Water," Master Thesis, Oklahoma State University, Stillwater, Oklahoma (1984).

12. Gosset, J.M., et al., "Mass Transfer Coefficients and Henry's Constant for Packed Tower Air Stripping of Volatile Organics: Measurement and Correlation," Final report to Air Force Engineering and Service Center, Tyndall Air Force Base, Florida, ESL-TR-85-18, June, 1985.

13. Munz, C., and Robert, P.V., "The Ratio of Gas-Phase to Liquid-Phase Mass Transfer Coefficients in Gas-Liquid Contacting Processes," presented at the International Symposium on Gas Transfer at Water Surfaces, June 13-15, 1983.

14. Treybal, R.E., Mass Transfer Operations, 3rd ed., McGraw-Hill Book Co., New York, New York, 1980.

15. Symons, J.M., et al., "Treatment Techniques for Controlling Trihalomethanes in Drinking Water," EPA-600/2-81-156, MERL, USEPA, Cincinnati, Ohio (1981).

16. Robert, P.V., and Dandliker, P.G., "Mass Transfer of Volatile Organic Contaminants from Aqueous Solution to the Atmosphere During Surface Aeration," Envi. Sci. and Tech., 17, 483 (1983).

17. Ball, W.P., Jones, M.D., and Kavanaugh, M.C., "Mass Transfer of Volatile Organic Compounds in Packed Tower Aeration," Jour. AWWA, 56, 113 (1984).

18. Umphres, M.D., et al., "Trihalomethane Removal by Packed-Tower Aeration," Jour. AWWA, 75, 8, 414 (1983).

19. Roberts, P.V., et al., "Evaluating Two Resistance Models for Air Stripping of Volatile Organic Contaminants in a Countercurrent, Packed-Column," Envi. Sci. and Tech., 19, 164 (1985).

20. Roberts, P.V., and Levy, J.A., "Energy Requirements for Air Stripping Trihalomethanes," Jour. AWWA, 29, 138 (1985).

21. Roberts, P.V., Munz, C., and Dandliker, P.D., "Modeling Volatile Organic Solute Removal by Surface and Bubble Aeration," Jour. WPCF, 56, 157 (1984).

22. Knox, R.C., et al., "In-Situ Technologists," State-of-the-Art of Aquifer Restoration, Section VI, (P.O. James McNabb), USEPA, Ada, Oklahoma, EPA 600/2-84-139, August, 1984.

23. Shuka, H.M., and Hicks, R.E., "Process Design Manual for Stripping of Organics," (P.O. Kenneth A. Dostal), USEPA, Cincinnati, Ohio, EPA 600/2-84-139, August, 1984.

24. Hazen, A., Clean Water and How to Get It, John Wiley and Sons, Inc., New York, New York, 1907.

25. USEPA, "Control of Organic Chemical Contaminants in Drinking Water," Federal Reg. 43(28)5756 (1978).

26. USEPA, "National Intern Primary Drinking Water Regulations: Control of THMs in Drinking Water, " Final Rule, Fed. Reg. 44(231) 68624 (1979).

27. USEPA, "National Primary Drinking Water Regulations," Fed. Reg. 40(248)59566 (1975).

28. Federal Resister, Vol. 50, No. 219, Wednesday, November 13, 1985, p. 46902.

29. Weinstein, N.J., "A Successful Underground Water Decontamination System: Its Meaning for Future Projects," presented at the 2nd National Symposium on Aquifer Restoration and Groundwater Monitoring, Columbus, Ohio, May 26-28, 1982.

30. Engelbrecht, R.S., et al., "Diffused Air Stripping of Volatile Waste Components of Petrochemical Wastes," Jour. WPCF, 33, 127-135 (1961).

31. McCarty, P.L., "Volatile Organic Contaminants Removal by Air Stripping," presented at the American Water Works Association Conference, San Francisco, California, June 24, 1979.

32. McKinnor, R.L., "Aeration Plus Carbon Remove Organics from Rockaway Township (N.J.) Groundwater Supply," presented at the Annual Convention of American Society of Civil Engineers, New Orleans, Louisiana, October 25-27, 1982.

33. Gaudy, A.F., et al., "Stripping Kinetics of Volatile Components of Petrochemical Wastes," Jour. WPCF, 33, 382-392 (1961).

34. Dyksen, J.E., "The Use of Aeration to Remove Volatile Organics from Groundwater," presented at the Annual Conference of American Water Works Association, Miami Beach, Florida, May 16-20, 1982.

35. Gosset, J.M., "Solute-Gas Equilibrium in Multiorganic Aqueous Systems," Final report to Air Force Office of Scientific Research, Bolling Air Force Base, Washington, D.C. (1983).

36. Stover, E.L., et al., "Contaminated Groundwater Treatability - A Case Study," Jour. AWWA, 77, 6, 292 (1983).

37. Lamarre, B.L., et al., "Design, Operation and Results of Pilot Plant for Removal of Contaminants from Groundwater," Proceedings of the 3rd National Symposium on Aquifer Restoration and Groundwater Monitoring, Columbus, Ohio, May, 1983.

38. Sullivan, K.M., Johnson, T.E., and Lenzo, F.C., "Pilot Testing and Design of a Modular High-Temperature Air Stripping System," presented at the Purdue Industrial Waste Conference, West Lafayette, Indiana, May 14-16, 1985.

39. Kavanaugh, M.C., and Trussell, R.R., "Design of Aeration Towers to Strip Volatile Contaminants from Drinking Water," Jour. AWWA, 72, 684-692 (1980).

40. Singley, J.E., et al., "Trace Organics Removal by Air Stripping," prepared for the American Water Works Association Research Foundation, May (1980).

40. Singley, J.E., et al., "Trace Organics Removal by Air Stripping," prepared for the American Water Works Association Research Foundation, May (1980).

41. Kavanaugh, M.C., and Trussell, R.R., "Air Stripping as a Treatment Process," proceedings of the American Water Works Association Annual Conference, St. Louis, Missouri, 1981.

42. Roberts, P.V., and Munz, C., "Air-Water Phase Equilibria of Volatile Organic Solutes," Dept. of Civil Engineering, Stanford University, Stanford, California (1987).

43. Lewis, W.K., and Whitman, W.G., "Principles of Gas Absorption," Ind. Eng. Chem, 16, 1215 (1924).

44. Mumford, R.L., and Schnoor, J.L, "Mass Transfer of Volatile Organics in a Packed Bed Stripper," proceedings of the American Water Works Association Annual Conference, Washington, D.C., 1985

45. Dobbins, W.E., "Mechanisms of Gas Absorption by Turbulent Liquids," proceedings International Conference on Water Pollution Research, 2, 61 (1964).

46. Tamir, A., and Merchuk, J., "Effect of Diffusivity on Gas-Liquid Mass Transfer Coefficients," Chem. Eng. Sci., 34, 1077 (1978).

47. Smith, J.H., et al., "Prediction of Volatilization of High-Velocity Chemicals from Natural Water Bodies," Envi. Sci. and Tech., 14, 1332 (1980).

48. Higbie, R., "The Rate of Absorption of a Pure Gas into a Still Liquid During Short Periods of Exposure," Trans. Am. Inst. Chem. Engr., 31, 365 (1935).

49. Danckwerts, P.V., "Significance of Liquid-Film Coefficients in Gas Absorption," Ind. Eng. Chem., 43, 1468 (1951).

50. Atkins, P.W., Physical Chemistry, W.H. Freeman and Company, San Francisco, California, p. 804, 1970.

51. Liss, P., and Slatter, P., "Flux of Gases Across the Air-Sea Interface," Nature, 247, 181 (1974).

52. Sherwood, T., and Holloway, F.A., "Performance of Packed Tower-Liquid Film Data for Several Packings," Trans. Am. Inst. Chem. Engr., 36, 39 (1940).

53. Shulman, H.L., et al., "Performance of Packed Towers - I. Total Static- and Operating-Holdups," AIChE. Jour., 1, 247 (1955).

54. Shulman, H.L., et al., "Performance of Packed Towers - II. Wetted- and Effective-Interfacial Areas, Gas- and Liquid-Phase Mass Transfer Rates," AIChE. Jour., 1, 253 (1955).

55. Riojas, A., et al., "A Two-Resistance Model for Trace Organic Contaminant Stripping in a Packed Column," presented at the American Water Works Association Conference, Las Vegas, Nevada, 1983.

56. Onda, K., Tadeuchi, H., and Gkumoto, Y., "Mass Transfer Coefficients Between Gas and Liquid Phases in Packed Columns," Jour. Chem. Eng. Japan, 1, 56 (1968).

57. Yoshida, E., and Koyanagi, T., "Mass Transfer and Effective-Interfacial Areas in Packed Columns," AIChE. Jour., 8, 309 (1962).

58. Meda, J., et al., "Correlation of Previously Reported Data on Wetted and Effective Interfacial Area in Packed Towers," Kalaku, Kogaku, 2, 111 (1964).

59. Wilke, C.R., and Chang, P., "Correlation of Diffusion Coefficients in Dilute Solutions," AIChE. Jour., 1, 264 (1955).

60. Scheibal, E.G., "Liquid Diffusitivities," Ind. Eng. Chem., 46, 2007 (1954).

61. Othmer, D.F., and Thaker, M.S., "Correlating Diffusivities in Liquids," Ind. Eng. Chem., 45, 589 (1983).

62. Hayduk, W., and Laudie, H., "Predictions of Diffusions Coefficients for Nonelectrolytes in Dilute Aqueous Solutions," AIChE. Jour., 20, 611 (1974).

63. Bird, R.B., "Theory of Diffusion," in Advances in Chemical Engineering, Vol. I, Academic Press, New York, New York, 1956.

64. Gainer, J.L., and Metzner, A.B., American Industrial Chemical Engineer, Industrial Chemical Engineer Symposium Series Number 6, 74 (1965).

65. Lusis, M.A., "Predicting Liquid Diffusion Coefficients," Clinical Processing Engineer, 27 (1971).

66. Chapman, and Enskog, T.G., Mathematical Theory of Non-Uniform Gases, 2nd ed., Cambridge University Press, Chap. 10 and 14, 1951.

67. Bird, R.B., et al., Transport Phenomena, John Wiley and Sons, Inc., New York, New York, 1960.

68. Hirschfelder, J.O., Curtiss, C.F., and Bird, R.B., Molecular Theory of Gases and Liquids, John Wiley and Sons, Inc., New York, New York, 1954.

69. Hirschefelder, J.O., Bird, R.B., and Spotz, E.L., Chem. Revs., 44, 205 (1949).

70. Sherwood, T.K., Pigford, R.L., and Wilke, C.W., Mass Transfer, McGraw-Hill Co., New York, New York, 1975).

71. Perry, R.H., and Chilton, C.H. Chemical Engineer's Handbook, 5th ed., McGraw-Hill Co., New York, New York, 1973.

72. Roberts, P.V., et al., "Volatilization of Trace Organic Contaminants by Air Stripping for Water Reclamation," Technical completion report, No. OWRT/RU-82/11, Dept. of Civil Engineering, Stanford University, Stanford, California, 1982.

73. Umphres, M.D., et al., "Trihalomethane Removal by Packed Tower Aeration," Jour. AWWA, 75, 414 (1983).

74. Singley, J.E., and Billelo, L.J., "Advances in the Development of Design Criteria for Packed Column Aeration," Envi. Sci. and Tech., 14, 1332 (1980).

75. Ball, W.P., et al., "Mass Transfer of Volatile Organic Compounds in Packed Tower Aeration," Jour. WPCF, 56, 127 (1984).

76. Mackay, D., Shiu, W.Y., and Sutherland, R.P., "Determination of Air-Water Henry's Constant for Hydrophobic Pollutants," Envi. Sci. and Tech., 13, 333 (1979).

77. Goldstein, D.J., "Air and Steam Stripping of Toxic Pollutants," Volumes 1 and 2, Industrial Environmental Research Laboratory, USEPA, Cincinnati, Ohio, 68-03-002, May, 1982.

78. Supelco Catalog, p. 13, 1985.

79. Rhodes, J.W., and Nulton, R.W., "Microextraction as an Approach to Analysis for Priority Pollutants," Jour. Sci. Health, A15, 5, 467-484 (1980).

80. Junk, G.A., Ogawa, I., and Svec, H.J., "Extraction of Organic Compounds from Water Using Small Amounts of Solvent," Jour. Sci. Health, A15, 5, 500-512 (1980).

APPENDIXES

APPENDIX A

SOLUTE PROPERTIES AT VARIOUS TEMPERATURES

EFFECTS OF TEMPERATURE ON VISCOSITY, DENSITY,
AND SURFACE TENSION

Parameter	Temperature (°C)					
	5	10	15	25	35	55
Gas Viscosity[1] (10^{-5} kg/m.sec)	1.8381	1.8482	1.8644	1.8965	1.9280	1.9889
Liquid Viscosity[1] (10^{-3} kg/m.sec)	1.5292	1.3192	1.1500	0.8980	0.7230	0.5035
Gas Density[2] (kg/m^3)	1.2709	1.2485	1.2268	1.1857	1.1472	1.0077
Liquid Density[3] (kg/m^3)	989.7	989.7	1000.2	1000.2	994.6	986.7
Surface Tension[4] (kg/sec^2)	0.0749	0.0741	0.0733	0.0718	0.0719	0.0668

[1]"The Properties of Gases and Liquids", Reid et al. (1977).
[2]"Gas Condition and Processing", Campbell (1976).
[3]"Thermal Environmental Engineering", Threlkeld (1970).
[4]"Introduction to Fluid Mechanic and Heat Transfer", Parker (1974).

EFFECTS OF TEMPERATURE ON AIR DIFFUSIVITY

Compound	Diffusivity in Air[1] (m^2/sec x 10^6) Temperature 5°C	15°C	25°C	35°C	55°C
Toluene	6.712	7.118	7.672	8.176	9.284
Chlorobenzene	6.502	6.949	7.419	7.909	8.983
Ethylbenzene	6.079	6.498	6.937	7.395	8.400
Tetrachloroethane	5.880	6.295	6.721	7.167	8.149
1,3-Dichlorobenzene	5.882	6.240	6.660	7.099	8.072
1,2-Dichlorobenzene	5.801	6.216	6.374	7.442	8.051
Nitrobenzene	6.249	6.691	7.149	7.625	8.686
Napthalene	5.599	6.000	6.408	6.836	7.778
1-Chloronapthalene	5.093	5.458	5.832	6.222	7.079
2,6-Dinitrotoluene	5.149	5.523	5.878	6.571	7.168
Fluorene	4.771	5.116	5.467	5.833	6.645
2,4-Dinitrotoluene	5.116	5.488	5.864	6.258	7.129
Hexachlorobenzene	4.242	4.550	4.864	5.191	5.917
Phenanthrene	4.308	4.881	5.216	5.568	6.347
Fluoranthene	4.271	4.582	4.899	5.231	5.963

[1]Estimated using Chapman-Enskog (66).

EFFECTS OF TEMPERATURE ON LIQUID DIFFUSIVITY

Compound	Diffusivity in Water[1] (m^2/sec x 10^{10}) Temperature				
	5°C	15°C	25°C	35°C	55°C
Toluene	5.7857	7.2441	8.9490	12.322	18.842
Chlorobenzene	5.8234	7.2914	9.0076	12.403	18.965
Ethylbenzene	5.2812	6.5336	8.0714	11.114	16.994
Tetrachloroethane	5.3326	6.6767	8.2483	11.357	17.366
1,3-Dichlorobenzene	5.2765	6.6066	8.1616	11.238	17.184
1,2-Dichlorobenzene	5.2765	6.6066	8.1616	11.238	17.184
Nitrobenzene	5.8724	7.3527	9.0833	12.507	19.124
Napthalene	5.9637	6.3400	7.8323	10.784	16.490
1-Chloronapthalene	4.6774	5.8654	7.2349	9.9619	15.233
2,6-Dinitrotoluene	4.8836	6.1146	7.5537	10.401	15.904
Fluorene	4.3815	5.4860	6.7772	9.3316	14.269
2,4-Dinitrotoluene	4.8821	6.1127	7.5515	10.398	15.900
Hexachlorobenzene	3.9701	4.9708	6.1408	8.4553	12.929
Phenanthrene	4.2304	5.2907	6.5434	8.9834	13.777
Fluoranthene	4.0147	5.0267	6.2099	8.5508	13.074

[1]Estimated using Wilke-Chang method (59).

APPENDIX B

THE VALUES OF $\ln (C_i/C_o)$ and $\sum_{i=1}^{i} (\Delta t_i/V_i)$ FOR ALL ORGANIC COMPOUNDS IN THIS STUDY

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR TOLUENE

Time (min)	$\sum_{i=1}^{i} = \frac{\Delta t_i}{V_i}$ ($min/m^3 \times 10^3$)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.2877	-0.0699	-0.0241	-0.0836
3	3.158	-0.3340	-0.2216	-0.3968	-0.5784
5	5.405	-0.4163	-0.3350	-0.7517	-1.9057
10	11.11	-0.4192	-0.9381	-0.9657	-2.4503
15	17.14	-0.9100	-1.2118	-1.2650	-2.7829
20	23.53	-1.0488	-1.5123	-2.6000	-3.1359
30	36.26	-1.5091	-2.6896	-3.4800	-4.2760

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval ($mole/m^3$).
C_o = Initial reactor concentration ($mole/m^3$).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR ETHYLBENZENE

Time (min)	$\sum_{i=1}^{i} = \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0995	-0.0837	-0.0459	-0.3105
3	3.158	-0.2550	-0.1905	-0.6170	-0.5527
5	5.405	-0.4168	-0.2653	-0.6009	-1.2327
10	11.11	-0.6146	-0.9828	-1.3632	-2.0899
15	17.14	-0.8527	-1.2150	-2.1871	-2.6651
20	23.53	-1.2135	-1.6787	-2.6695	-3.3591
30	36.26	-1.7240	-2.553	-3.1377	-4.2018

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR CHLOROBENZENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0686	-0.9050	-0.0640	-0.1286
3	3.158	-0.1228	-0.1042	-0.2660	-0.1105
5	5.405	-0.1782	-0.1686	-0.2986	-1.2823
10	11.11	-0.4361	-0.4399	-0.5476	-1.6506
15	17.14	-0.4982	-0.5152	-0.9248	-2.1855
20	23.53	-0.6763	-0.8252	-1.8159	-2.6205
30	36.26	-1.1620	-1.1680	-2.1101	-3.4677

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR TETRACHLOROETHANE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0110	-0.0020	-0.0120	-0.0912
3	3.158	-0.0220	-0.0250	-0.0340	-0.0582
5	5.405	-0.0149	-0.1600	-0.0320	-0.1985
10	11.11	-0.0493	-0.0459	-0.1244	-0.2031
15	17.14	-0.0742	-0.0914	-0.2008	-0.4000
20	23.53	-0.1378	-0.2227	-0.3171	-0.5143
30	36.26	-0.2002	-0.2514	-0.4002	-0.5611

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR 1,3-DICHLOROBENZENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0520	-0.0356	-0.1355	-0.1481
3	3.158	-0.0840	-0.1133	-0.3959	-0.2500
5	5.405	-0.3400	-0.1331	-0.5311	-0.5216
10	11.11	-0.3962	-0.3778	-1.1470	-0.9924
15	17.14	-0.5656	-0.5723	-1.3600	-1.4168
20	23.53	-0.6371	-0.6866	-1.7656	-1.7125
30	36.26	-0.8297	-1.1972	-1.9997	-2.6417

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR 1,2-DICHLOROBENZENE

Time (min)	$\sum_{i=1}^{i} = \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0423	-0.0385	-0.0614	-0.2094
3	3.158	-0.1048	-0.0656	-0.2573	-0.3120
5	5.405	-0.1902	-0.1706	-0.3746	-0.5796
10	11.11	-0.2829	-0.4291	-0.5634	-1.0157
15	17.14	-0.4581	-0.5568	-0.8878	-1.4994
20	23.53	-0.6129	-0.6027	-1.2130	-1.8390
30	36.26	-0.7728	-1.1972	-1.5438	-2.6167

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR NITROBENZENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0114	-0.0270	-0.0245	-0.0154
3	3.158	-0.0231	-0.0111	-0.0597	-0.0207
5	5.405	-0.0226	-0.0314	-0.0893	-0.0507
10	11.11	-0.0206	-0.0480	-0.0966	-0.0988
15	17.14	-0.0303	-0.0493	-0.1106	-0.1318
20	23.53	-0.0581	-0.0656	-0.1269	-0.1523
30	36.26	-0.0813	-0.0892	-0.1467	-0.1786

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR NAPTHALENE

Time (min)	$\sum_{i=1}^{i} = \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0264	-0.0156	-0.0048	-0.0835
3	3.158	-0.0294	-0.0664	-0.0459	-0.1292
5	5.405	-0.0459	-0.0781	-0.0603	-0.0961
10	11.11	-0.0983	-0.0861	-0.0909	-0.3015
15	17.14	-0.1807	-0.1079	-0.1936	-0.4892
20	23.53	-0.2407	-0.2597	-0.2916	-0.6047
30	36.26	-0.2643	-0.3462	-0.4126	-0.7209

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR 1-CHLORONAPTHALENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ ($min/m^3 \times 10^3$)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	0.0166	-0.0034	-0.0462	-0.0114
3	3.158	-0.0592	-0.0605	-0.0434	-0.0347
5	5.405	-0.0816	-0.0922	-0.0479	-0.1018
10	11.11	-0.0631	-0.0622	-0.0778	-0.2123
15	17.14	-0.0954	-0.0925	-0.1689	-0.3636
20	23.53	-0.2229	-0.1602	-0.2578	-0.5497
30	36.26	-0.2594	-0.3295	-0.3947	-0.6057

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval ($mole/m^3$).
C_o = Initial reactor concentration ($mole/m^3$).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR 2,6-DINITROTOLUENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0039	-0.0588	-0.0434	-0.0397
3	3.158	-0.0340	-0.0341	-0.0303	-0.0563
5	5.405	-0.0196	-0.0654	-0.0370	-0.0247
10	11.11	-0.0566	-0.0814	-0.0544	-0.1027
15	17.14	-0.0881	-0.0897	-0.1276	-0.1385
20	23.53	-0.1084	-0.1182	-0.1893	-0.2023
30	36.26	-0.1673	-0.2001	-0.2302	-0.2678

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR FLUORENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0096	-0.0364	-0.0079	-0.0688
3	3.158	-0.1008	-0.1778	-0.0885	-0.1033
5	5.405	-0.1499	-0.2303	-0.3394	-0.3680
10	11.11	-0.2260	-0.2304	-0.3930	-0.4832
15	17.14	-0.2405	-0.3167	-0.5059	-0.5742
20	23.53	-0.3137	-0.5266	-0.5562	-0.5751
30	36.26	-0.5254	-0.4441	-0.6496	-0.6231

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR 2,4-DINITROTOLUENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0436	-0.0221	-0.0101	-0.0228
3	3.158	-0.0250	-0.0256	-0.0141	-0.0254
5	5.405	-0.0365	-0.0526	-0.0486	-0.0367
10	11.11	-0.0767	-0.0629	-0.0775	-0.1640
15	17.14	-0.0951	-0.0794	-0.1006	-0.1885
20	23.53	-0.1202	-0.1303	-0.1645	-0.2249
30	36.26	-0.1844	-0.1951	-0.2183	-0.2786

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR HEXACHLOROBENZENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0400	-0.0143	-0.1203	-0.0171
3	3.158	-0.0110	-0.0876	-0.2499	-0.0805
5	5.405	-0.0125	-0.1610	-0.3287	-0.2230
10	11.11	-0.0149	-0.2172	-0.5627	-0.6248
15	17.14	-0.1676	-0.5016	-0.6923	-0.9229
20	23.53	-0.3684	-0.4466	-0.7025	-1.1772
30	36.26	-0.5642	-0.6837	-0.8020	-1.6277

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR PHENANTHRENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0135	-0.0285	-0.0296	-0.0155
3	3.158	-0.0133	-0.0378	-0.0320	-0.0199
5	5.405	-0.0441	-0.0620	-0.0160	-0.0228
10	11.11	-0.0606	-0.0867	-0.1016	-0.1184
15	17.14	-0.0857	-0.1016	-0.1485	-0.2052
20	23.53	-0.1125	-0.1236	-0.1950	-0.3014
30	36.26	-0.1328	-0.1650	-0.2813	-0.4085

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

DATA REQUIRED FOR GRAPHICAL DETERMINATION OF
HENRY'S CONSTANT FOR FLUORANTHRENE

Time (min)	$\sum_{i=1}^{i} \frac{\Delta t_i}{V_i}$ (min/m^3 x 10^3)	Natural Log of C_i/C_o at 10°C	25°C	35°C	55°C
1	1.026	-0.0165	-0.0272	-0.0491	-0.0144
3	3.158	-0.0164	-0.0612	-0.0788	-0.0175
5	5.405	-0.0620	-0.0840	-0.0827	-0.0376
10	11.11	-0.0893	-0.1196	-0.1106	-0.1288
15	17.14	-0.0938	-0.1276	-0.1656	-0.2637
20	23.53	-0.1209	-0.1491	-0.2020	-0.3264
30	36.26	-0.1246	-0.1630	-0.2550	-0.4476

Δt_i = Duration of i^{th} interval (min).
V_i = Reactor volume during the i^{th} interval (m^3).
C_i = Concentration at the end of the i^{th} time interval (mole/m^3).
C_o = Initial reactor concentration (mole/m^3).

APPENDIX C

THE EXPERIMENTAL VALUES FOR ALL ORGANIC COMPOUNDS OF PERCENT REMOVAL, HEIGHT TRANSFER UNIT, NUMBER TRANSFER UNIT, AND OVERALL MASS TRANSFER COEFFICIENTS (K_1a) AT ALL COMBINATIONS OF WATER TEMPERATURES, GAS-TO-LIQUID RATIOS, AIR TEMPERATURES AND BED DEPTHS

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 5 °C AIR, 30 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	76.32	1.6671	0.3600	90.13
Chlorobenzene	66.16	1.2750	0.4710	68.91
Ethylbenzene	65.57	1.1870	0.5053	64.18
Tetrachloroethane	19.66	0.2900	0.2060	15.67
1,3-Dichlorobenzene	64.89	1.3080	0.4587	70.70
1,2-Dichlorobenzene	58.16	1.0810	0.5546	58.48
Nitrobenzene	7.14	0.0961	6.2496	5.19
Napthalene	31.17	0.5333	1.1250	28.82
1-Chloronapthalene	30.20	0.5516	1.0880	29.81
2,6-Dinitrotoluene	8.50	0.1013	5.9240	5.47
Fluorene	19.19	0.2350	2.5530	12.70
2,4-Dinitrotoluene	7.56	0.0888	6.7600	4.80
Hexachlorobenzene	19.01	0.2314	2.5920	12.51
Phenanthrene	13.38	0.2017	2.9740	10.90
Fluoranthene	19.08	0.4536	1.3226	24.52

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 5 °C AIR, 90 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	79.12	1.6430	0.3650	30.37
Chlorobenzene	75.75	1.5040	0.3988	27.81
Ethylbenzene	77.73	1.5650	0.3833	28.93
Tetrachloroethane	27.14	0.3546	1.6920	6.55
1,3-Dichlorobenzene	81.84	1.8710	0.3270	34.58
1,2-Dichlorobenzene	79.07	1.7250	0.3478	31.73
Nitrobenzene	7.98	0.0903	6.6450	1.66
Napthalene	57.85	1.0660	0.5626	19.62
1-Chloronapthalene	53.27	0.9149	0.6558	16.91
2,6-Dinitrotoluene	11.68	0.1311	4.5740	2.42
Fluorene	37.75	0.5063	1.1850	9.36
2,4-Dinitrotoluene	14.00	0.1622	3.7000	2.99
Hexachlorobenzene	22.89	0.2694	2.2265	4.98
Phenanthrene	22.61	0.3041	1.9730	5.62
Fluoranthene	20.66	0.2756	2.1770	5.09

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 5 °C AIR, 150 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	85.72	2.0090	0.2986	21.43
Chlorobenzene	84.10	1.9170	0.3131	20.44
Ethylbenzene	80.77	1.6920	0.3546	18.05
Tetrachloroethane	29.54	0.3763	1.5940	4.01
1,3-Dichlorobenzene	82.00	1.8100	0.3315	19.31
1,2-Dichlorobenzene	83.45	1.9140	0.3134	20.42
Nitrobenzene	10.83	0.1217	4.9290	1.30
Napthalene	68.99	1.3592	0.4414	14.50
1-Chloronapthalene	66.40	1.2920	0.4643	13.78
2,6-Dinitrotoluene	15.36	0.1739	3.4510	1.86
Fluorene	42.93	0.5867	1.0230	6.26
2,4-Dinitrotoluene	18.13	0.2109	2.8440	2.25
Hexachlorobenzene	27.76	0.3335	1.8000	3.56
Phenanthrene	26.36	0.3436	1.7460	3.66
Fluoranthene	24.80	0.2937	2.0430	4.00

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 5 °C AIR, 30 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	81.21	2.0130	0.4471	72.53
Ethylbenzene	78.18	1.7070	0.5270	61.50
Tetrachloroethane	29.80	0.5354	1.6810	19.30
1,3-Dichlorobenzene	77.96	1.9350	0.4651	69.72
1,2-Dichlorobenzene	72.69	1.6670	0.5400	60.07
Nitrobenzene	8.94	0.1248	7.2110	4.98
Napthalene	42.00	0.8729	1.0310	31.45
1-Chloronapthalene	43.64	1.0660	0.8470	38.39
2,6-Dinitrotoluene	9.78	0.1186	7.5860	4.28
Fluorene	36.70	0.5537	1.6250	19.95
2,4-Dinitrotoluene	22.57	0.3920	2.2960	14.12
Hexachlorobenzene	41.20	0.6466	1.3920	23.30
Phenanthrene	25.04	0.3167	1.5230	21.29
Fluoranthene	24.48	0.6919	1.3010	24.93

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 15 °C WATER, 5 °C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	-	-	-	-
Chlorobenzene	89.18	2.4040	0.3743	29.63
Ethylbenzene	85.56	2.0330	0.4426	25.06
Tetrachloroethane	31.90	0.4426	2.0330	5.46
1,3-Dichlorobenzene	88.80	2.4340	0.3697	30.00
1,2-Dichlorobenzene	88.06	2.3890	0.3767	29.44
Nitrobenzene	8.42	0.0957	9.4040	1.18
Napthalene	60.19	1.1500	0.7829	14.17
1-Chloronapthalene	59.62	1.1830	0.7608	14.51
2,6-Dinitrotoluene	13.60	0.1558	5.7760	1.92
Fluorene	41.96	0.5865	1.5340	7.28
2,4-Dinitrotoluene	18.50	0.2254	3.9940	2.78
Hexachlorobenzene	38.27	0.5137	1.7520	6.33
Phenanthrene	37.30	0.6458	1.3880	7.99
Fluoranthene	37.22	0.6837	1.3160	8.43

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 5 °C AIR, 150 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.40	3.0950	0.2965	21.58
Ethylbenzene	89.20	2.2950	0.3922	16.32
Tetrachloroethane	39.18	0.5500	1.6370	3.91
1,3-Dichlorobenzene	94.25	3.0630	0.2938	21.88
1,2-Dichlorobenzene	92.54	2.7970	0.3217	19.89
Nitrobenzene	17.49	0.1942	4.6340	1.38
Napthalene	66.77	1.2700	0.7086	9.03
1-Chloronapthalene	65.73	1.2660	0.7110	4.10
2,6-Dinitrotoluene	18.24	0.2123	4.2390	1.51
Fluorene	48.79	0.7049	1.2769	5.01
2,4-Dinitrotoluene	22.89	0.2792	3.2240	1.99
Hexachlorobenzene	40.22	0.5351	1.6820	3.81
Phenanthrene	45.19	0.7532	1.1949	5.36
Fluoranthene	37.06	0.5658	1.5970	4.02

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 5 °C AIR, 30 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	87.00	2.6250	0.4572	70.74
Ethylbenzene	81.55	1.9500	0.6154	52.69
Tetrachloroethane	27.91	0.5197	2.3090	14.04
1,3-Dichlorobenzene	82.36	2.4070	0.4986	65.04
1,2-Dichlorobenzene	78.30	2.1510	0.5578	58.14
Nitrobenzene	9.21	0.1345	8.9190	3.64
Napthalene	45.53	1.1870	1.0110	32.07
1-Chloronapthalene	43.39	0.2444	4.9090	6.61
2,6-Dinitrotoluene	17.97	0.2743	4.3740	7.41
Fluorene	34.26	0.5116	2.3450	13.83
2,4-Dinitrotoluene	17.46	0.2673	4.4890	7.22
Hexachlorobenzene	41.13	0.6504	1.8450	17.58
Phenanthrene	22.75	0.6220	1.9290	16.81
Fluoranthene	20.28	0.5460	2.1970	14.76

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 5°C AIR, 90 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	86.64	2.1680	0.5535	20.03
Ethylbenzene	87.88	2.2190	0.5470	20.51
Tetrachloroethane	30.68	0.4186	2.8670	3.87
1,3-Dichlorobenzene	89.11	2.4670	0.4863	22.80
1,2-Dichlorobenzene	86.47	2.2400	0.5357	20.70
Nitrobenzene	11.40	0.1364	8.7950	1.26
Napthalene	61.25	1.1780	1.0190	10.88
1-Chloronapthalene	60.93	1.2370	0.9699	11.43
2,6-Dinitrotoluene	16.50	0.1962	6.1190	1.81
Fluorene	43.77	0.6227	1.9270	5.77
2,4-Dinitrotoluene	20.87	0.2617	4.5840	2.42
Hexachlorobenzene	40.70	0.5588	2.1470	5.16
Phenanthrene	37.88	0.6664	1.8000	6.16
Fluoranthene	37.56	0.6958	1.7240	6.43

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 5°C AIR, 150 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	96.01	3.4240	0.3504	18.26
Ethylbenzene	90.38	2.4150	0.4968	12.88
Tetrachloroethane	41.40	0.5970	2.0180	3.17
1,3-Dichlorobenzene	94.53	3.1170	0.3848	16.63
1,2-Dichlorobenzene	92.70	2.8220	0.4252	15.05
Nitrobenzene	18.24	0.2255	5.3320	1.20
Napthalene	71.21	1.4550	0.8246	7.76
1-Chloronapthalene	67.28	1.3280	0.9037	7.08
2,6-Dinitrotoluene	22.72	0.2758	4.3510	1.47
Fluorene	49.41	0.7189	1.6690	3.83
2,4-Dinitrotoluene	25.90	0.3247	3.6950	1.73
Hexachlorobenzene	39.61	0.5242	2.2890	2.80
Phenanthrene	45.88	0.7723	1.5536	4.12
Fluoranthene	43.49	0.7303	1.6430	3.90

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15 °C WATER, 15 °C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	77.60	1.7000	0.3528	91.91
Chlorobenzene	72.94	1.5280	0.3927	82.58
Ethylbenzene	70.71	1.3550	0.4427	73.26
Tetrachloroethane	27.85	0.4747	1.2680	25.66
1,3-Dichlorobenzene	68.15	1.3980	0.4293	75.55
1,2-Dichlorobenzene	67.68	1.4140	0.4243	76.42
Nitrobenzene	12.30	0.2055	2.9190	11.11
Napthalene	44.96	1.0137	0.5919	54.79
1-Chloronapthalene	43.45	1.0580	0.5694	56.96
2,6-Dinitrotoluene	8.89	0.1058	5.6730	5.72
Fluorene	31.92	0.4156	1.3280	24.40
2,4-Dinitrotoluene	11.37	0.1436	4.1800	7.76
Hexachlorobenzene	22.13	0.2747	2.1839	14.85
Phenanthrene	19.72	0.3544	1.6930	19.16
Fluoranthene	22.85	0.5549	1.0810	30.00

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 15 °C AIR, 90 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	84.41	1.9460	0.3084	35.96
Chlorobenzene	76.30	1.5160	0.3960	28.01
Ethylbenzene	77.89	1.5660	0.3836	28.91
Tetrachloroethane	32.47	0.4429	1.3546	8.19
1,3-Dichlorobenzene	81.72	1.8380	0.3264	33.97
1,2-Dichlorobenzene	79.32	1.7130	0.3502	31.67
Nitrobenzene	15.91	0.2023	2.9657	3.79
Napthalene	60.43	1.1245	0.5336	20.78
1-Chloronapthalene	59.29	1.1174	0.5370	20.65
2,6-Dinitrotoluene	12.90	0.1465	4.0965	2.71
Fluorene	40.63	0.5561	1.0790	10.28
2,4-Dinitrotoluene	15.14	0.1763	3.4040	3.26
Hexachlorobenzene	28.60	0.3507	1.7120	6.48
Phenanthrene	25.05	0.3382	1.7740	6.25
Fluoranthene	26.25	0.3684	1.6290	6.81

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 15 °C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	90.10	2.4160	0.2483	25.77
Chlorobenzene	85.37	2.0020	0.3000	21.35
Ethylbenzene	83.68	1.8530	0.3234	19.77
Tetrachloroethane	40.70	0.5717	1.0490	6.10
1,3-Dichlorobenzene	83.12	1.8650	0.3217	19.89
1,2-Dichlorobenzene	82.18	1.8130	0.3310	19.36
Nitrobenzene	16.00	0.1900	3.1570	2.03
Napthalene	68.67	1.3211	0.4542	14.09
1-Chloronapthalene	66.34	1.2960	0.4631	13.82
2,6-Dinitrotoluene	15.38	0.1741	3.4450	1.86
Fluorene	43.82	0.6009	0.9980	6.41
2,4-Dinitrotoluene	18.82	0.2197	2.7300	2.34
Hexachlorobenzene	35.19	0.4466	1.3440	4.76
Phenanthrene	30.26	0.4033	4.3026	4.30
Fluoranthene	29.43	0.3938	1.5240	4.20

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 15 °C AIR, 30 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	80.82	2.0590	0.4370	74.20
Ethylbenzene	78.95	1.7850	0.5042	64.32
Tetrachloroethane	30.20	0.6100	1.4750	21.98
1,3-Dichlorobenzene	77.19	1.9790	0.4547	71.31
1,2-Dichlorobenzene	72.81	1.7630	0.5105	63.53
Nitrobenzene	7.23	0.0960	6.2490	5.19
Napthalene	42.20	0.9775	0.9207	35.22
1-Chloronapthalene	41.19	1.1190	0.8041	40.32
2,6-Dinitrotoluene	9.50	0.1157	7.7770	4.17
Fluorene	31.97	0.4624	1.9460	16.66
2,4-Dinitrotoluene	14.67	0.2060	4.3690	7.23
Hexachlorobenzene	31.81	0.4523	1.9900	16.30
Phenanthrene	21.16	0.4987	1.8050	17.97
Fluoranthene	21.36	0.6756	1.3320	24.34

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 15 °C AIR, 90 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	92.66	2.8040	0.3209	34.56
Ethylbenzene	88.14	2.2270	0.4040	27.44
Tetrachloroethane	38.67	0.5659	1.5900	6.97
1,3-Dichlorobenzene	92.04	2.7880	0.3228	34.35
1,2-Dichlorobenzene	90.55	2.6200	0.3435	32.28
Nitrobenzene	15.65	0.1981	4.5440	2.44
Napthalene	71.45	1.6040	0.5612	19.76
1-Chloronapthalene	65.90	1.3870	0.6491	17.09
2,6-Dinitrotoluene	16.85	0.2000	4.5100	2.46
Fluorene	46.52	0.6751	1.3333	8.32
2,4-Dinitrotoluene	28.42	0.3866	2.3270	4.77
Hexachlorobenzene	41.60	0.5709	1.5760	7.04
Phenanthrene	42.40	0.7560	1.1905	9.32
Fluoranthene	40.36	0.7231	1.2440	8.91

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15 °C WATER, 15°C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.52	3.0340	0.2966	21.58
Ethylbenzene	89.46	2.3110	0.3895	16.43
Tetrachloroethane	56.13	0.9473	0.9500	6.74
1,3-Dichlorobenzene	94.41	3.0620	0.2939	21.78
1,2-Dichlorobenzene	92.64	2.7820	0.3235	19.78
Nitrobenzene	19.71	0.2455	3.6650	1.76
Napthalene	79.30	1.8490	0.4869	13.14
1-Chloronapthalene	78.18	1.8230	0.4936	12.97
2,6-Dinitrotoluene	18.79	0.2192	4.1060	1.56
Fluorene	61.67	1.0120	0.8814	7.26
2,4-Dinitrotoluene	33.29	0.4480	2.0090	3.19
Hexachlorobenzene	44.80	0.6174	1.4580	4.39
Phenanthrene	51.92	0.9132	0.9855	6.49
Fluoranthene	48.12	0.8317	1.0820	5.91

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 15 °C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	84.64	2.2870	0.5247	61.80
Ethylbenzene	88.80	2.4370	0.4924	65.86
Tetrachloroethane	47.35	2.3860	0.5030	14.49
1,3-Dichlorobenzene	82.00	2.2431	0.5350	60.62
1,2-Dichlorobenzene	79.88	2.1480	0.5587	58.04
Nitrobenzene	10.76	0.1648	7.2810	4.45
Napthalene	51.76	1.4553	0.8245	39.33
1-Chloronapthalene	48.25	1.4370	0.8351	38.83
2,6-Dinitrotoluene	22.22	0.3770	3.1830	10.19
Fluorene	47.98	0.8581	1.3980	23.19
2,4-Dinitrotoluene	25.65	0.5009	2.3960	13.53
Hexachlorobenzene	41.08	0.6436	1.8640	17.39
Phenanthrene	24.36	0.5636	2.1290	15.23
Fluoranthene	26.00	0.8947	1.3410	24.18

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15 °C WATER, 15 °C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	90.66	2.5380	0.4729	23.45
Ethylbenzene	91.35	2.5650	0.4680	23.70
Tetrachloroethane	50.23	0.8590	1.3970	7.94
1,3-Dichlorobenzene	91.39	2.7000	0.4448	24.93
1,2-Dichlorobenzene	89.80	2.5310	0.4741	23.39
Nitrobenzene	20.00	0.2752	4.3610	2.53
Napthalene	66.07	1.3460	0.8920	12.44
1-Chloronapthalene	65.67	1.3760	0.8720	12.72
2,6-Dinitrotoluene	23.07	0.2934	4.0900	2.71
Fluorene	50.88	0.7734	1.5520	7.15
2,4-Dinitrotoluene	25.19	0.3420	3.5090	3.16
Hexachlorobenzene	44.00	0.6180	1.9420	5.71
Phenanthrene	40.01	0.6832	1.7560	6.31
Fluoranthene	39.97	0.7110	1.6880	6.57

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 15 °C AIR, 150 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	95.19	3.1720	0.3782	16.92
Ethylbenzene	93.91	2.8820	0.4164	15.37
Tetrachloroethane	56.50	0.9531	1.2590	5.08
1,3-Dichlorobenzene	95.27	3.2440	0.3700	17.30
1,2-Dichlorobenzene	93.39	2.9000	0.4139	15.47
Nitrobenzene	20.10	0.2517	4.7680	1.34
Napthalene	80.00	1.8930	0.6338	10.10
1-Chloronapthalene	77.36	1.7740	0.6760	9.42
2,6-Dinitrotoluene	23.74	0.2897	4.1420	1.54
Fluorene	60.17	0.9776	1.2280	5.22
2,4-Dinitrotoluene	31.25	0.4110	2.9190	2.19
Hexachlorobenzene	44.41	0.6098	1.9680	3.25
Phenanthrene	53.29	0.9568	1.2540	5.10
Fluoranthene	50.52	0.8883	1.3509	4.77

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 25 °C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	85.15	2.1680	0.2767	117.20
Chlorobenzene	75.04	1.5910	0.3771	86.00
Ethylbenzene	71.54	1.3700	0.4378	74.07
Tetrachloroethane	33.60	0.6156	0.9747	33.27
1,3-Dichlorobenzene	69.40	1.4100	0.4260	76.18
1,2-Dichlorobenzene	67.95	1.3760	0.4360	74.39
Nitrobenzene	14.54	0.2613	2.2960	14.12
Napthalene	47.70	1.0545	0.5689	57.00
1-Chloronapthalene	45.78	1.0590	0.5664	57.26
2,6-Dinitrotoluene	11.74	0.1471	4.0770	7.95
Fluorene	31.77	0.4418	1.3580	23.88
2,4-Dinitrotoluene	11.27	0.1399	4.2890	7.56
Hexachlorobenzene	29.07	0.3837	1.5640	20.74
Phenanthrene	25.60	0.5217	1.1500	28.20
Fluoranthene	26.85	0.6559	0.9147	35.35

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 25°C AIR, 90 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	91.47	2.5770	0.2328	47.63
Chlorobenzene	79.64	1.6680	0.3596	30.83
Ethylbenzene	78.34	1.5780	0.3801	29.18
Tetrachloroethane	34.01	0.4635	1.2945	8.57
1,3-Dichlorobenzene	84.17	1.9770	0.3030	36.55
1,2-Dichlorobenzene	83.80	1.9680	0.3048	36.38
Nitrobenzene	16.33	0.2056	2.9180	3.80
Napthalene	64.28	1.2370	0.4849	22.87
1-Chloronapthalene	64.15	1.2660	0.4739	23.40
2,6-Dinitrotoluene	14.97	0.1730	3.4690	3.19
Fluorene	42.30	0.5841	1.0270	10.80
2,4-Dinitrotoluene	17.83	0.2124	2.8240	3.93
Hexachlorobenzene	33.12	0.4185	1.4335	7.74
Phenanthrene	27.14	0.3716	1.6146	6.87
Fluoranthene	27.00	0.3696	1.6230	6.83

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15 °C WATER, 25 °C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	94.13	2.9190	0.2055	31.13
Chlorobenzene	85.52	1.9140	0.3135	20.42
Ethylbenzene	83.14	1.8170	0.3302	19.38
Tetrachloroethane	83.14	0.6231	0.9628	6.00
1,3-Dichlorobenzene	86.75	2.1110	0.2842	22.52
1,2-Dichlorobenzene	86.07	2.0680	0.2401	22.06
Nitrobenzene	21.60	0.2727	2.2000	2.91
Napthalene	70.30	1.3650	0.4394	14.56
1-Chloronapthalene	68.11	1.2990	0.4619	13.86
2,6-Dinitrotoluene	22.09	0.2640	2.2730	2.82
Fluorene	47.02	0.6616	0.9068	7.06
2,4-Dinitrotoluene	31.82	0.4185	1.4340	4.46
Hexachlorobenzene	41.94	0.3920	1.5300	4.18
Phenanthrene	31.57	0.4185	1.4340	4.46
Fluoranthene	23.91	0.2956	2.2090	3.15

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15 °C WATER, 25 °C AIR, 30 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	79.79	1.8580	0.4843	66.95
Ethylbenzene	78.01	1.6710	0.5378	60.20
Tetrachloroethane	33.56	0.6140	1.4660	22.13
1,3-Dichlorobenzene	77.22	1.8140	0.4962	65.36
1,2-Dichlorobenzene	72.04	1.5680	0.5740	56.50
Nitrobenzene	15.44	0.2964	3.0360	10.68
Napthalene	43.01	0.8492	1.0500	30.60
1-Chloronapthalene	44.49	0.9929	0.9064	35.78
2,6-Dinitrotoluene	16.01	0.2222	4.0500	8.01
Fluorene	35.30	0.5119	1.7580	18.44
2,4-Dinitrotoluene	24.92	0.4470	2.0130	16.11
Hexachlorobenzene	44.23	0.7018	1.2820	25.29
Phenanthrene	30.36	0.8085	1.1131	29.13
Fluoranthene	28.15	0.7572	1.1886	27.28

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 15°C WATER, 25°C AIR, 90 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	92.89	2.8090	0.3290	34.61
Ethylbenzene	89.42	2.3350	0.3854	28.78
Tetrachloroethane	47.49	0.7593	1.1850	9.36
1,3-Dichlorobenzene	92.21	2.7740	0.3244	34.18
1,2-Dichlorobenzene	91.25	2.6690	0.3372	32.88
Nitrobenzene	15.74	0.1967	4.5740	2.42
Napthalene	72.14	1.5880	0.5667	19.57
1-Chloronapthalene	66.39	1.3610	0.6651	16.76
2,6-Dinitrotoluene	15.70	0.1830	4.9280	2.25
Fluorene	35.17	0.4548	1.9790	5.60
2,4-Dinitrotoluene	25.24	0.3271	2.7510	4.03
Hexachlorobenzene	46.55	0.6645	1.3540	8.19
Phenanthrene	43.70	0.7496	1.2010	9.23
Fluoranthene	44.56	0.7981	1.1280	9.84

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 25 °C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	95.65	3.2590	0.2761	23.17
Ethylbenzene	92.48	2.6520	0.3393	18.86
Tetrachloroethane	58.20	0.9841	0.9145	7.00
1,3-Dichlorobenzene	95.19	3.1990	0.2814	22.75
1,2-Dichlorobenzene	94.66	3.1050	0.2900	22.08
Nitrobenzene	20.61	0.2571	3.5010	1.83
Napthalene	82.39	2.0170	0.4460	14.34
1-Chloronapthalene	80.50	1.9270	0.4670	13.70
2,6-Dinitrotoluene	19.14	0.2235	4.0270	1.60
Fluorene	61.71	1.0150	0.8864	7.22
2,4-Dinitrotoluene	32.31	2.0790	0.4261	3.03
Hexachlorobenzene	45.76	0.6301	1.4210	4.50
Phenanthrene	50.24	0.8310	1.0830	5.91
Fluoranthene	49.14	0.8157	1.1030	5.80

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15°C WATER, 25°C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	93.54	3.3550	0.3578	90.66
Ethylbenzene	96.57	3.9090	0.3069	105.60
Tetrachloroethane	40.03	0.8805	1.3630	23.79
1,3-Dichlorobenzene	95.62	4.2730	0.2809	115.50
1,2-Dichlorobenzene	94.38	3.0490	0.3935	82.41
Nitrobenzene	20.40	0.6840	1.7540	18.49
Napthalene	63.98	2.4660	0.4866	66.64
1-Chloronapthalene	61.50	2.7970	0.4291	75.58
2,6-Dinitrotoluene	27.03	0.5211	2.3030	14.08
Fluorene	56.76	1.1350	1.0570	30.68
2,4-Dinitrotoluene	29.59	0.6344	1.8910	17.15
Hexachlorobenzene	47.85	0.7986	1.5030	21.58
Phenanthrene	30.46	0.8166	1.4690	22.07
Fluoranthene	30.08	0.9653	1.2430	26.09

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 15 °C WATER, 25 °C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.95	3.1820	0.3770	29.42
Ethylbenzene	93.97	2.9320	0.4093	27.09
Tetrachloroethane	54.78	0.9678	1.2400	8.95
1,3-Dichlorobenzene	93.66	3.0060	0.3991	27.78
1,2-Dichlorobenzene	94.02	3.1050	0.3865	28.69
Nitrobenzene	20.52	0.2771	4.3310	2.56
Napthalene	75.69	1.7870	0.6713	16.51
1-Chloronapthalene	73.34	1.7100	0.7016	15.81
2,6-Dinitrotoluene	26.02	0.3401	3.5280	3.14
Fluorene	56.38	0.9039	1.3270	8.35
2,4-Dinitrotoluene	31.77	0.4457	2.6930	4.12
Hexachlorobenzene	48.32	0.7021	1.7090	6.49
Phenanthrene	43.30	0.7384	1.6250	6.82
Fluoranthene	44.07	0.7862	1.5260	7.27

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 15°C WATER, 25°C AIR, 150 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.77	3.0640	0.3916	16.34
Ethylbenzene	94.06	2.8970	0.4142	15.45
Tetrachloroethane	58.31	0.9882	1.2140	5.27
1,3-Dichlorobenzene	95.03	3.1610	0.3794	16.87
1,2-Dichlorobenzene	95.01	3.1780	0.3776	16.95
Nitrobenzene	25.62	0.3389	3.5400	1.80
Napthalene	81.67	1.9660	0.6104	10.48
1-Chloronapthalene	81.39	1.9880	0.6036	10.60
2,6-Dinitrotoluene	33.10	0.4404	2.7240	2.35
Fluorene	62.08	1.0260	1.1700	5.47
2,4-Dinitrotoluene	33.36	0.4445	2.7000	2.37
Hexachlorobenzene	52.61	0.7773	1.5440	4.14
Phenanthrene	56.76	1.0290	1.1660	5.49
Fluoranthene	51.06	0.8705	1.3780	4.64

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 35°C WATER, 5 °C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	92.92	3.0820	1.9470	166.60
Chlorobenzene	88.10	2.5440	0.2358	137.50
Ethylbenzene	90.21	2.6340	0.2277	142.40
Tetrachloroethane	52.29	1.9440	0.3086	105.10
1,3-Dichlorobenzene	86.31	2.5460	0.2356	137.60
1,2-Dichlorobenzene	86.57	2.6640	0.2252	144.00
Nitrobenzene	20.26	0.6620	0.9063	35.78
Napthalene	65.68	2.7510	0.2180	148.70
1-Chloronapthalene	63.10	3.2290	0.1857	174.50
2,6-Dinitrotoluene	11.89	0.1496	4.0100	8.09
Fluorene	39.31	0.6007	0.9988	32.47
2,4-Dinitrotoluene	12.78	0.1646	3.6440	8.99
Hexachlorobenzene	26.86	0.3458	1.7350	18.69
Phenanthrene	22.04	0.3863	1.5530	20.88
Fluoranthene	21.91	0.4107	1.4606	22.20

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 5°C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	94.96	3.1400	0.1910	58.04
Chlorobenzene	89.99	2.4380	0.2461	45.05
Ethylbenzene	92.32	2.6750	0.2243	49.44
Tetrachloroethane	76.16	1.9850	0.3023	36.68
1,3-Dichlorobenzene	90.32	2.5290	0.2372	46.74
1,2-Dichlorobenzene	88.33	2.3400	0.2563	43.25
Nitrobenzene	29.50	0.4715	1.2720	8.71
Napthalene	83.50	2.3760	0.2525	43.92
1-Chloronapthalene	83.10	2.4450	0.2454	45.18
2,6-Dinitrotoluene	12.30	0.1381	4.3450	2.55
Fluorene	58.47	0.9611	0.6242	17.76
2,4-Dinitrotoluene	22.41	0.2810	2.1350	5.19
Hexachlorobenzene	25.05	0.2968	2.0210	5.49
Phenanthrene	32.96	0.4812	1.2468	8.90
Fluoranthene	24.26	0.3197	1.9000	5.91

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 5 °C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	98.85	4.6190	0.1300	49.26
Chlorobenzene	92.79	2.7250	0.2200	29.70
Ethylbenzene	94.18	2.9180	0.2056	31.12
Tetrachloroethane	80.94	2.0130	0.2981	21.47
1,3-Dichlorobenzene	91.72	2.6150	0.2295	27.89
1,2-Dichlorobenzene	90.33	2.4610	0.2437	26.26
Nitrobenzene	31.98	0.4607	1.3020	4.91
Napthalene	87.75	2.4810	0.2481	26.46
1-Chloronapthalene	86.54	2.3690	0.2534	25.26
2,6-Dinitrotoluene	21.63	0.2579	2.3260	2.75
Fluorene	60.96	0.9936	0.6039	10.60
2,4-Dinitrotoluene	20.19	0.2377	2.5240	2.54
Hexachlorobenzene	38.97	0.5083	1.1800	5.42
Phenanthrene	36.73	0.5155	1.1640	5.50
Fluoranthene	30.01	0.3956	1.5160	4.22

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 35°C WATER, 5°C AIR, 30 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.67	3.6120	0.2491	130.20
Ethylbenzene	92.38	2.9370	0.3064	105.80
Tetrachloroethane	56.07	2.7900	0.3225	100.54
1,3-Dichlorobenzene	93.86	3.7530	0.2398	135.20
1,2-Dichlorobenzene	93.09	3.7210	0.2419	134.07
Nitrobenzene	20.97	0.8126	1.1070	29.28
Napthalene	70.52	3.9860	0.2258	143.64
1-Chloronapthalene	64.60	3.7780	0.2381	136.10
2,6-Dinitrotoluene	17.30	0.2472	3.6400	8.90
Fluorene	40.08	0.2037	4.4170	33.44
2,4-Dinitrotoluene	24.56	0.4358	2.0650	15.70
Hexachlorobenzene	32.12	0.4385	2.0520	15.80
Phenanthrene	28.80	0.6920	1.3006	24.93
Fluoranthene	27.13	0.6746	1.3340	24.31

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 5 °C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.75	4.0680	0.2212	50.13
Ethylbenzene	95.78	3.3120	0.2718	40.81
Tetrachloroethane	79.50	2.2500	0.4000	27.72
1,3-Dichlorobenzene	98.27	4.4810	0.2009	55.21
1,2-Dichlorobenzene	97.85	4.2830	0.2101	52.78
Nitrobenzene	34.47	0.6149	1.4640	7.58
Napthalene	93.51	3.8860	0.2316	47.88
1-Chloronapthalene	93.00	3.9870	0.2257	49.13
2,6-Dinitrotoluene	23.50	0.2979	3.6710	3.67
Fluorene	58.58	0.9640	0.9336	11.88
2,4-Dinitrotoluene	33.29	0.4767	1.8880	5.87
Hexachlorobenzene	46.36	0.6604	1.3630	8.14
Phenanthrene	36.00	0.5489	1.6390	6.76
Fluoranthene	36.87	0.5830	1.5430	7.18

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 5°C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.76	4.5830	0.3270	19.55
Ethylbenzene	96.52	3.4510	0.3477	18.40
Tetrachloroethane	80.24	1.9640	0.6110	10.47
1,3-Dichlorobenzene	98.59	4.5200	0.2655	24.11
1,2-Dichlorobenzene	97.84	4.0880	0.2936	21.80
Nitrobenzene	41.20	0.6805	1.7630	3.63
Napthalene	95.54	3.8050	0.3154	20.29
1-Chloronapthalene	94.66	3.6730	0.3267	19.59
2,6-Dinitrotoluene	31.82	0.4180	2.8700	2.30
Fluorene	63.05	1.0540	1.1380	5.62
2,4-Dinitrotoluene	34.64	0.4682	2.5630	2.50
Hexachlorobenzene	51.94	0.7624	1.5740	4.07
Phenanthrene	39.30	0.5671	2.1160	3.02
Fluoranthene	40.72	0.6064	1.9790	3.23

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 5 °C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	96.53	4.1910	0.2863	113.30
Ethylbenzene	93.67	3.1620	0.3794	85.46
Tetrachloroethane	58.10	3.7260	0.3221	100.70
1,3-Dichlorobenzene	94.05	3.9220	0.3056	106.00
1,2-Dichlorobenzene	94.84	4.1970	0.2859	113.40
Nitrobenzene	21.06	0.8515	1.4090	23.01
Napthalene	71.00	4.1630	0.2882	112.50
1-Chloronapthalene	65.40	4.1600	0.2884	112.40
2,6-Dinitrotoluene	28.50	0.5861	2.0470	15.84
Fluorene	41.00	0.6452	1.8600	17.44
2,4-Dinitrotoluene	28.53	0.5873	2.0430	15.87
Hexachlorobenzene	41.70	0.6390	1.8760	17.29
Phenanthrene	30.11	0.7887	1.5210	21.31
Fluoranthene	30.55	1.0380	1.1560	28.05

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 35°C WATER, 5°C AIR, 90 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.87	4.8240	0.2487	44.58
Ethylbenzene	99.06	4.9110	0.2443	45.39
Tetrachloroethane	87.52	3.1760	0.3778	29.35
1,3-Dichlorobenzene	98.44	4.5980	0.2610	42.50
1,2-Dichlorobenzene	98.66	4.8300	0.2484	44.64
Nitrobenzene	37.08	0.7038	1.7050	6.50
Napthalene	94.26	4.0900	0.2933	37.80
1-Chloronapthalene	93.10	4.0120	0.3000	37.08
2,6-Dinitrotoluene	35.57	0.5235	2.2920	4.84
Fluorene	63.90	1.1260	1.0650	10.41
2,4-Dinitrotoluene	35.75	0.5273	2.2750	4.87
Hexachlorobenzene	49.44	0.9336	1.2810	8.66
Phenanthrene	36.24	0.5537	2.1670	5.12
Fluoranthene	38.68	0.6298	1.9050	5.82

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 5 °C AIR, 150 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.95	4.7590	0.2521	25.38
Ethylbenzene	98.66	4.4420	0.2701	23.69
Tetrachloroethane	95.92	4.2140	0.2847	22.47
1,3-Dichlorobenzene	99.10	5.0050	0.2398	26.69
1,2-Dichlorobenzene	99.15	5.1020	0.2352	27.21
Nitrobenzene	44.19	0.7659	1.5670	4.09
Napthalene	95.72	3.8590	0.3109	20.58
1-Chloronapthalene	95.46	3.8970	0.3080	20.78
2,6-Dinitrotoluene	36.00	0.4938	2.4300	2.63
Fluorene	64.52	1.0990	1.0920	5.86
2,4-Dinitrotoluene	42.22	0.6197	1.9360	3.31
Hexachlorobenzene	52.44	0.7737	1.5510	4.13
Phenanthrene	43.12	0.6512	1.8430	3.47
Fluoranthene	41.92	0.6336	1.8940	3.38

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15°C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	96.56	3.8970	0.1353	210.60
Chlorobenzene	89.12	2.5870	0.2319	139.80
Ethylbenzene	91.04	2.6950	0.2227	145.60
Tetrachloroethane	64.56	3.8540	0.1557	208.30
1,3-Dichlorobenzene	87.80	2.6820	0.2236	145.00
1,2-Dichlorobenzene	86.99	2.7290	0.2198	147.50
Nitrobenzene	22.42	0.7860	0.7634	42.48
Napthalene	78.14	5.0420	0.1190	272.50
1-Chloronapthalene	74.54	6.3280	0.0948	342.10
2,6-Dinitrotoluene	18.97	0.2775	2.1620	15.00
Fluorene	44.28	0.7079	0.8476	38.26
2,4-Dinitrotoluene	14.79	0.1958	3.0630	10.59
Hexachlorobenzene	28.87	0.3747	1.6011	20.25
Phenanthrene	35.03	0.9456	0.6345	51.11
Fluoranthene	28.00	0.5873	1.0210	31.74

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15 °C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	97.75	3.9780	0.1508	73.53
Chlorobenzene	91.77	2.6270	0.2283	48.56
Ethylbenzene	94.25	2.9660	0.2022	54.82
Tetrachloroethane	77.67	1.9920	0.3012	36.82
1,3-Dichlorobenzene	90.97	2.5780	0.2327	47.65
1,2-Dichlorobenzene	87.50	2.2360	0.2684	41.32
Nitrobenzene	28.41	0.4315	1.3910	7.98
Napthalene	85.47	2.4810	0.2418	45.86
1-Chloronapthalene	84.10	2.4360	0.2463	45.02
2,6-Dinitrotoluene	23.93	0.3034	1.9780	5.61
Fluorene	56.18	0.8906	0.6737	16.46
2,4-Dinitrotoluene	24.69	0.3150	1.9050	5.82
Hexachlorobenzene	38.69	0.5100	1.1770	9.42
Phenanthrene	35.07	0.5097	1.1770	9.42
Fluoranthene	28.71	0.3904	1.5370	7.22

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 15 °C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	98.93	4.6760	0.1283	49.88
Chlorobenzene	95.10	3.1160	0.1926	33.23
Ethylbenzene	95.01	3.0670	0.1956	32.72
Tetrachloroethane	81.57	2.0026	0.2996	21.36
1,3-Dichlorobenzene	93.57	2.8880	0.2077	30.81
1,2-Dichlorobenzene	95.53	3.2710	0.1834	34.89
Nitrobenzene	29.19	0.3986	1.5050	4.25
Napthalene	89.20	2.5900	0.2316	27.63
1-Chloronapthalene	87.80	2.4870	0.2414	26.53
2,6-Dinitrotoluene	23.70	0.2872	2.0890	3.06
Fluorene	63.03	1.0480	0.5726	11.18
2,4-Dinitrotoluene	23.62	0.2852	2.1030	3.04
Hexachlorobenzene	41.68	0.5541	1.0830	5.91
Phenanthrene	42.70	0.6270	0.9569	6.69
Fluoranthene	31.60	0.4159	1.4430	4.44

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15°C AIR, 30 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	93.13	3.1710	0.2838	114.30
Ethylbenzene	93.50	3.1380	0.1912	169.70
Tetrachloroethane	66.06	4.7120	0.1910	169.80
1,3-Dichlorobenzene	94.81	3.8240	0.2353	137.80
1,2-Dichlorobenzene	93.89	3.7140	0.2423	133.80
Nitrobenzene	23.07	0.9595	0.9380	34.57
Napthalene	80.36	6.2130	0.1448	223.90
1-Chloronapthalene	74.81	6.5940	0.1364	237.60
2,6-Dinitrotoluene	19.97	0.3000	3.0090	10.78
Fluorene	44.72	0.7190	1.2520	25.91
2,4-Dinitrotoluene	29.68	0.5959	1.5100	21.47
Hexachlorobenzene	35.29	0.4905	1.8350	17.68
Phenanthrene	36.60	1.0920	0.8241	39.35
Fluoranthene	32.81	0.8869	1.0150	31.96

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15 °C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.37	4.3760	0.2056	53.92
Ethylbenzene	96.49	3.4870	0.2581	42.97
Tetrachloroethane	80.40	2.2030	0.4084	27.15
1,3-Dichlorobenzene	98.42	4.5200	0.2000	55.70
1,2-Dichlorobenzene	98.07	4.3400	0.2073	53.48
Nitrobenzene	32.10	0.5231	1.7200	6.45
Napthalene	92.49	3.4840	0.2584	42.93
1-Chloronapthalene	91.61	3.4640	0.2598	42.68
2,6-Dinitrotoluene	28.41	0.3798	2.3700	4.68
Fluorene	56.54	0.9001	1.0000	11.09
2,4-Dinitrotoluene	31.74	0.4394	2.0480	5.41
Hexachlorobenzene	40.52	0.5427	1.6580	6.69
Phenanthrene	37.80	0.5699	1.5790	7.02
Fluoranthene	41.17	0.6631	1.3570	8.17

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15 °C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.61	4.4350	0.2029	31.54
Ethylbenzene	97.87	4.0110	0.2244	28.52
Tetrachloroethane	81.64	2.0080	0.4483	14.28
1,3-Dichlorobenzene	98.61	4.5000	0.2000	32.00
1,2-Dichlorobenzene	98.68	4.5820	0.1964	32.58
Nitrobenzene	32.97	0.4730	1.9030	3.36
Napthalene	94.61	3.4710	0.2593	24.69
1-Chloronapthalene	93.89	3.3910	0.2654	24.11
2,6-Dinitrotoluene	31.49	0.4103	2.1930	2.92
Fluorene	59.80	0.9566	0.9480	6.80
2,4-Dinitrotoluene	39.40	0.5552	1.6210	3.95
Hexachlorobenzene	44.08	0.5979	1.5050	4.25
Phenanthrene	38.84	0.5467	1.6460	3.89
Fluoranthene	41.97	0.6177	1.4570	4.39

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 35°C WATER, 15°C AIR, 30 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	95.08	3.5980	0.3335	97.23
Ethylbenzene	94.58	3.2886	0.3649	88.87
Tetrachloroethane	67.25	5.8830	0.2040	159.00
1,3-Dichlorobenzene	94.71	3.7960	0.3161	102.60
1,2-Dichlorobenzene	93.77	3.6850	0.3257	94.57
Nitrobenzene	23.09	0.9595	1.2510	25.93
Napthalene	83.61	9.3030	0.1290	251.40
1-Chloronapthalene	75.92	8.0560	0.1490	217.70
2,6-Dinitrotoluene	29.65	0.6012	1.9960	16.25
Fluorene	50.01	0.8670	1.3840	23.43
2,4-Dinitrotoluene	29.57	0.5913	2.0290	15.98
Hexachlorobenzene	47.73	0.7726	1.5540	20.87
Phenanthrene	38.55	1.3410	0.8943	36.26
Fluoranthene	35.49	1.1810	1.0160	31.92

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15°C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.50	4.4660	0.2687	41.28
Ethylbenzene	98.11	4.1410	0.2900	38.27
Tetrachloroethane	94.48	4.4310	0.2708	40.95
1,3-Dichlorobenzene	98.84	4.8660	0.2466	44.97
1,2-Dichlorobenzene	97.22	3.9270	0.3055	36.29
Nitrobenzene	42.94	0.8922	1.3450	8.25
Napthalene	95.90	4.4290	0.2709	40.93
1-Chloronapthalene	92.76	3.7070	0.3237	34.26
2,6-Dinitrotoluene	31.37	0.4332	2.7700	4.00
Fluorene	57.40	1.1576	1.0370	10.70
2,4-Dinitrotoluene	31.66	0.3977	3.0170	3.68
Hexachlorobenzene	53.83	0.8217	1.4600	7.59
Phenanthrene	41.12	0.6484	1.8510	5.99
Fluoranthene	40.62	0.6487	1.8490	5.99

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 15°C AIR, 150 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.71	4.4780	0.2679	23.89
Ethylbenzene	99.33	5.1430	0.2333	27.43
Tetrachloroethane	94.92	3.7460	0.3203	19.98
1,3-Dichlorobenzene	98.89	4.7400	0.2530	25.28
1,2-Dichlorobenzene	98.70	4.5980	0.2610	24.52
Nitrobenzene	58.11	1.2490	0.9608	6.66
Napthalene	97.54	4.4780	0.2680	23.88
1-Chloronapthalene	96.54	4.1440	0.2896	22.10
2,6-Dinitrotoluene	40.23	0.5730	2.0940	3.06
Fluorene	61.11	0.9923	1.2091	5.29
2,4-Dinitrotoluene	41.09	0.5902	2.0330	3.15
Hexachlorobenzene	69.29	1.2400	0.9674	6.62
Phenanthrene	51.16	0.8320	1.4420	4.44
Fluoranthene	50.53	0.8257	1.4530	4.40

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 25°C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	98.97	5.2600	0.1140	284.30
Chlorobenzene	88.90	2.5050	0.2395	135.40
Ethylbenzene	90.50	2.5900	0.2317	140.00
Tetrachloroethane	72.88	4.9550	0.1211	267.80
1,3-Dichlorobenzene	88.99	2.6670	0.2249	144.20
1,2-Dichlorobenzene	81.57	2.0310	0.2954	109.80
Nitrobenzene	23.35	0.7023	0.8542	37.96
Napthalene	77.36	3.5840	0.1674	193.70
1-Chloronapthalene	70.05	2.8670	0.2093	155.00
2,6-Dinitrotoluene	25.71	0.4404	1.3620	23.80
Fluorene	51.58	0.8926	0.6721	48.25
2,4-Dinitrotoluene	26.52	0.4576	1.3110	24.73
Hexachlorobenzene	29.29	0.3769	1.5920	20.37
Phenanthrene	33.86	0.7160	0.8380	38.70
Fluoranthene	32.20	0.6815	0.8804	36.83

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 25°C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	99.23	5.0890	0.1179	94.09
Chlorobenzene	95.61	3.2790	0.1829	60.61
Ethylbenzene	94.20	4.3410	0.1382	80.23
Tetrachloroethane	80.10	2.0860	0.2877	112.73
1,3-Dichlorobenzene	94.10	3.0200	0.1986	55.83
1,2-Dichlorobenzene	92.53	2.7830	0.2156	51.43
Nitrobenzene	29.44	0.4430	1.3540	8.19
Napthalene	87.03	2.5680	0.2337	47.46
1-Chloronapthalene	84.26	2.3640	0.2538	43.69
2,6-Dinitrotoluene	26.44	0.3418	1.7560	6.32
Fluorene	52.21	0.7861	0.7632	14.53
2,4-Dinitrotoluene	28.33	0.3729	1.6090	6.89
Hexachlorobenzene	41.73	0.5619	1.0680	10.39
Phenanthrene	36.07	0.4964	1.2090	9.20
Fluoranthene	34.27	0.4852	1.2360	8.97

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 25°C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	95.72	3.2420	0.1851	34.58
Ethylbenzene	96.96	3.5680	0.1681	38.06
Tetrachloroethane	83.56	2.1030	0.2853	22.43
1,3-Dichlorobenzene	94.08	2.9370	0.2043	31.33
1,2-Dichlorobenzene	93.83	2.9070	0.2064	31.00
Nitrobenzene	36.73	0.5447	1.1010	5.81
Napthalene	90.63	2.7200	0.2205	29.01
1-Chloronapthalene	89.53	2.6300	0.2281	28.05
2,6-Dinitrotoluene	28.94	0.3659	1.6400	3.90
Fluorene	62.14	1.0170	0.5910	10.84
2,4-Dinitrotoluene	35.30	0.4739	1.2660	5.06
Hexachlorobenzene	48.97	0.4443	1.3510	4.74
Phenanthrene	38.26	0.5270	1.1390	5.62
Fluoranthene	40.54	0.5756	1.0420	6.14

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 35 °C WATER, 25 °C AIR, 30 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.52	3.3710	0.2670	121.50
Ethylbenzene	94.47	3.2140	0.2800	115.80
Tetrachloroethane	73.20	5.1340	0.1753	185.00
1,3-Dichlorobenzene	94.50	3.6030	0.2498	129.80
1,2-Dichlorobenzene	93.17	3.4020	0.2645	122.60
Nitrobenzene	24.97	0.9903	0.9088	35.68
Napthalene	84.00	5.6580	0.1591	203.70
1-Chloronapthalene	81.48	7.0840	0.1270	255.20
2,6-Dinitrotoluene	25.95	0.4471	2.0130	16.11
Fluorene	52.00	0.9054	0.9940	32.62
2,4-Dinitrotoluene	34.58	0.7847	1.1470	28.27
Hexachlorobenzene	35.92	0.4955	1.8160	17.86
Phenanthrene	38.33	0.9700	0.9278	34.95
Fluoranthene	41.52	1.4380	0.6260	51.81

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35°C WATER, 25°C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.47	4.4070	0.2042	54.30
Ethylbenzene	97.12	3.6770	0.2447	45.31
Tetrachloroethane	83.06	2.3330	0.3858	28.74
1,3-Dichlorobenzene	98.37	4.4340	0.2029	54.64
1,2-Dichlorobenzene	98.03	4.2630	0.2110	52.52
Nitrobenzene	34.59	0.5719	1.5740	7.05
Napthalene	92.32	3.3250	0.2707	40.97
1-Chloronapthalene	92.35	3.4560	0.2604	42.59
2,6-Dinitrotoluene	31.07	0.4242	2.1210	5.29
Fluorene	55.66	0.8706	1.0340	10.73
2,4-Dinitrotoluene	35.66	0.5117	1.7590	6.31
Hexachlorobenzene	40.25	0.6490	1.3870	8.00
Phenanthrene	39.44	0.5889	1.5280	7.26
Fluoranthene	42.60	0.6721	1.3390	8.28

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 35°C WATER, 25°C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.70	4.4820	0.2008	31.88
Ethylbenzene	98.49	4.2880	0.2099	30.50
Tetrachloroethane	85.53	2.2660	0.3972	16.11
1,3-Dichlorobenzene	98.92	4.7370	0.1900	33.68
1,2-Dichlorobenzene	99.01	4.8540	0.1854	34.52
Nitrobenzene	36.60	0.5412	1.6630	3.85
Napthalene	95.40	3.6000	0.2500	25.60
1-Chloronapthalene	95.80	3.7920	0.2374	26.96
2,6-Dinitrotoluene	35.46	0.4775	1.8850	3.40
Fluorene	64.42	1.0840	0.8300	7.71
2,4-Dinitrotoluene	38.33	0.5306	1.6960	3.77
Hexachlorobenzene	55.20	0.8295	1.0850	5.90
Phenanthrene	40.84	0.5772	1.5590	4.11
Fluoranthene	43.06	0.6280	1.4330	4.47

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 25 °C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	95.76	3.6880	0.3254	99.66
Ethylbenzene	96.57	3.7690	0.3184	101.90
Tetrachloroethane	74.79	6.2880	0.1908	169.90
1,3-Dichlorobenzene	96.00	4.0370	0.2972	109.10
1,2-Dichlorobenzene	95.21	3.9050	0.3073	105.50
Nitrobenzene	24.10	0.8029	1.4950	21.70
Napthalene	85.00	6.1460	0.1952	166.10
1-Chloronapthalene	80.91	6.6390	0.1807	179.40
2,6-Dinitrotoluene	30.10	0.5938	2.0210	16.05
Fluorene	51.98	0.9047	1.3270	24.45
2,4-Dinitrotoluene	31.00	0.6145	1.9530	16.61
Hexachlorobenzene	47.66	0.7530	1.5940	20.35
Phenanthrene	44.00	1.5330	0.7829	41.42
Fluoranthene	45.32	2.4600	0.4897	66.47

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 35 °C WATER, 25 °C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.25	5.1700	0.2321	47.78
Ethylbenzene	98.31	4.2370	0.2832	39.16
Tetrachloroethane	94.00	4.0110	0.2992	37.07
1,3-Dichlorobenzene	98.21	4.2770	0.2805	39.53
1,2-Dichlorobenzene	99.13	5.1730	0.2320	47.81
Nitrobenzene	45.15	0.9330	1.2850	8.63
Napthalene	97.01	4.7230	0.2541	43.64
1-Chloronapthalene	94.54	3.9820	0.3014	36.80
2,6-Dinitrotoluene	31.94	0.4401	2.7260	4.07
Fluorene	59.06	0.9612	1.2480	8.88
2,4-Dinitrotoluene	37.09	0.5423	2.2130	5.01
Hexachlorobenzene	54.88	0.8406	1.4280	7.77
Phenanthrene	41.55	0.6378	1.8810	5.89
Fluoranthene	42.14	0.6606	1.8160	6.11

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 35°C WATER, 25°C AIR, 150 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.46	5.3970	0.2223	28.79
Ethylbenzene	99.16	4.8920	0.2453	26.09
Tetrachloroethane	99.00	5.7950	0.2071	30.91
1,3-Dichlorobenzene	98.83	4.6520	0.2580	24.81
1,2-Dichlorobenzene	98.84	4.6760	0.2566	24.94
Nitrobenzene	59.55	1.2650	0.9488	6.75
Napthalene	96.93	4.1040	0.2923	21.89
1-Chloronapthalene	95.48	3.6980	0.3245	19.72
2,6-Dinitrotoluene	45.60	0.6848	1.7520	3.65
Fluorene	67.60	1.1860	1.0120	6.33
2,4-Dinitrotoluene	40.80	0.5791	2.0720	3.09
Hexachlorobenzene	71.95	1.3300	0.9019	7.10
Phenanthrene	52.59	0.8498	1.4120	4.53
Fluoranthene	50.93	0.8143	1.4740	4.34

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 5°C AIR, 30 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	95.71	3.5620	0.1684	192.50
Chlorobenzene	94.01	3.2610	0.1840	176.20
Ethylbenzene	92.07	2.7970	0.2144	151.20
Tetrachloroethane	72.72	4.8730	0.1231	263.30
1,3-Dichlorobenzene	91.37	2.9930	0.2004	161.80
1,2-Dichlorobenzene	90.38	2.9930	0.2053	158.00
Nitrobenzene	21.78	0.5458	1.0990	29.50
Napthalene	80.48	4.3680	0.1373	236.10
1-Chloronapthalene	75.77	4.1900	0.1431	226.50
2,6-Dinitrotoluene	27.08	0.4881	1.2290	26.38
Fluorene	38.43	1.2390	0.4842	66.98
2,4-Dinitrotoluene	25.91	0.3284	1.8270	17.75
Hexachlorobenzene	34.08	0.4607	1.3020	24.90
Phenanthrene	26.15	0.4364	1.3750	23.59
Fluoranthene	24.40	0.4020	1.4920	21.73

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 5 °C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	95.51	3.2430	0.1850	59.95
Chlorobenzene	95.61	3.3050	0.1815	61.09
Ethylbenzene	95.58	3.2430	0.1849	59.95
Tetrachloroethane	85.79	2.7430	0.2188	50.69
1,3-Dichlorobenzene	95.09	3.2250	0.1834	60.17
1,2-Dichlorobenzene	95.73	3.4420	0.1743	63.63
Nitrobenzene	40.38	0.7886	0.7628	14.54
Napthalene	93.64	3.7400	0.1604	69.13
1-Chloronapthalene	92.27	3.6000	0.1668	66.53
2,6-Dinitrotoluene	29.41	0.3970	1.5110	7.40
Fluorene	66.63	1.6150	0.3710	9.15
2,4-Dinitrotoluene	30.49	0.3780	1.5877	11.54
Hexachlorobenzene	38.73	0.5106	1.1750	9.44
Phenanthrene	40.73	0.6338	0.9391	11.88
Fluoranthene	34.23	0.4992	1.2020	9.23

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 5°C AIR, 150 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	96.20	3.3710	0.1779	35.97
Chlorobenzene	96.70	3.5490	0.1690	37.86
Ethylbenzene	95.67	3.2243	0.1860	34.39
Tetrachloroethane	88.55	2.7350	0.2194	29.18
1,3-Dichlorobenzene	96.25	3.4750	0.1726	37.06
1,2-Dichlorobenzene	99.35	3.8650	0.1552	41.22
Nitrobenzene	48.40	0.6585	0.9110	7.02
Napthalene	94.86	3.6170	0.1659	38.59
1-Chloronapthalene	94.00	3.5120	0.1780	37.47
2,6-Dinitrotoluene	30.41	0.3937	1.5240	4.20
Fluorene	76.25	1.8890	0.3175	20.15
2,4-Dinitrotoluene	29.19	0.3532	1.6980	3.77
Hexachlorobenzene	52.91	0.7800	0.7693	8.32
Phenanthrene	45.73	0.7135	0.8409	7.61
Fluoranthene	41.52	0.6243	0.9610	6.66

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 5°C AIR, 30 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.73	4.5950	0.1958	165.60
Ethylbenzene	95.74	3.5740	0.2518	128.80
Tetrachloroethane	60.55	2.6250	0.3429	94.57
1,3-Dichlorobenzene	97.50	4.8820	0.1843	175.90
1,2-Dichlorobenzene	97.54	5.0990	0.1765	183.70
Nitrobenzene	21.55	0.6502	1.3840	23.43
Napthalene	81.37	6.9310	0.1299	249.70
1-Chloronapthalene	72.65	4.9720	0.1810	179.20
2,6-Dinitrotoluene	27.18	0.5046	1.7830	18.18
Fluorene	40.45	1.4730	0.6110	53.07
2,4-Dinitrotoluene	30.17	0.4045	2.2250	14.59
Hexachlorobenzene	35.52	0.4954	1.8170	17.85
Phenanthrene	28.46	0.5657	1.5910	20.38
Fluoranthene	31.22	0.7680	1.1720	27.68

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 5 °C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.00	4.9050	0.1838	60.44
Ethylbenzene	98.94	4.7630	0.1890	58.69
Tetrachloroethane	88.16	3.0580	0.2943	37.68
1,3-Dichlorobenzene	99.17	5.2400	0.1717	64.58
1,2-Dichlorobenzene	97.85	4.1280	0.2134	51.98
Nitrobenzene	46.88	1.0840	0.8306	13.35
Napthalene	95.40	4.2480	0.2119	52.34
1-Chloronapthalene	96.94	5.1620	0.1794	63.60
2,6-Dinitrotoluene	30.00	0.4079	2.2060	5.03
Fluorene	61.60	1.3440	0.6695	16.56
2,4-Dinitrotoluene	32.77	0.4133	2.1787	5.09
Hexachlorobenzene	52.90	0.7990	1.1260	9.85
Phenanthrene	39.80	0.6163	1.4600	7.59
Fluoranthene	43.31	0.7203	1.2490	8.88

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 5 °C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.52	5.5850	0.1611	39.72
Ethylbenzene	99.37	5.2260	0.1722	37.16
Tetrachloroethane	94.23	3.7080	0.2427	6.65
1,3-Dichlorobenzene	98.61	4.5360	0.1982	32.25
1,2-Dichlorobenzene	98.95	4.8730	0.1847	34.65
Nitrobenzene	57.11	1.2600	0.7141	8.96
Napthalene	97.10	4.3770	0.2056	31.21
1-Chloronapthalene	97.52	4.7350	0.1900	33.67
2,6-Dinitrotoluene	32.38	0.4277	2.1040	3.04
Fluorene	77.87	2.0020	0.4496	14.23
2,4-Dinitrotoluene	33.43	0.4181	2.1530	2.97
Hexachlorobenzene	55.17	0.8372	1.0750	5.95
Phenanthrene	42.51	0.6371	1.4130	4.53
Fluoranthene	46.43	0.7434	1.2110	5.29

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 5°C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	96.51	4.0400	0.2970	109.20
Ethylbenzene	96.53	3.8180	0.3142	103.20
Tetrachloroethane	67.43	6.1350	0.1956	165.80
1,3-Dichlorobenzene	98.15	5.3210	0.2255	143.80
1,2-Dichlorobenzene	98.26	5.5490	0.2162	150.00
Nitrobenzene	23.00	0.9595	1.2570	25.93
Napthalene	84.76	11.3700	0.1056	307.20
1-Chloronapthalene	76.15	8.4910	0.1413	229.50
2,6-Dinitrotoluene	31.62	0.6941	1.7290	18.76
Fluorene	40.63	1.5040	0.7978	40.65
2,4-Dinitrotoluene	29.31	0.3931	3.0530	10.62
Hexachlorobenzene	50.70	0.8538	1.4050	23.07
Phenanthrene	40.82	1.8570	0.6463	50.17
Fluoranthene	38.50	1.9510	0.6150	52.72

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 5°C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.59	4.5330	0.2647	41.89
Ethylbenzene	98.56	4.4290	0.2710	40.93
Tetrachloroethane	94.16	4.3270	0.2773	34.00
1,3-Dichlorobenzene	99.07	5.1130	0.2347	47.25
1,2-Dichlorobenzene	97.91	4.2500	0.2823	39.28
Nitrobenzene	54.82	1.6455	0.7292	15.20
Napthalene	98.32	5.8490	0.2052	54.05
1-Chloronapthalene	92.37	3.6210	0.3314	33.46
2,6-Dinitrotoluene	32.63	0.4574	2.6336	4.22
Fluorene	76.58	2.3770	0.5049	21.96
2,4-Dinitrotoluene	37.17	0.4873	2.4620	4.50
Hexachlorobenzene	59.45	0.9673	1.2400	8.94
Phenanthrene	42.43	0.6819	1.7600	6.30
Fluoranthene	43.10	0.7140	1.6800	6.60

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 5 °C AIR, 150 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	98.83	4.6490	0.2584	24.77
Ethylbenzene	99.00	4.7640	0.2528	25.31
Tetrachloroethane	96.45	4.4190	0.2716	23.57
1,3-Dichlorobenzene	99.24	5.1870	0.2313	27.67
1,2-Dichlorobenzene	98.85	4.7740	0.2514	25.46
Nitrobenzene	60.74	1.4510	0.8267	7.74
Napthalene	98.79	5.5440	0.2164	29.57
1-Chloronapthalene	98.47	5.4100	0.2218	28.85
2,6-Dinitrotoluene	38.33	0.5400	2.2220	2.88
Fluorene	86.10	2.7710	0.4330	14.78
2,4-Dinitrotoluene	43.16	0.5857	2.0490	3.12
Hexachlorobenzene	69.20	1.2360	0.9706	6.59
Phenanthrene	50.67	0.8426	1.4240	4.49
Fluoranthene	47.59	0.7736	1.5510	4.13

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 15°C AIR, 30 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	97.25	4.0240	0.1491	217.50
Chlorobenzene	94.69	3.3370	0.1797	180.40
Ethylbenzene	92.50	2.8260	0.2123	152.80
Tetrachloroethane	74.36	3.6390	0.1649	196.70
1,3-Dichlorobenzene	92.03	3.0140	0.2000	162.90
1,2-Dichlorobenzene	91.56	3.0070	0.1996	162.50
Nitrobenzene	22.67	0.5327	1.1260	28.79
Napthalene	83.52	4.6700	0.1285	252.40
1-Chloronapthalene	83.66	5.5200	0.1987	298.40
2,6-Dinitrotoluene	36.06	0.8458	0.7093	45.72
Fluorene	44.58	1.5070	0.3981	81.46
2,4-Dinitrotoluene	31.66	0.4214	1.4240	22.78
Hexachlorobenzene	40.56	0.5792	1.0360	31.31
Phenanthrene	26.54	0.4182	1.4347	22.60
Fluoranthene	27.73	0.4507	1.3313	24.36

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 55°C WATER, 15°C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	97.50	3.8440	0.1561	71.05
Chlorobenzene	96.37	3.4825	0.1723	64.37
Ethylbenzene	95.78	3.2770	0.1831	60.56
Tetrachloroethane	87.40	2.7980	0.2141	51.72
1,3-Dichlorobenzene	97.02	3.7710	0.1591	69.69
1,2-Dichlorobenzene	96.42	3.5980	0.1667	66.51
Nitrobenzene	41.37	0.7854	0.7639	14.52
Napthalene	93.67	3.6090	0.1663	66.16
1-Chloronapthalene	92.29	3.4440	0.1742	63.67
2,6-Dinitrotoluene	37.57	0.5555	1.0800	10.27
Fluorene	67.40	1.6010	0.3747	29.60
2,4-Dinitrotoluene	32.26	0.4037	1.4860	7.46
Hexachlorobenzene	48.40	0.6937	0.8650	12.82
Phenanthrene	33.58	0.4674	1.2840	8.64
Fluoranthene	36.56	0.5327	1.1260	9.85

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 15°C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	98.43	4.2600	0.1408	45.44
Chlorobenzene	96.91	3.5810	0.1675	38.20
Ethylbenzene	97.07	3.6060	0.1664	38.47
Tetrachloroethane	94.18	3.4510	0.1739	36.81
1,3-Dichlorobenzene	97.72	3.9460	0.1521	42.09
1,2-Dichlorobenzene	97.42	3.8420	0.1565	40.90
Nitrobenzene	42.36	0.6782	0.8847	7.23
Napthalene	95.86	3.7310	0.1608	39.80
1-Chloronapthalene	94.62	3.4750	0.1727	37.07
2,6-Dinitrotoluene	42.63	0.6193	0.9688	6.61
Fluorene	76.52	1.8250	0.3287	19.47
2,4-Dinitrotoluene	39.70	0.5195	1.1550	5.54
Hexachlorobenzene	54.77	0.8195	0.7321	8.74
Phenanthrene	46.15	0.6913	0.8679	7.37
Fluoranthene	44.37	0.6570	0.9132	7.01

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 35°C WATER, 25°C AIR, 90 G/L, 34°C AVERAGE WATER TEMPERATURE, 28°C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	247.9	6.366	5.928	50.58
Chlorobenzene	247.9	6.226	5.946	50.17
Ethylbenzene	247.9	5.955	5.629	48.24
Tetrachloroethane	247.9	5.829	5.619	36.95
1,3-Dichlorobenzene	247.9	5.793	5.661	46.68
1,2-Dichlorobenzene	247.9	5.883	5.661	46.34
Nitrobenzene	247.9	6.076	5.970	25.03
Napthalene	247.9	5.648	5.544	37.99
1-Chloronapthalene	247.9	5.306	5.340	35.40
2,6-Dinitrotoluene	247.9	5.419	5.446	29.52
Fluorene	247.9	5.081	5.158	38.76
2,4-Dinitrotoluene	247.9	3.233	5.446	29.66
Hexachlorobenzene	247.9	4.702	4.910	37.78
Phenanthrene	247.9	4.923	5.061	27.96
Fluoranthene	247.9	4.727	4.938	26.41

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C AIR, 150 G/L, 34 °C AVERAGE WATER TEMPERATURE, 28 °C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.365	4.725	34.26
Chlorobenzene	208.8	6.225	4.740	34.06
Ethylbenzene	208.8	5.955	4.487	32.65
Tetrachloroethane	208.8	5.805	4.537	26.32
1,3-Dichlorobenzene	208.8	5.805	4.513	31.83
1,2-Dichlorobenzene	208.8	5.883	4.513	31.64
Nitrobenzene	208.8	6.076	4.759	18.83
Napthalene	208.8	5.635	4.419	26.75
1-Chloronapthalene	208.8	5.304	4.257	25.07
2,6-Dinitrotoluene	208.8	5.417	4.341	21.53
Fluorene	208.8	5.081	4.111	26.88
2,4-Dinitrotoluene	208.8	5.323	4.341	21.62
Hexachlorobenzene	208.8	4.697	3.913	26.09
Phenanthrene	208.8	4.929	4.038	20.36
Fluoranthene	208.8	4.720	3.936	19.29

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 30 G/L, 54 °C AVERAGE WATER
TEMPERATURE, 29 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	377.5	6.366	15.51	188.70
Chlorobenzene	377.5	6.226	15.61	184.20
Ethylbenzene	377.5	5.953	14.77	181.20
Tetrachloroethane	377.5	5.829	14.93	102.40
1,3-Dichlorobenzene	377.5	5.793	14.85	166.00
1,2-Dichlorobenzene	377.5	5.882	14.85	163.20
Nitrobenzene	377.5	6.075	15.67	53.73
Napthalene	377.5	5.648	14.55	110.20
1-Chloronapthalene	377.5	5.304	13.98	99.60
2,6-Dinitrotoluene	377.5	5.419	14.29	72.03
Fluorene	377.5	5.081	13.53	123.30
2,4-Dinitrotoluene	377.5	5.324	14.29	72.58
Hexachlorobenzene	377.5	4.700	12.88	123.40
Phenanthrene	377.5	4.925	13.30	69.07
Fluoranthene	377.5	4.723	12.95	63.92

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 90 G/L, 50 °C AVERAGE WATER
TEMPERATURE, 26 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	262.7	6.214	7.809	69.01
Chlorobenzene	262.7	5.930	7.834	67.84
Ethylbenzene	262.7	7.415	5.811	69.95
Tetrachloroethane	262.7	5.690	7.500	45.04
1,3-Dichlorobenzene	262.7	5.656	7.456	62.56
1,2-Dichlorobenzene	262.7	5.493	7.456	61.55
Nitrobenzene	262.7	5.930	7.866	27.95
Napthalene	262.7	5.513	7.305	47.47
1-Chloronapthalene	262.7	5.175	7.091	43.58
2,6-Dinitrotoluene	262.7	5.205	7.174	35.03
Fluorene	262.7	4.960	6.796	50.26
2,4-Dinitrotoluene	262.7	5.193	7.171	35.22
Hexachlorobenzene	262.7	4.584	6.468	49.15
Phenanthrene	262.7	4.808	6.675	32.07
Fluoranthene	262.7	4.609	6.504	29.80

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 5 °C
AIR, 150 G/L, 46 °C AVERAGE WATER
TEMPERATURE, 22 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	218.5	6.068	5.965	44.15
Chlorobenzene	218.5	5.933	5.985	43.51
Ethylbenzene	218.5	5.673	5.239	39.15
Tetrachloroethane	218.5	5.555	5.727	29.76
1,3-Dichlorobenzene	218.5	5.522	5.696	40.19
1,2-Dichlorobenzene	218.5	5.510	5.696	39.72
Nitrobenzene	218.5	5.787	6.010	19.51
Napthalene	218.5	5.380	5.581	31.37
1-Chloronapthalene	218.5	5.052	5.364	28.88
2,6-Dinitrotoluene	218.5	4.997	5.482	24.09
Fluorene	218.5	4.839	5.190	32.88
2,4-Dinitrotoluene	218.5	5.070	5.480	24.21
Hexachlorobenzene	218.5	4.476	4.940	31.89
Phenanthrene	218.5	4.689	5.100	21.23
Fluoranthene	218.5	4.496	4.968	19.65

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 30 G/L, 48 °C AVERAGE WATER
TEMPERATURE, 26°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	368.0	6.214	12.98	154.00
Chlorobenzene	368.0	6.078	13.02	150.10
Ethylbenzene	368.0	5.831	12.32	147.70
Tetrachloroethane	368.0	5.690	12.47	84.46
1,3-Dichlorobenzene	368.0	5.656	12.40	135.50
1,2-Dichlorobenzene	368.0	5.490	12.40	132.20
Nitrobenzene	368.0	5.930	13.08	46.05
Napthalene	368.0	5.796	12.14	93.53
1-Chloronapthalene	368.0	5.175	11.67	82.68
2,6-Dinitrotoluene	368.0	5.205	11.92	61.79
Fluorene	368.0	4.960	11.30	102.25
2,4-Dinitrotoluene	368.0	5.193	12.00	62.22
Hexachlorobenzene	368.0	4.584	10.75	101.30
Phenanthrene	368.0	4.808	11.10	56.32
Fluoranthene	368.0	4.609	10.81	51.72

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 90 G/L, 49 °C AVERAGE WATER
TEMPERATURE, 24 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	262.6	6.214	7.808	68.98
Chlorobenzene	262.6	6.087	7.833	67.96
Ethylbenzene	262.6	5.813	7.414	65.92
Tetrachloroethane	262.6	5.690	7.500	45.03
1,3-Dichlorobenzene	262.6	5.656	7.455	62.54
1,2-Dichlorobenzene	262.6	5.490	7.455	61.56
Nitrobenzene	262.6	5.300	7.866	27.94
Napthalene	262.6	5.796	7.305	48.19
1-Chloronapthalene	262.6	5.175	7.019	43.57
2,6-Dinitrotoluene	262.6	5.205	7.173	35.02
Fluorene	262.6	4.960	6.795	50.24
2,4-Dinitrotoluene	262.6	5.193	7.171	35.22
Hexachlorobenzene	262.6	4.584	6.468	49.13
Phenanthrene	262.6	4.808	6.675	32.06
Fluoranthene	262.6	4.609	6.504	29.79

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 5 °C
AIR, 150 G/L, 49 °C AVERAGE WATER
TEMPERATURE, 21 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	219.9	6.068	6.253	46.45
Chlorobenzene	219.9	5.937	6.273	45.74
Ethylbenzene	219.9	5.674	5.937	43.32
Tetrachloroethane	219.9	5.556	6.005	30.91
1,3-Dichlorobenzene	219.9	5.522	5.970	42.19
1,2-Dichlorobenzene	219.9	5.510	5.970	41.68
Nitrobenzene	219.9	5.786	6.298	20.02
Napthalene	219.9	5.377	5.849	32.64
1-Chloronapthalene	219.9	5.049	5.620	30.00
2,6-Dinitrotoluene	219.9	4.995	5.744	24.88
Fluorene	219.9	4.838	5.441	34.37
2,4-Dinitrotoluene	219.9	5.073	5.739	25.02
Hexachlorobenzene	219.9	4.477	5.179	33.37
Phenanthrene	219.9	4.690	5.345	21.91
Fluoranthene	219.9	4.496	5.207	20.25

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 30 G/L, 50°C AVERAGE WATER
TEMPERATURE, 26°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	368.0	6.214	12.98	154.00
Chlorobenzene	368.0	6.078	13.02	150.10
Ethylbenzene	368.0	5.831	12.32	147.70
Tetrachloroethane	368.0	5.690	12.47	84.46
1,3-Dichlorobenzene	368.0	5.656	12.40	135.50
1,2-Dichlorobenzene	368.0	5.490	12.40	132.20
Nitrobenzene	368.0	5.930	13.08	46.05
Napthalene	368.0	5.796	12.14	93.53
1-Chloronapthalene	368.0	5.175	11.67	82.68
2,6-Dinitrotoluene	368.0	5.205	11.92	61.79
Fluorene	368.0	4.960	11.30	102.25
2,4-Dinitrotoluene	368.0	5.193	12.00	62.22
Hexachlorobenzene	368.0	4.584	10.75	101.30
Phenanthrene	368.0	4.808	11.10	56.32
Fluoranthene	368.0	4.609	10.81	51.72

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 5 °C
AIR, 90 G/L, 49 °C AVERAGE WATER
TEMPERATURE, 25 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	262.7	6.214	7.809	69.01
Chlorobenzene	262.7	5.930	7.834	67.84
Ethylbenzene	262.7	7.415	5.811	69.95
Tetrachloroethane	262.7	5.690	7.500	45.04
1,3-Dichlorobenzene	262.7	5.656	7.456	62.56
1,2-Dichlorobenzene	262.7	5.493	7.456	61.55
Nitrobenzene	262.7	5.930	7.866	27.95
Napthalene	262.7	5.513	7.305	47.47
1-Chloronapthalene	262.7	5.175	7.091	43.58
2,6-Dinitrotoluene	262.7	5.205	7.174	35.03
Fluorene	262.7	4.960	6.796	50.26
2,4-Dinitrotoluene	262.7	5.193	7.171	35.22
Hexachlorobenzene	262.7	4.584	6.468	49.15
Phenanthrene	262.7	4.808	6.675	32.07
Fluoranthene	262.7	4.609	6.504	29.80

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 5 °C
AIR, 150 G/L, 48 °C AVERAGE WATER
TEMPERATURE, 21 °C AVERAGE AIR
TEMPERATURE, AND 1.2M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	219.9	6.068	6.253	46.45
Chlorobenzene	219.9	5.937	6.273	45.74
Ethylbenzene	219.9	5.674	5.937	43.32
Tetrachloroethane	219.9	5.556	6.005	30.91
1,3-Dichlorobenzene	219.9	5.522	5.970	42.19
1,2-Dichlorobenzene	219.9	5.510	5.970	41.68
Nitrobenzene	219.9	5.786	6.298	20.02
Napthalene	219.9	5.377	5.849	32.64
1-Chloronapthalene	219.9	5.049	5.620	30.00
2,6-Dinitrotoluene	219.9	4.995	5.744	24.88
Fluorene	219.9	4.838	5.441	34.37
2,4-Dinitrotoluene	219.9	5.073	5.739	25.02
Hexachlorobenzene	219.9	4.477	5.179	33.37
Phenanthrene	219.9	4.690	5.345	21.91
Fluoranthene	219.9	4.496	5.207	20.25

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 15 °C
AIR, 30 G/L, 54°C AVERAGE WATER
TEMPERATURE, 36°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	377.5	6.517	15.55	191.50
Chlorobenzene	377.5	6.373	15.60	188.00
Ethylbenzene	377.5	6.096	14.77	183.60
Tetrachloroethane	377.5	5.969	14.93	109.80
1,3-Dichlorobenzene	377.5	5.930	14.85	170.40
1,2-Dichlorobenzene	377.5	6.118	14.85	168.30
Nitrobenzene	377.5	6.222	15.67	58.15
Napthalene	377.5	5.785	14.55	116.50
1-Chloronapthalene	377.5	5.430	13.98	105.90
2,6-Dinitrotoluene	377.5	5.632	14.29	76.21
Fluorene	377.5	5.200	13.53	128.00
2,4-Dinitrotoluene	377.5	5.453	14.29	76.80
Hexachlorobenzene	377.5	4.812	12.88	128.60
Phenanthrene	377.5	5.044	13.30	76.53
Fluoranthene	377.5	4.837	12.95	71.56

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 15 °C
AIR, 90 G/L, 50°C AVERAGE WATER
TEMPERATURE, 31°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	262.7	6.366	8.229	73.17
Chlorobenzene	262.7	6.215	8.257	72.30
Ethylbenzene	262.7	5.953	7.816	69.92
Tetrachloroethane	262.7	5.829	7.897	48.13
1,3-Dichlorobenzene	262.7	5.805	7.854	66.67
1,2-Dichlorobenzene	262.7	5.883	7.854	66.01
Nitrobenzene	262.7	6.074	8.286	30.52
Napthalene	262.7	5.648	7.695	51.42
1-Chloronapthalene	262.7	5.304	7.395	47.24
2,6-Dinitrotoluene	262.7	5.419	7.556	37.66
Fluorene	262.7	5.081	7.158	53.70
2,4-Dinitrotoluene	262.7	5.323	7.556	37.88
Hexachlorobenzene	262.7	4.700	6.814	52.74
Phenanthrene	262.7	4.925	7.034	35.85
Fluoranthene	262.7	4.723	6.850	33.60

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 15 °C
AIR, 150 G/L, 46 °C AVERAGE WATER
TEMPERATURE, 26 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	218.4	6.214	5.963	44.51
Chlorobenzene	218.4	6.078	5.985	44.04
Ethylbenzene	218.4	5.813	5.239	39.44
Tetrachloroethane	218.4	5.699	5.727	31.30
1,3-Dichlorobenzene	218.4	5.656	5.696	40.83
1,2-Dichlorobenzene	218.4	5.490	5.696	40.31
Nitrobenzene	218.4	5.930	6.010	20.83
Napthalene	218.4	5.513	5.581	32.56
1-Chloronapthalene	218.4	5.175	5.364	30.14
2,6-Dinitrotoluene	218.4	5.205	5.482	25.13
Fluorene	218.4	4.960	5.190	33.65
2,4-Dinitrotoluene	218.4	5.193	5.480	25.25
Hexachlorobenzene	218.4	4.584	4.940	32.73
Phenanthrene	218.4	4.808	5.079	23.00
Fluoranthene	218.4	4.609	4.968	21.55

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 15°C
AIR, 30 G/L, 50°C AVERAGE WATER
TEMPERATURE, 34°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	368.0	6.518	12.98	158.30
Chlorobenzene	368.0	6.374	13.02	155.80
Ethylbenzene	368.0	6.096	12.32	151.50
Tetrachloroethane	368.0	5.970	12.47	96.69
1,3-Dichlorobenzene	368.0	5.930	12.39	142.70
1,2-Dichlorobenzene	368.0	6.119	12.39	140.80
Nitrobenzene	368.0	6.222	13.08	53.74
Napthalene	368.0	5.785	12.14	101.70
1-Chloronapthalene	368.0	5.430	11.67	92.97
2,6-Dinitrotoluene	368.0	5.632	11.92	68.94
Fluorene	368.0	5.200	11.30	109.60
2,4-Dinitrotoluene	368.0	5.453	11.92	69.42
Hexachlorobenzene	368.0	4.782	10.75	109.20
Phenanthrene	368.0	5.045	11.10	68.82
Fluoranthene	368.0	4.819	10.81	64.42

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 15°C
AIR, 90 G/L, 50°C AVERAGE WATER
TEMPERATURE, 31°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	262.7	6.369	7.812	69.67
Chlorobenzene	262.7	6.223	7.834	68.84
Ethylbenzene	262.7	5.953	7.414	66.49
Tetrachloroethane	262.7	5.829	7.500	42.65
1,3-Dichlorobenzene	262.7	5.793	7.455	61.41
1,2-Dichlorobenzene	262.7	5.883	7.455	63.01
Nitrobenzene	262.7	6.076	7.865	29.90
Napthalene	262.7	5.648	7.305	49.35
1-Chloronapthalene	262.7	5.304	7.019	45.59
2,6-Dinitrotoluene	262.7	5.419	7.173	36.63
Fluorene	262.7	5.080	6.795	51.52
2,4-Dinitrotoluene	262.7	5.324	7.171	36.83
Hexachlorobenzene	262.7	4.702	6.468	50.53
Phenanthrene	262.7	4.930	6.675	34.85
Fluoranthene	262.7	4.723	6.504	32.70

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 15 °C
AIR, 150 G/L, 49°C AVERAGE WATER
TEMPERATURE, 29°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	221.8	6.364	6.218	47.63
Chlorobenzene	221.8	6.223	6.238	46.96
Ethylbenzene	221.8	5.595	5.904	45.18
Tetrachloroethane	221.8	5.827	5.971	34.22
1,3-Dichlorobenzene	221.8	5.793	5.937	43.63
1,2-Dichlorobenzene	221.8	5.883	5.937	43.30
Nitrobenzene	221.8	6.075	6.263	22.89
Napthalene	221.8	5.648	5.816	35.25
1-Chloronapthalene	221.8	5.304	5.589	32.74
2,6-Dinitrotoluene	221.8	5.419	5.712	27.18
Fluorene	221.8	5.081	5.411	36.10
2,4-Dinitrotoluene	221.8	5.324	5.710	27.30
Hexachlorobenzene	221.8	4.702	5.128	35.09
Phenanthrene	221.8	4.925	5.315	25.78
Fluoranthene	221.8	4.723	5.179	24.30

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 15°C
AIR, 30 G/L, 52°C AVERAGE WATER
TEMPERATURE, 34°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	368.0	6.518	12.98	158.30
Chlorobenzene	368.0	6.374	13.02	155.80
Ethylbenzene	368.0	6.096	12.32	151.50
Tetrachloroethane	368.0	5.970	12.47	96.69
1,3-Dichlorobenzene	368.0	5.930	12.39	142.70
1,2-Dichlorobenzene	368.0	6.119	12.39	140.80
Nitrobenzene	368.0	6.222	13.08	53.74
Napthalene	368.0	5.785	12.14	101.70
1-Chloronapthalene	368.0	5.430	11.67	92.97
2,6-Dinitrotoluene	368.0	5.632	11.92	68.94
Fluorene	368.0	5.200	11.30	109.60
2,4-Dinitrotoluene	368.0	5.453	11.92	69.42
Hexachlorobenzene	368.0	4.782	10.75	109.20
Phenanthrene	368.0	5.045	11.10	68.82
Fluoranthene	368.0	4.819	10.81	64.42

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 55°C WATER, 15°C AIR, 90 G/L, 50°C AVERAGE WATER TEMPERATURE, 29°C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	262.7	6.369	7.812	69.67
Chlorobenzene	262.7	6.223	7.834	68.84
Ethylbenzene	262.7	5.953	7.414	66.49
Tetrachloroethane	262.7	5.829	7.500	42.65
1,3-Dichlorobenzene	262.7	5.793	7.455	61.41
1,2-Dichlorobenzene	262.7	5.883	7.455	63.01
Nitrobenzene	262.7	6.076	7.865	29.90
Napthalene	262.7	5.648	7.305	49.35
1-Chloronapthalene	262.7	5.304	7.019	45.59
2,6-Dinitrotoluene	262.7	5.419	7.173	36.63
Fluorene	262.7	5.080	6.795	51.52
2,4-Dinitrotoluene	262.7	5.324	7.171	36.83
Hexachlorobenzene	262.7	4.702	6.468	50.53
Phenanthrene	262.7	4.930	6.675	34.85
Fluoranthene	262.7	4.723	6.504	32.70

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 15 °C
AIR, 150 G/L, 50 °C AVERAGE WATER
TEMPERATURE, 26 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	221.8	6.214	6.549	49.38
Chlorobenzene	221.8	6.078	6.572	48.78
Ethylbenzene	221.8	5.813	6.221	47.16
Tetrachloroethane	221.8	5.690	6.289	33.88
1,3-Dichlorobenzene	221.8	6.709	6.254	45.81
1,2-Dichlorobenzene	221.8	5.490	6.254	44.49
Nitrobenzene	221.8	5.930	6.598	22.00
Napthalene	221.8	5.513	6.127	35.40
1-Chloronapthalene	221.8	5.175	5.888	32.67
2,6-Dinitrotoluene	221.8	5.205	6.017	26.90
Fluorene	221.8	4.960	5.700	36.88
2,4-Dinitrotoluene	221.8	5.193	6.017	27.04
Hexachlorobenzene	221.8	4.584	5.426	35.94
Phenanthrene	221.8	4.808	5.601	24.66
Fluoranthene	221.8	4.609	5.455	23.01

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 25°C
AIR, 30 G/L, 54 °C AVERAGE WATER
TEMPERATURE, 39 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^{3})	Liquid Phase Mass Transfer Coefficient (m/sec x 10^{5})	K_1a (1/hr)
Toluene	377.5	6.726	15.55	194.00
Chlorobenzene	377.5	6.578	15.60	191.40
Ethylbenzene	377.5	6.291	14.77	185.80
Tetrachloroethane	377.5	6.165	14.93	117.40
1,3-Dichlorobenzene	377.5	6.115	14.85	174.30
1,2-Dichlorobenzene	377.5	6.109	14.85	171.70
Nitrobenzene	377.5	6.427	15.67	63.03
Napthalene	377.5	5.975	14.55	122.83
1-Chloronapthalene	377.5	5.611	13.98	112.40
2,6-Dinitrotoluene	377.5	5.651	14.29	78.75
Fluorene	377.5	5.376	13.53	132.70
2,4-Dinitrotoluene	377.5	5.634	14.29	81.41
Hexachlorobenzene	377.5	4.972	12.88	133.50
Phenanthrene	377.5	5.216	13.30	84.40
Fluoranthene	377.5	4.997	12.95	79.60

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 25 °C
AIR, 90 G/L, 50°C AVERAGE WATER
TEMPERATURE, 36°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	266.6	6.518	8.142	74.03
Chlorobenzene	266.6	6.374	8.170	74.25
Ethylbenzene	266.6	6.097	7.737	70.75
Tetrachloroethane	266.6	5.970	7.818	51.95
1,3-Dichlorobenzene	266.6	5.931	7.775	68.02
1,2-Dichlorobenzene	266.6	6.119	7.775	67.55
Nitrobenzene	266.6	6.222	8.202	32.88
Napthalene	266.6	5.785	7.617	53.54
1-Chloronapthalene	266.6	5.430	7.320	49.61
2,6-Dinitrotoluene	266.6	5.632	7.479	39.65
Fluorene	266.6	5.200	7.068	55.32
2,4-Dinitrotoluene	266.6	5.453	7.480	39.87
Hexachlorobenzene	266.6	4.812	6.745	54.41
Phenanthrene	266.6	5.045	6.963	39.00
Fluoranthene	266.6	4.819	6.781	36.82

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55°C WATER, 25 °C
AIR, 150 G/L, 46°C AVERAGE WATER
TEMPERATURE, 34°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	218.5	6.518	5.965	45.11
Chlorobenzene	218.5	6.374	5.984	44.86
Ethylbenzene	218.5	6.097	5.239	39.88
Tetrachloroethane	218.5	5.970	5.727	33.99
1,3-Dichlorobenzene	218.5	5.931	5.696	41.83
1,2-Dichlorobenzene	218.5	6.119	5.696	41.62
Nitrobenzene	218.5	6.222	6.010	23.39
Napthalene	218.5	5.785	5.581	34.63
1-Chloronapthalene	218.5	5.430	5.364	32.34
2,6-Dinitrotoluene	218.5	5.632	5.482	27.05
Fluorene	218.5	5.200	5.190	34.95
2,4-Dinitrotoluene	218.5	5.453	5.480	27.17
Hexachlorobenzene	218.5	4.812	4.940	34.16
Phenanthrene	218.5	5.045	5.100	26.35
Fluoranthene	218.5	4.819	4.968	25.01

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C
AIR, 30 G/L, 52 °C AVERAGE WATER
TEMPERATURE, 38 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	368.0	6.726	12.98	160.03
Chlorobenzene	368.0	6.578	13.02	158.20
Ethylbenzene	368.0	6.291	12.32	153.00
Tetrachloroethane	368.0	6.165	12.47	102.70
1,3-Dichlorobenzene	368.0	6.115	12.39	145.10
1,2-Dichlorobenzene	368.0	6.109	12.39	143.20
Nitrobenzene	368.0	6.427	13.08	58.04
Napthalene	368.0	5.975	12.14	106.60
1-Chloronapthalene	368.0	5.610	11.67	98.02
2,6-Dinitrotoluene	368.0	5.615	11.92	71.05
Fluorene	368.0	5.376	11.30	113.10
2,4-Dinitrotoluene	368.0	5.634	11.92	73.26
Hexachlorobenzene	368.0	4.972	10.75	113.05
Phenanthrene	368.0	5.216	11.10	75.29
Fluoranthene	368.0	4.997	10.81	71.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C
AIR, 90 G/L, 51 °C AVERAGE WATER
TEMPERATURE, 36 °C AVERAGE AIR
TEMPERATURE, AND 0.9M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	262.6	6.518	7.808	70.17
Chlorobenzene	262.6	6.374	7.834	69.58
Ethylbenzene	262.6	6.097	7.414	66.96
Tetrachloroethane	262.6	5.970	7.499	49.72
1,3-Dichlorobenzene	262.6	5.931	7.455	64.51
1,2-Dichlorobenzene	262.6	6.119	7.455	64.08
Nitrobenzene	262.6	6.222	7.866	31.83
Napthalene	262.6	5.785	7.304	51.15
1-Chloronapthalene	262.6	5.430	7.019	49.05
2,6-Dinitrotoluene	262.6	5.632	7.173	38.17
Fluorene	262.6	5.200	6.795	52.68
2,4-Dinitrotoluene	262.6	5.453	7.171	38.37
Hexachlorobenzene	262.6	4.782	6.468	51.69
Phenanthrene	262.6	5.046	6.675	37.49
Fluoranthene	262.6	4.856	6.504	35.54

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C
AIR, 150 G/L, 52°C AVERAGE WATER
TEMPERATURE, 39°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	221.8	6.530	6.218	47.66
Chlorobenzene	221.8	6.386	6.238	47.37
Ethylbenzene	221.8	6.108	5.904	45.44
Tetrachloroethane	221.8	5.918	5.971	35.62
1,3-Dichlorobenzene	221.8	5.942	5.937	44.14
1,2-Dichlorobenzene	221.8	6.130	5.937	43.90
Nitrobenzene	221.8	6.234	6.260	24.25
Napthalene	221.8	5.796	5.816	36.33
1-Chloronapthalene	221.8	5.440	5.590	33.89
2,6-Dinitrotoluene	221.8	5,642	5.712	28.19
Fluorene	221.8	5.210	5.411	36.78
2,4-Dinitrotoluene	221.8	5.464	5.710	28.32
Hexachlorobenzene	221.8	4.791	5.150	35.90
Phenanthrene	221.8	5.066	5.313	27.51
Fluoranthene	221.8	4.828	5.179	26.09

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C
AIR, 30 G/L, 52 °C AVERAGE WATER
TEMPERATURE, 41 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	368.0	6.726	12.98	160.03
Chlorobenzene	368.0	6.578	13.02	158.20
Ethylbenzene	368.0	6.291	12.32	153.00
Tetrachloroethane	368.0	6.165	12.47	102.70
1,3-Dichlorobenzene	368.0	6.115	12.39	145.10
1,2-Dichlorobenzene	368.0	6.109	12.39	143.20
Nitrobenzene	368.0	6.427	13.08	58.04
Napthalene	368.0	5.975	12.14	106.60
1-Chloronapthalene	368.0	5.610	11.67	98.02
2,6-Dinitrotoluene	368.0	5.615	11.92	71.05
Fluorene	368.0	5.376	11.30	113.10
2,4-Dinitrotoluene	368.0	5.634	11.92	73.26
Hexachlorobenzene	368.0	4.972	10.75	113.05
Phenanthrene	368.0	5.216	11.10	75.29
Fluoranthene	368.0	4.997	10.81	71.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C AIR, 90 G/L, 51 °C AVERAGE WATER TEMPERATURE, 36 °C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	262.6	6.518	7.808	70.17
Chlorobenzene	262.6	6.374	7.834	69.58
Ethylbenzene	262.6	6.097	7.414	66.96
Tetrachloroethane	262.6	5.970	7.499	49.72
1,3-Dichlorobenzene	262.6	5.931	7.455	64.51
1,2-Dichlorobenzene	262.6	6.119	7.455	64.08
Nitrobenzene	262.6	6.222	7.866	31.83
Napthalene	262.6	5.785	7.304	51.15
1-Chloronapthalene	262.6	5.430	7.019	49.05
2,6-Dinitrotoluene	262.6	5.632	7.173	38.17
Fluorene	262.6	5.200	6.795	52.68
2,4-Dinitrotoluene	262.6	5.453	7.171	38.37
Hexachlorobenzene	262.6	4.782	6.468	51.69
Phenanthrene	262.6	5.046	6.675	37.49
Fluoranthene	262.6	4.856	6.504	35.54

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 55 °C WATER, 25 °C
AIR, 150 G/L, 52°C AVERAGE WATER
TEMPERATURE, 39°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	221.8	6.530	6.218	47.66
Chlorobenzene	221.8	6.386	6.238	47.37
Ethylbenzene	221.8	6.108	5.904	45.44
Tetrachloroethane	221.8	5.918	5.971	35.62
1,3-Dichlorobenzene	221.8	5.942	5.937	44.14
1,2-Dichlorobenzene	221.8	6.130	5.937	43.90
Nitrobenzene	221.8	6.234	6.260	24.25
Napthalene	221.8	5.796	5.816	36.33
1-Chloronapthalene	221.8	5.440	5.590	33.89
2,6-Dinitrotoluene	221.8	5.642	5.712	28.19
Fluorene	221.8	5.210	5.411	36.78
2,4-Dinitrotoluene	221.8	5.464	5.710	28.32
Hexachlorobenzene	221.8	4.791	5.150	35.90
Phenanthrene	221.8	5.066	5.313	27.51
Fluoranthene	221.8	4.828	5.179	26.09

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 15 °C AIR, 30 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.70	4.3430	0.2072	156.50
Ethylbenzene	97.27	3.9780	0.2262	143.40
Tetrachloroethane	77.52	4.5730	0.1968	164.80
1,3-Dichlorobenzene	96.71	4.1670	0.2150	150.10
1,2-Dichlorobenzene	96.44	4.1700	0.2158	150.30
Nitrobenzene	26.03	0.8680	1.0370	31.28
Napthalene	89.48	4.8970	0.1838	176.40
1-Chloronapthalene	84.00	5.6730	0.1587	204.40
2,6-Dinitrotoluene	36.95	0.9000	1.0000	32.43
Fluorene	47.62	2.0680	0.4352	74.52
2,4-Dinitrotoluene	32.58	0.4380	2.0550	15.78
Hexachlorobenzene	47.59	0.7366	1.2220	26.54
Phenanthrene	29.87	0.5090	1.7680	18.40
Fluoranthene	35.56	0.7250	1.2410	26.12

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 15 °C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.10	4.9750	0.1809	61.30
Ethylbenzene	99.31	5.1780	0.1738	63.80
Tetrachloroethane	95.50	4.4930	0.2003	55.37
1,3-Dichlorobenzene	99.30	5.3660	0.1677	66.12
1,2-Dichlorobenzene	99.17	5.2260	0.1722	64.40
Nitrobenzene	51.78	1.2740	0.7063	15.70
Napthalene	96.39	4.4200	0.2035	54.47
1-Chloronapthalene	97.04	4.9480	0.1819	60.97
2,6-Dinitrotoluene	39.08	0.5887	1.5290	7.25
Fluorene	68.02	1.6380	0.5495	20.18
2,4-Dinitrotoluene	40.39	0.5423	1.6590	6.68
Hexachlorobenzene	56.00	0.8686	1.0360	10.70
Phenanthrene	42.00	0.6438	1.3880	8.00
Fluoranthene	43.67	0.6993	1.2870	8.62

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 15°C AIR, 150 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.28	5.0980	0.1765	36.25
Ethylbenzene	99.33	5.1260	0.1756	36.45
Tetrachloroethane	97.00	4.3280	0.2790	30.78
1,3-Dichlorobenzene	99.50	5.5520	0.1621	39.48
1,2-Dichlorobenzene	99.65	5.9630	0.1509	42.40
Nitrobenzene	61.64	1.3640	0.6598	9.70
Napthalene	96.89	4.0880	0.2202	29.07
1-Chloronapthalene	97.63	4.5270	0.1980	32.19
2,6-Dinitrotoluene	40.00	0.5651	1.5930	4.02
Fluorene	76.69	1.8360	0.4902	13.06
2,4-Dinitrotoluene	44.13	0.6002	1.4990	4.27
Hexachlorobenzene	59.49	0.9367	0.9608	6.66
Phenanthrene	44.00	0.6438	1.3980	4.59
Fluoranthene	45.00	0.6707	1.3420	4.77

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 15 °C AIR, 30 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.51	4.3490	0.2760	117.50
Ethylbenzene	98.64	4.8470	0.2476	131.00
Tetrachloroethane	74.70	6.2020	0.1935	167.60
1,3-Dichlorobenzene	98.82	5.7190	0.2098	154.50
1,2-Dichlorobenzene	97.60	4.8930	0.2452	132.20
Nitrobenzene	25.40	1.1550	1.0390	31.22
Napthalene	91.36	12.4300	0.0966	335.80
1-Chloronapthalene	84.50	11.0100	0.1090	297.60
2,6-Dinitrotoluene	39.53	1.2050	0.9956	32.57
Fluorene	40.40	1.2210	0.9827	33.00
2,4-Dinitrotoluene	33.59	0.4624	2.5950	12.50
Hexachlorobenzene	54.41	0.9397	1.2770	25.40
Phenanthrene	43.20	1.4240	0.8427	38.48
Fluoranthene	44.60	2.1380	0.5613	57.77

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
($K_l a$) FOR 55°C WATER, 15°C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	$K_l a$ (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.30	5.2440	0.2288	48.47
Ethylbenzene	98.96	4.7470	0.2528	43.87
Tetrachloroethane	94.54	4.1690	0.2878	38.53
1,3-Dichlorobenzene	97.94	4.1770	0.2873	38.60
1,2-Dichlorobenzene	98.40	4.9460	0.2670	41.53
Nitrobenzene	58.58	1.7930	0.6692	16.57
Napthalene	98.10	5.4040	0.2221	49.94
1-Chloronapthalene	97.99	5.5660	0.2156	51.43
2,6-Dinitrotoluene	39.96	0.6097	1.9680	5.64
Fluorene	79.77	2.5850	0.4614	23.89
2,4-Dinitrotoluene	44.35	0.6174	1.9440	5.71
Hexachlorobenzene	57.04	0.8951	1.3410	8.27
Phenanthrene	44.56	0.7120	1.6850	6.58
Fluoranthene	50.40	0.8901	1.3470	8.23

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 15°C AIR, 150 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.52	5.4950	0.2162	29.60
Ethylbenzene	98.53	4.4316	0.2780	23.02
Tetrachloroethane	98.49	5.2220	0.2298	27.85
1,3-Dichlorobenzene	99.49	5.5270	0.2171	29.48
1,2-Dichlorobenzene	99.22	5.1040	0.2351	27.22
Nitrobenzene	69.76	1.8400	0.6521	9.81
Napthalene	98.65	5.1160	0.2345	27.29
1-Chloronapthalene	98.18	4.8500	0.2474	25.87
2,6-Dinitrotoluene	40.98	0.5838	2.0570	3.11
Fluorene	80.00	2.0530	0.5845	10.95
2,4-Dinitrotoluene	45.04	0.6175	1.9430	3.30
Hexachlorobenzene	71.32	1.3050	0.9192	6.96
Phenanthrene	44.00	0.6426	1.8680	3.43
Fluoranthene	51.50	0.8272	1.4510	4.41

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 25°C AIR, 30 G/L, AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	94.10	3.1570	0.1910	170.60
Ethylbenzene	92.71	2.8290	0.2121	152.90
Tetrachloroethane	78.86	3.7490	0.1600	202.60
1,3-Dichlorobenzene	95.72	3.7250	0.1611	201.30
1,2-Dichlorobenzene	92.89	3.1490	0.1906	170.20
Nitrobenzene	28.32	0.9773	0.1640	52.82
Napthalene	87.00	4.5060	0.1332	243.60
1-Chloronapthalene	80.59	3.6110	0.1662	195.20
2,6-Dinitrotoluene	40.29	1.0640	0.5637	57.53
Fluorene	50.46	2.2040	0.2722	119.10
2,4-Dinitrotoluene	43.62	0.6479	0.9261	35.02
Hexachlorobenzene	44.64	0.6576	0.9125	35.54
Phenanthrene	43.31	0.9583	0.6261	51.79
Fluoranthene	33.15	0.6419	1.0330	31.38

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 25°C AIR, 90 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.11	3.7010	0.1621	68.40
Ethylbenzene	96.84	3.5650	0.1683	65.89
Tetrachloroethane	93.06	3.5880	0.1672	66.31
1,3-Dichlorobenzene	97.99	4.1640	0.1441	76.97
1,2-Dichlorobenzene	97.08	3.7860	0.1585	69.98
Nitrobenzene	40.01	0.7090	0.8461	13.11
Napthalene	93.97	3.5640	0.1683	65.88
1-Chloronapthalene	92.58	3.3760	0.1777	62.40
2,6-Dinitrotoluene	45.70	0.7449	0.8054	13.77
Fluorene	63.07	1.3370	0.4486	24.27
2,4-Dinitrotoluene	46.83	0.6643	0.9032	12.28
Hexachlorobenzene	56.70	0.8800	0.6818	16.27
Phenanthrene	47.90	0.8245	0.7277	15.24
Fluoranthene	38.63	1.6780	1.0700	10.36

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 25 °C AIR, 150 G/L,
AND 0.6 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.03	3.6080	0.1663	38.49
Ethylbenzene	97.37	3.7080	0.1668	39.55
Tetrachloroethane	95.08	3.5780	0.1677	38.17
1,3-Dichlorobenzene	99.07	4.8670	0.1233	51.91
1,2-Dichlorobenzene	97.43	3.8150	0.1573	40.70
Nitrobenzene	45.29	0.7415	0.8092	7.91
Napthalene	96.20	3.7720	0.1591	40.23
1-Chloronapthalene	94.72	3.4300	0.1749	36.58
2,6-Dinitrotoluene	45.96	0.6882	0.8718	7.34
Fluorene	73.58	1.6260	0.3689	17.35
2,4-Dinitrotoluene	45.65	0.6276	0.9561	6.97
Hexachlorobenzene	58.19	0.8993	0.6672	9.59
Phenanthrene	47.94	0.7205	0.8327	7.69
Fluoranthene	44.82	0.6545	0.9167	6.98

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 25°C AIR, 30 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	97.53	4.1770	0.2155	150.50
Ethylbenzene	97.28	3.9230	0.2294	141.40
Tetrachloroethane	86.60	6.5200	0.1380	234.90
1,3-Dichlorobenzene	97.29	4.3020	0.2091	155.00
1,2-Dichlorobenzene	97.30	4.4070	0.2042	158.80
Nitrobenzene	29.50	1.2570	0.7159	45.30
Napthalene	90.53	5.7340	0.1570	206.60
1-Chloronapthalene	86.10	5.0800	0.1771	183.10
2,6-Dinitrotoluene	40.77	1.1000	0.8182	39.64
Fluorene	50.61	2.2410	0.4016	80.76
2,4-Dinitrotoluene	44.68	0.6811	1.3210	24.54
Hexachlorobenzene	51.93	0.8327	1.0810	30.01
Phenanthrene	44.00	0.9938	0.9056	35.81
Fluoranthene	43.33	0.9957	0.9039	35.88

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55 °C WATER, 25°C AIR, 90 G/L,
AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.48	5.5200	0.1630	68.03
Ethylbenzene	99.58	4.8520	0.1854	59.80
Tetrachloroethane	97.90	5.4590	0.1649	67.28
1,3-Dichlorobenzene	99.04	4.9690	0.1811	61.22
1,2-Dichlorobenzene	98.86	4.8190	0.1860	59.38
Nitrobenzene	46.20	0.9306	0.9672	11.47
Napthalene	96.73	4.2830	0.2101	52.78
1-Chloronapthalene	96.07	4.3150	0.2086	53.18
2,6-Dinitrotoluene	46.00	0.7528	1.1960	9.28
Fluorene	65.26	1.4420	0.6240	17.77
2,4-Dinitrotoluene	45.57	0.6348	1.4100	7.87
Hexachlorobenzene	53.80	0.8098	1.1111	9.98
Phenanthrene	49.08	0.8076	1.1140	9.95
Fluoranthene	42.41	0.6462	1.3930	7.96

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 25°C AIR, 150 G/L, AND 0.9 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.60	5.8000	0.1552	41.32
Ethylbenzene	97.40	3.7200	0.2419	26.45
Tetrachloroethane	98.90	5.5000	0.1636	39.11
1,3-Dichlorobenzene	99.37	5.2760	0.1757	37.52
1,2-Dichlorobenzene	99.15	4.9840	0.1806	35.44
Nitrobenzene	58.33	1.1720	0.7681	8.33
Napthalene	97.64	4.3520	0.2068	30.94
1-Chloronapthalene	97.32	4.2750	0.2105	30.40
2,6-Dinitrotoluene	47.96	0.7354	1.2240	5.23
Fluorene	77.32	1.8420	0.4885	13.10
2,4-Dinitrotoluene	46.88	0.6519	1.3800	4.64
Hexachlorobenzene	60.82	0.9677	0.9300	6.88
Phenanthrene	51.51	0.8060	1.1170	5.73
Fluoranthene	47.10	0.7051	1.2760	5.01

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55°C WATER, 25 °C AIR, 30 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.21	5.6340	0.2130	152.30
Ethylbenzene	98.66	4.7920	0.2504	129.50
Tetrachloroethane	84.30	9.2070	0.1303	248.80
1,3-Dichlorobenzene	99.28	6.1700	0.1945	166.70
1,2-Dichlorobenzene	98.65	5.4930	0.2184	148.50
Nitrobenzene	27.63	1.3150	0.9126	35.54
Napthalene	93.40	9.5930	0.1251	259.20
1-Chloronapthalene	88.33	8.4930	0.1431	229.50
2,6-Dinitrotoluene	38.28	0.9903	1.2120	26.76
Fluorene	50.47	3.4600	0.3467	93.51
2,4-Dinitrotoluene	47.12	0.7518	1.5960	20.32
Hexachlorobenzene	58.24	1.0360	1.1590	27.99
Phenanthrene	51.64	2.0400	0.5881	55.14
Fluoranthene	53.83	3.7410	0.3208	101.10

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS
(K_1a) FOR 55°C WATER, 25 °C AIR, 90 G/L,
AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.20	5.0630	0.2370	46.80
Ethylbenzene	98.88	4.5750	0.2622	42.28
Tetrachloroethane	96.52	4.6630	0.2574	43.09
1,3-Dichlorobenzene	99.16	5.1130	0.2347	47.25
1,2-Dichlorobenzene	98.87	4.8230	0.2488	44.57
Nitrobenzene	59.28	1.6800	0.7145	15.52
Napthalene	98.37	5.4270	0.2211	50.16
1-Chloronapthalene	98.05	5.3660	0.2236	49.59
2,6-Dinitrotoluene	40.00	0.6042	1.9860	5.58
Fluorene	80.97	2.5880	0.4636	23.92
2,4-Dinitrotoluene	48.20	0.6931	1.7310	6.41
Hexachlorobenzene	60.45	0.9764	1.2250	9.05
Phenanthrene	46.05	0.7283	1.6480	6.73
Fluoranthene	53.83	0.9594	1.2510	8.87

EXPERIMENTAL OVERALL MASS TRANSFER COEFFICIENTS (K_1a) FOR 55 °C WATER, 25 °C AIR, 150 G/L, AND 1.2 M BED DEPTH

Compound	Percent Removal	Number Transfer Unit	Height Transfer Unit (m)	K_1a (1/hr)
Toluene	-	-	-	-
Chlorobenzene	99.36	5.2200	0.2298	27.84
Ethylbenzene	99.00	4.7310	0.2546	25.14
Tetrachloroethane	96.37	4.0750	0.2944	21.73
1,3-Dichlorobenzene	98.97	4.7910	0.2505	25.55
1,2-Dichlorobenzene	98.92	4.7620	0.2502	25.40
Nitrobenzene	73.81	2.1100	0.5687	11.25
Napthalene	99.14	5.7000	0.2106	30.39
1-Chloronapthalene	98.07	4.7920	0.2504	25.56
2,6-Dinitrotoluene	39.97	0.5651	2.1230	3.01
Fluorene	80.03	2.0630	0.5816	11.00
2,4-Dinitrotoluene	47.43	0.6646	1.8060	3.54
Hexachlorobenzene	73.70	1.4000	0.8570	7.47
Phenanthrene	46.33	0.6952	1.7260	3.71
Fluoranthene	53.29	0.8777	1.3670	4.68

APPENDIX D

ESTIMATED INTERFACIAL AREA PER UNIT BED VOLUME, GAS PHASE MASS TRANSFER COEFFICIENTS, LIQUID PHASE MASS TRANSFER COEFFICIENTS, AND OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS AT ALL COMBINATIONS OF WATER TEMPERATURES, GAS-TO-LIQUID RATIOS, AIR TEMPERATURES, AND BED DEPTHS

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 5 °C
AIR, 30 G/L, 15 °C AVERAGE WATER
TEMPERATURE, 10 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	332.9	5.773	5.280	58.76
Chlorobenzene	332.9	5.648	5.297	57.48
Ethylbenzene	332.9	5.446	5.014	56.18
Tetrachloroethane	332.9	5.285	5.069	36.96
1,3-Dichlorobenzene	332.9	5.252	5.043	52.84
1,2-Dichlorobenzene	332.9	5.239	5.043	51.94
Nitrobenzene	332.9	5.504	5.320	24.34
Napthalene	332.9	5.117	4.939	40.22
1-Chloronapthalene	332.9	4.804	4.751	36.30
2,6-Dinitrotoluene	332.9	4.840	4.851	32.04
Fluorene	332.9	4.600	4.595	43.07
2,4-Dinitrotoluene	332.9	4.831	4.850	31.49
Hexachlorobenzene	332.9	4.256	4.374	41.44
Phenanthrene	332.9	4.380	4.516	24.86
Fluoranthene	332.9	4.256	4.399	22.65

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C
AIR, 90 G/L, 15 °C AVERAGE WATER
TEMPERATURE, 10 °C AVERAGE AIR
TEMPERATURE, AND 0.6M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	5.773	3.204	25.87
Chlorobenzene	234.8	5.648	3.213	25.47
Ethylbenzene	234.8	5.406	3.042	24.68
Tetrachloroethane	234.8	5.285	3.075	18.78
1,3-Dichlorobenzene	234.8	5.252	3.059	23.77
1,2-Dichlorobenzene	234.8	5.239	3.059	23.57
Nitrobenzene	234.8	2.555	3.226	13.88
Napthalene	234.8	5.117	2.997	19.70
1-Chloronapthalene	234.8	4.803	2.882	18.12
2,6-Dinitrotoluene	234.8	4.840	2.943	16.65
Fluorene	234.8	4.600	2.788	20.16
2,4-Dinitrotoluene	234.8	4.830	2.943	16.44
Hexachlorobenzene	234.8	4.253	2.654	19.34
Phenanthrene	234.8	4.380	2.740	13.51
Fluoranthene	234.8	4.256	2.669	12.50

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C
AIR, 150 G/L, 14 °C AVERAGE WATER
TEMPERATURE, 9 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	197.5	5.773	2.558	17.52
Chlorobenzene	197.5	5.648	2.556	17.35
Ethylbenzene	197.5	5.401	2.429	16.69
Tetrachloroethane	197.5	5.285	2.456	13.36
1,3-Dichlorobenzene	197.5	5.252	2.443	16.22
1,2-Dichlorobenzene	197.5	5.239	2.443	16.09
Nitrobenzene	197.5	5.987	2.577	10.34
Napthalene	197.5	5.116	2.393	13.86
1-Chloronapthalene	197.5	4.804	2.302	12.82
2,6-Dinitrotoluene	197.5	4.840	2.350	11.97
Fluorene	197.5	4.600	2.226	13.93
2,4-Dinitrotoluene	197.5	4.830	2.350	11.84
Hexachlorobenzene	197.5	4.253	2.119	13.36
Phenanthrene	197.5	4.380	2.188	9.90
Fluoranthene	197.5	4.256	2.131	9.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 5 °C
AIR, 30 G/L, 15 °C AVERAGE WATER
TEMPERATURE, 10 °C AVERAGE AIR
TEMPERATURE, AND 0.9M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	5.773	5.280	58.76
Chlorobenzene	332.9	5.648	5.297	57.48
Ethylbenzene	332.9	5.446	5.014	56.18
Tetrachloroethane	332.9	5.285	5.069	36.96
1,3-Dichlorobenzene	332.9	5.252	5.043	52.84
1,2-Dichlorobenzene	332.9	5.239	5.043	51.94
Nitrobenzene	332.9	5.504	5.320	24.34
Napthalene	332.9	5.117	4.939	40.22
1-Chloronapthalene	332.9	4.804	4.751	36.30
2,6-Dinitrotoluene	332.9	4.840	4.851	32.04
Fluorene	332.9	4.600	4.595	43.07
2,4-Dinitrotoluene	332.9	4.831	4.850	31.49
Hexachlorobenzene	332.9	4.256	4.374	41.44
Phenanthrene	332.9	4.380	4.516	24.86
Fluoranthene	332.9	4.256	4.399	22.65

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C AIR, 90 G/L, 15 °C AVERAGE WATER TEMPERATURE, 10 °C AVERAGE AIR TEMPERATURE, AND 0.9 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	234.8	5.773	3.204	25.87
Chlorobenzene	234.8	5.648	3.213	25.47
Ethylbenzene	234.8	5.406	3.042	24.68
Tetrachloroethane	234.8	5.285	3.075	18.78
1,3-Dichlorobenzene	234.8	5.252	3.059	23.77
1,2-Dichlorobenzene	234.8	5.239	3.059	23.57
Nitrobenzene	234.8	2.555	3.226	13.88
Napthalene	234.8	5.117	2.997	19.70
1-Chloronapthalene	234.8	4.803	2.882	18.12
2,6-Dinitrotoluene	234.8	4.840	2.943	16.65
Fluorene	234.8	4.600	2.788	20.16
2,4-Dinitrotoluene	234.8	4.880	2.943	16.44
Hexachlorobenzene	234.8	4.253	2.654	19.34
Phenanthrene	234.8	4.380	2.740	13.51
Fluoranthene	234.8	4.256	2.669	12.50

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C AIR, 150 G/L, 14°C AVERAGE WATER TEMPERATURE, 9°C AVERAGE AIR TEMPERATURE, AND 0.9 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	197.5	5.773	2.558	17.52
Chlorobenzene	197.5	5.648	2.556	17.35
Ethylbenzene	197.5	5.401	2.429	16.69
Tetrachloroethane	197.5	5.285	2.456	13.36
1,3-Dichlorobenzene	197.5	5.252	2.443	16.22
1,2-Dichlorobenzene	197.5	5.239	2.443	16.09
Nitrobenzene	197.5	5.987	2.577	10.34
Napthalene	197.5	5.116	2.393	13.86
1-Chloronapthalene	197.5	4.804	2.302	12.82
2,6-Dinitrotoluene	197.5	4.840	2.350	11.97
Fluorene	197.5	4.600	2.226	13.93
2,4-Dinitrotoluene	197.5	4.830	2.350	11.84
Hexachlorobenzene	197.5	4.253	2.119	13.36
Phenanthrene	197.5	4.380	2.188	9.90
Fluoranthene	197.5	4.256	2.131	9.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 5 °C
AIR, 30 G/L, 14 °C AVERAGE WATER
TEMPERATURE, 10 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	5.773	5.280	58.76
Chlorobenzene	332.9	5.648	5.297	57.48
Ethylbenzene	332.9	5.446	5.014	56.18
Tetrachloroethane	332.9	5.285	5.069	36.96
1,3-Dichlorobenzene	332.9	5.252	5.043	52.84
1,2-Dichlorobenzene	332.9	5.239	5.043	51.94
Nitrobenzene	332.9	5.504	5.320	24.34
Napthalene	332.9	5.117	4.939	40.22
1-Chloronapthalene	332.9	4.804	4.751	36.30
2,6-Dinitrotoluene	332.9	4.840	4.851	32.04
Fluorene	332.9	4.600	4.595	43.07
2,4-Dinitrotoluene	332.9	4.831	4.850	31.49
Hexachlorobenzene	332.9	4.256	4.374	41.44
Phenanthrene	332.9	4.380	4.516	24.86
Fluoranthene	332.9	4.256	4.399	22.65

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C
AIR, 90 G/L, 15°C AVERAGE WATER
TEMPERATURE, 10°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	5.773	3.204	25.87
Chlorobenzene	234.8	5.648	3.213	25.47
Ethylbenzene	234.8	5.406	3.042	24.68
Tetrachloroethane	234.8	5.285	3.075	18.78
1,3-Dichlorobenzene	234.8	5.252	3.059	23.77
1,2-Dichlorobenzene	234.8	5.239	3.059	23.57
Nitrobenzene	234.8	2.555	3.226	13.88
Napthalene	234.8	5.117	2.997	19.70
1-Chloronapthalene	234.8	4.803	2.882	18.12
2,6-Dinitrotoluene	234.8	4.840	2.943	16.65
Fluorene	234.8	4.600	2.788	20.16
2,4-Dinitrotoluene	234.8	4.830	2.943	16.44
Hexachlorobenzene	234.8	4.253	2.654	19.34
Phenanthrene	234.8	4.380	2.740	13.51
Fluoranthene	234.8	4.256	2.669	12.50

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 5 °C
AIR, 150 G/L, 14 °C AVERAGE WATER
TEMPERATURE, 9 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	197.5	5.773	2.558	17.52
Chlorobenzene	197.5	5.648	2.556	17.35
Ethylbenzene	197.5	5.401	2.429	16.69
Tetrachloroethane	197.5	5.285	2.456	13.36
1,3-Dichlorobenzene	197.5	5.252	2.443	16.22
1,2-Dichlorobenzene	197.5	5.239	2.443	16.09
Nitrobenzene	197.5	5.987	2.577	10.34
Napthalene	197.5	5.116	2.393	13.86
1-Chloronapthalene	197.5	4.804	2.302	12.82
2,6-Dinitrotoluene	197.5	4.840	2.350	11.97
Fluorene	197.5	4.600	2.226	13.93
2,4-Dinitrotoluene	197.5	4.830	2.350	11.84
Hexachlorobenzene	197.5	4.253	2.119	13.36
Phenanthrene	197.5	4.380	2.188	9.90
Fluoranthene	197.5	4.256	2.131	9.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15 °C WATER, 15°C AIR, 30 G/L, 15°C AVERAGE WATER TEMPERATURE, 15°C AVERAGE AIR TEMPERATURE, AND 0.6 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	5.919	5.280	59.41
Chlorobenzene	332.9	5.787	5.297	58.42
Ethylbenzene	332.9	5.534	5.015	56.76
Tetrachloroethane	332.9	5.418	5.069	39.60
1,3-Dichlorobenzene	332.9	5.387	5.043	53.94
1,2-Dichlorobenzene	332.9	5.373	5.043	53.29
Nitrobenzene	332.9	5.643	5.320	26.38
Napthalene	332.9	5.248	4.940	42.07
1-Chloronapthalene	332.9	4.927	4.751	38.65
2,6-Dinitrotoluene	332.9	4.969	4.851	33.30
Fluorene	332.9	4.719	4.595	44.29
2,4-Dinitrotoluene	332.9	4.945	4.850	32.97
Hexachlorobenzene	332.9	4.364	4.374	42.72
Phenanthrene	332.9	4.572	4.517	27.73
Fluoranthene	332.9	4.384	4.400	25.44

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15 °C WATER, 15 °C AIR, 90 G/L, 15°C AVERAGE WATER TEMPERATURE, 15°C AVERAGE AIR TEMPERATURE, AND 0.6 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	5.919	3.203	26.05
Chlorobenzene	234.8	5.787	3.213	25.56
Ethylbenzene	234.8	5.534	3.042	24.87
Tetrachloroethane	234.8	5.418	3.075	19.63
1,3-Dichlorobenzene	234.8	5.387	3.059	24.10
1,2-Dichlorobenzene	234.8	5.373	3.059	23.92
Nitrobenzene	234.8	5.643	3.227	14.67
Napthalene	234.8	5.248	2.997	20.31
1-Chloronapthalene	234.8	4.927	2.882	18.93
2,6-Dinitrotoluene	234.8	4.966	2.943	17.13
Fluorene	234.8	4.719	2.788	20.53
2,4-Dinitrotoluene	234.8	4.364	2.943	16.32
Hexachlorobenzene	234.8	4.364	2.653	19.72
Phenanthrene	234.8	4.572	2.740	14.68
Fluoranthene	234.8	4.384	2.669	13.67

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15°C WATER, 15 °C AIR, 150 G/L, 15 °C AVERAGE WATER TEMPERATURE, 15 °C AVERAGE AIR TEMPERATURE, AND 0.6 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	197.5	5.919	2.556	17.63
Chlorobenzene	197.5	5.787	2.566	17.51
Ethylbenzene	197.5	5.534	2.429	16.79
Tetrachloroethane	197.5	5.418	2.456	13.87
1,3-Dichlorobenzene	197.5	5.387	2.443	16.41
1,2-Dichlorobenzene	197.5	5.373	2.443	16.31
Nitrobenzene	197.5	5.643	2.577	10.86
Napthalene	197.5	5.248	2.393	14.21
1-Chloronapthalene	197.5	4.927	2.302	13.31
2,6-Dinitrotoluene	197.5	4.966	2.350	12.27
Fluorene	197.5	4.719	2.226	14.15
2,4-Dinitrotoluene	197.5	4.945	2.350	12.20
Hexachlorobenzene	197.5	4.364	2.119	13.61
Phenanthrene	197.5	4.572	2.188	10.64
Fluoranthene	197.5	4.384	2.131	9.97

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15°C WATER, 15°C AIR, 30 G/L, 15°C AVERAGE WATER TEMPERATURE, 15°C AVERAGE AIR TEMPERATURE, AND 0.9 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	332.9	5.919	5.280	59.41
Chlorobenzene	332.9	5.787	5.297	58.42
Ethylbenzene	332.9	5.534	5.015	56.76
Tetrachloroethane	332.9	5.418	5.069	39.60
1,3-Dichlorobenzene	332.9	5.387	5.043	53.94
1,2-Dichlorobenzene	332.9	5.373	5.043	53.29
Nitrobenzene	332.9	5.643	5.320	26.38
Napthalene	332.9	5.248	4.940	42.07
1-Chloronapthalene	332.9	4.927	4.751	38.65
2,6-Dinitrotoluene	332.9	4.969	4.851	33.30
Fluorene	332.9	4.719	4.595	44.29
2,4-Dinitrotoluene	332.9	4.945	4.850	32.97
Hexachlorobenzene	332.9	4.364	4.374	42.72
Phenanthrene	332.9	4.572	4.517	27.73
Fluoranthene	332.9	4.384	4.400	25.44

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 15°C
AIR, 90 G/L, 15 °C AVERAGE WATER
TEMPERATURE, 15 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	234.8	5.919	3.203	26.05
Chlorobenzene	234.8	5.787	3.213	25.56
Ethylbenzene	234.8	5.534	3.042	24.87
Tetrachloroethane	234.8	5.418	3.075	19.63
1,3-Dichlorobenzene	234.8	5.387	3.059	24.10
1,2-Dichlorobenzene	234.8	5.373	3.059	23.92
Nitrobenzene	234.8	5.643	3.227	14.67
Napthalene	234.8	5.248	2.997	20.31
1-Chloronapthalene	234.8	4.927	2.882	18.93
2,6-Dinitrotoluene	234.8	4.966	2.943	17.13
Fluorene	234.8	4.719	2.788	20.53
2,4-Dinitrotoluene	234.8	4.364	2.943	16.32
Hexachlorobenzene	234.8	4.364	2.653	19.72
Phenanthrene	234.8	4.572	2.740	14.68
Fluoranthene	234.8	4.384	2.669	13.67

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 15 °C
AIR, 150 G/L, 15°C AVERAGE WATER
TEMPERATURE, 15°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	197.5	5.919	2.556	17.63
Chlorobenzene	197.5	5.787	2.566	17.51
Ethylbenzene	197.5	5.534	2.429	16.79
Tetrachloroethane	197.5	5.418	2.456	13.87
1,3-Dichlorobenzene	197.5	5.387	2.443	16.41
1,2-Dichlorobenzene	197.5	5.373	2.443	16.31
Nitrobenzene	197.5	5.643	2.577	10.86
Napthalene	197.5	5.248	2.393	14.21
1-Chloronapthalene	197.5	4.927	2.302	13.31
2,6-Dinitrotoluene	197.5	4.966	2.350	12.27
Fluorene	197.5	4.719	2.226	14.15
2,4-Dinitrotoluene	197.5	4.945	2.350	12.20
Hexachlorobenzene	197.5	4.364	2.119	13.61
Phenanthrene	197.5	4.572	2.188	10.64
Fluoranthene	197.5	4.384	2.131	9.97

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15°C WATER, 15°C AIR, 30 G/L, 15°C AVERAGE WATER TEMPERATURE, 15°C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	5.919	5.280	59.41
Chlorobenzene	332.9	5.787	5.297	58.42
Ethylbenzene	332.9	5.534	5.015	56.76
Tetrachloroethane	332.9	5.418	5.069	39.60
1,3-Dichlorobenzene	332.9	5.387	5.043	53.94
1,2-Dichlorobenzene	332.9	5.373	5.043	53.29
Nitrobenzene	332.9	5.643	5.320	26.38
Napthalene	332.9	5.248	4.940	42.07
1-Chloronapthalene	332.9	4.927	4.751	38.65
2,6-Dinitrotoluene	332.9	4.969	4.851	33.30
Fluorene	332.9	4.719	4.595	44.29
2,4-Dinitrotoluene	332.9	4.945	4.850	32.97
Hexachlorobenzene	332.9	4.364	4.374	42.72
Phenanthrene	332.9	4.572	4.517	27.73
Fluoranthene	332.9	4.384	4.400	25.44

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 15°C
AIR, 90 G/L, 15°C AVERAGE WATER
TEMPERATURE, 15°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	5.919	3.203	26.05
Chlorobenzene	234.8	5.787	3.213	25.56
Ethylbenzene	234.8	5.534	3.042	24.87
Tetrachloroethane	234.8	5.418	3.075	19.63
1,3-Dichlorobenzene	234.8	5.387	3.059	24.10
1,2-Dichlorobenzene	234.8	5.373	3.059	23.92
Nitrobenzene	234.8	5.643	3.227	14.67
Napthalene	234.8	5.248	2.997	20.31
1-Chloronapthalene	234.8	4.927	2.882	18.93
2,6-Dinitrotoluene	234.8	4.966	2.943	17.13
Fluorene	234.8	4.719	2.788	20.53
2,4-Dinitrotoluene	234.8	4.364	2.943	16.32
Hexachlorobenzene	234.8	4.364	2.653	19.72
Phenanthrene	234.8	4.572	2.740	14.68
Fluoranthene	234.8	4.384	2.669	13.67

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15°C WATER, 15 °C AIR, 150 G/L, 15°C AVERAGE WATER TEMPERATURE, 15°C AVERAGE AIR TEMPERATURE, AND 1.2 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	197.5	5.919	2.556	17.63
Chlorobenzene	197.5	5.787	2.566	17.51
Ethylbenzene	197.5	5.534	2.429	16.79
Tetrachloroethane	197.5	5.418	2.456	13.87
1,3-Dichlorobenzene	197.5	5.387	2.443	16.41
1,2-Dichlorobenzene	197.5	5.373	2.443	16.31
Nitrobenzene	197.5	5.643	2.577	10.86
Napthalene	197.5	5.248	2.393	14.21
1-Chloronapthalene	197.5	4.927	2.302	13.31
2,6-Dinitrotoluene	197.5	4.966	2.350	12.27
Fluorene	197.5	4.719	2.226	14.15
2,4-Dinitrotoluene	197.5	4.945	2.350	12.20
Hexachlorobenzene	197.5	4.364	2.119	13.61
Phenanthrene	197.5	4.572	2.188	10.64
Fluoranthene	197.5	4.384	2.131	9.97

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15 °C WATER, 25°C
AIR, 30 G/L, 16 °C AVERAGE WATER
TEMPERATURE, 21 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	6.068	5.280	59.96
Chlorobenzene	332.9	5.933	5.297	59.20
Ethylbenzene	332.9	5.673	5.015	57.23
Tetrachloroethane	332.9	5.554	5.069	41.78
1,3-Dichlorobenzene	332.9	5.521	5.043	54.85
1,2-Dichlorobenzene	332.9	5.508	5.043	54.27
Nitrobenzene	332.9	5.787	5.320	28.22
Napthalene	332.9	5.380	4.940	43.74
1-Chloronapthalene	332.9	5.052	4.751	40.44
2,6-Dinitrotoluene	332.9	4.997	4.851	34.23
Fluorene	332.9	4.839	4.595	45.38
2,4-Dinitrotoluene	332.9	5.070	4.850	34.40
Hexachlorobenzene	332.9	4.476	4.374	44.05
Phenanthrene	332.9	4.689	4.516	30.29
Fluoranthene	332.9	4.496	4.399	28.11

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 90 G/L, 15°C AVERAGE WATER
TEMPERATURE, 20°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	234.8	6.067	3.203	26.18
Chlorobenzene	234.8	5.932	3.214	26.01
Ethylbenzene	234.8	5.673	3.042	24.94
Tetrachloroethane	234.8	5.554	3.075	20.37
1,3-Dichlorobenzene	234.8	5.521	3.059	24.35
1,2-Dichlorobenzene	234.8	5.508	3.059	24.18
Nitrobenzene	234.8	5.787	3.227	15.46
Napthalene	234.8	5.380	2.997	20.85
1-Chloronapthalene	234.8	5.051	2.882	19.52
2,6-Dinitrotoluene	234.8	4.997	2.943	17.46
Fluorene	234.8	4.839	2.788	20.85
2,4-Dinitrotoluene	234.8	5.070	2.943	17.53
Hexachlorobenzene	234.8	4.476	2.654	20.07
Phenanthrene	234.8	4.689	2.740	15.67
Fluoranthene	234.8	4.496	2.669	14.70

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 150 G/L, 15 °C AVERAGE WATER
TEMPERATURE, 20°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	197.5	6.067	2.558	17.69
Chlorobenzene	197.5	5.933	2.556	17.61
Ethylbenzene	197.5	5.673	2.429	16.80
Tetrachloroethane	197.5	5.555	2.456	14.30
1,3-Dichlorobenzene	197.5	5.522	2.443	16.54
1,2-Dichlorobenzene	197.5	5.508	2.443	16.45
Nitrobenzene	197.5	5.787	2.577	11.37
Napthalene	197.5	5.380	2.393	14.51
1-Chloronapthalene	197.5	5.052	2.302	13.65
2,6-Dinitrotoluene	197.5	4.997	2.350	12.47
Fluorene	197.5	4.839	2.226	14.33
2,4-Dinitrotoluene	197.5	5.070	2.350	12.51
Hexachlorobenzene	197.5	4.476	2.119	13.76
Phenanthrene	197.5	4.690	2.188	11.23
Fluoranthene	197.5	4.496	2.131	10.61

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 30 G/L, 16°C AVERAGE WATER
TEMPERATURE, 21°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	6.068	5.280	59.96
Chlorobenzene	332.9	5.933	5.297	59.20
Ethylbenzene	332.9	5.673	5.015	57.23
Tetrachloroethane	332.9	5.554	5.069	41.78
1,3-Dichlorobenzene	332.9	5.521	5.043	54.85
1,2-Dichlorobenzene	332.9	5.508	5.043	54.27
Nitrobenzene	332.9	5.787	5.320	28.22
Napthalene	332.9	5.380	4.940	43.74
1-Chloronapthalene	332.9	5.052	4.751	40.44
2,6-Dinitrotoluene	332.9	4.997	4.851	34.23
Fluorene	332.9	4.839	4.595	45.38
2,4-Dinitrotoluene	332.9	5.070	4.850	34.40
Hexachlorobenzene	332.9	4.476	4.374	44.05
Phenanthrene	332.9	4.689	4.516	30.29
Fluoranthene	332.9	4.496	4.399	28.11

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 90 G/L, 15°C AVERAGE WATER
TEMPERATURE, 21°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	6.067	3.203	26.18
Chlorobenzene	234.8	5.932	3.214	26.01
Ethylbenzene	234.8	5.673	3.042	24.94
Tetrachloroethane	234.8	5.554	3.075	20.37
1,3-Dichlorobenzene	234.8	5.521	3.059	24.35
1,2-Dichlorobenzene	234.8	5.508	3.059	24.18
Nitrobenzene	234.8	5.787	3.227	15.46
Napthalene	234.8	5.380	2.997	20.85
1-Chloronapthalene	234.8	5.051	2.882	19.52
2,6-Dinitrotoluene	234.8	4.997	2.943	17.46
Fluorene	234.8	4.839	2.788	20.85
2,4-Dinitrotoluene	234.8	5.070	2.943	17.53
Hexachlorobenzene	234.8	4.476	2.654	20.07
Phenanthrene	234.8	4.689	2.740	15.67
Fluoranthene	234.8	4.496	2.669	14.70

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 15°C WATER, 25°C AIR, 150 G/L, 15 °C AVERAGE WATER TEMPERATURE, 20 °C AVERAGE AIR TEMPERATURE, AND 0.9 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	197.5	6.067	2.558	17.69
Chlorobenzene	197.5	5.933	2.556	17.61
Ethylbenzene	197.5	5.673	2.429	16.80
Tetrachloroethane	197.5	5.555	2.456	14.30
1,3-Dichlorobenzene	197.5	5.522	2.443	16.54
1,2-Dichlorobenzene	197.5	5.508	2.443	16.45
Nitrobenzene	197.5	5.787	2.577	11.37
Napthalene	197.5	5.380	2.393	14.51
1-Chloronapthalene	197.5	5.052	2.302	13.65
2,6-Dinitrotoluene	197.5	4.997	2.350	12.47
Fluorene	197.5	4.839	2.226	14.33
2,4-Dinitrotoluene	197.5	5.070	2.350	12.51
Hexachlorobenzene	197.5	4.476	2.119	13.76
Phenanthrene	197.5	4.690	2.188	11.23
Fluoranthene	197.5	4.496	2.131	10.61

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 30 G/L, 16 °C AVERAGE WATER
TEMPERATURE, 20°C AVERAGE AIR
TEMPERATURE, AND 1.2M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	332.9	6.068	5.280	59.96
Chlorobenzene	332.9	5.933	5.297	59.20
Ethylbenzene	332.9	5.673	5.015	57.23
Tetrachloroethane	332.9	5.554	5.069	41.78
1,3-Dichlorobenzene	332.9	5.521	5.043	54.85
1,2-Dichlorobenzene	332.9	5.508	5.043	54.27
Nitrobenzene	332.9	5.787	5.320	28.22
Napthalene	332.9	5.380	4.940	43.74
1-Chloronapthalene	332.9	5.052	4.751	40.44
2,6-Dinitrotoluene	332.9	4.997	4.851	34.23
Fluorene	332.9	4.839	4.595	45.38
2,4-Dinitrotoluene	332.9	5.070	4.850	34.40
Hexachlorobenzene	332.9	4.476	4.374	44.05
Phenanthrene	332.9	4.689	4.516	30.29
Fluoranthene	332.9	4.496	4.399	28.11

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 90 G/L, 16 °C AVERAGE WATER
TEMPERATURE, 20 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	234.8	6.067	3.203	26.18
Chlorobenzene	234.8	5.932	3.214	26.01
Ethylbenzene	234.8	5.673	3.042	24.94
Tetrachloroethane	234.8	5.554	3.075	20.37
1,3-Dichlorobenzene	234.8	5.521	3.059	24.35
1,2-Dichlorobenzene	234.8	5.508	3.059	24.18
Nitrobenzene	234.8	5.787	3.227	15.46
Napthalene	234.8	5.380	2.997	20.85
1-Chloronapthalene	234.8	5.051	2.882	19.52
2,6-Dinitrotoluene	234.8	4.997	2.943	17.46
Fluorene	234.8	4.839	2.788	20.85
2,4-Dinitrotoluene	234.8	5.070	2.943	17.53
Hexachlorobenzene	234.8	4.476	2.654	20.07
Phenanthrene	234.8	4.689	2.740	15.67
Fluoranthene	234.8	4.496	2.669	14.70

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 15°C WATER, 25°C
AIR, 150 G/L, 15°C AVERAGE WATER
TEMPERATURE, 20°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	197.5	6.067	2.558	17.69
Chlorobenzene	197.5	5.933	2.556	17.61
Ethylbenzene	197.5	5.673	2.429	16.80
Tetrachloroethane	197.5	5.555	2.456	14.30
1,3-Dichlorobenzene	197.5	5.522	2.443	16.54
1,2-Dichlorobenzene	197.5	5.508	2.443	16.45
Nitrobenzene	197.5	5.787	2.577	11.37
Napthalene	197.5	5.380	2.393	14.51
1-Chloronapthalene	197.5	5.052	2.302	13.65
2,6-Dinitrotoluene	197.5	4.997	2.350	12.47
Fluorene	197.5	4.839	2.226	14.33
2,4-Dinitrotoluene	197.5	5.070	2.350	12.51
Hexachlorobenzene	197.5	4.476	2.119	13.76
Phenanthrene	197.5	4.690	2.188	11.23
Fluoranthene	197.5	4.496	2.131	10.61

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 30 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 19 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	349.5	6.068	9.807	111.86
Chlorobenzene	349.5	5.933	9.839	109.11
Ethylbenzene	349.5	5.673	9.312	107.20
Tetrachloroethane	349.5	5.554	9.415	64.24
1,3-Dichlorobenzene	349.5	5.522	9.366	99.16
1,2-Dichlorobenzene	349.5	5.510	9.366	97.38
Nitrobenzene	349.5	5.786	9.877	37.22
Napthalene	349.5	5.378	9.173	69.67
1-Chloronapthalene	349.5	5.052	8.817	63.11
2,6-Dinitrotoluene	349.5	4.995	9.010	49.32
Fluorene	349.5	4.839	8.534	76.85
2,4-Dinitrotoluene	349.5	5.070	9.010	49.68
Hexachlorobenzene	349.5	4.476	8.124	75.21
Phenanthrene	349.5	4.659	8.381	42.68
Fluoranthene	349.5	4.496	8.169	39.14

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 90 G/L, 34°C AVERAGE WATER
TEMPERATURE, 18°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.8	6.067	5.925	49.76
Chlorobenzene	247.8	5.932	5.944	49.04
Ethylbenzene	247.8	5.673	5.626	47.52
Tetrachloroethane	247.8	5.554	5.689	33.61
1,3-Dichlorobenzene	247.8	5.521	5.659	45.32
1,2-Dichlorobenzene	247.8	5.510	5.659	44.80
Nitrobenzene	247.8	5.787	5.970	22.07
Napthalene	247.8	5.380	5.543	35.41
1-Chloronapthalene	247.8	5.052	5.327	32.60
2,6-Dinitrotoluene	247.8	4.997	5.443	27.22
Fluorene	247.8	4.838	5.156	37.09
2,4-Dinitrotoluene	247.8	5.070	5.443	27.37
Hexachlorobenzene	247.8	4.476	4.908	35.98
Phenanthrene	247.8	4.659	5.064	23.92
Fluoranthene	247.8	4.496	4.935	22.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 150 G/L, 33°C AVERAGE WATER
TEMPERATURE, 18°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	208.8	6.068	4.725	33.83
Chlorobenzene	208.8	5.932	4.740	33.46
Ethylbenzene	208.8	5.674	4.480	32.27
Tetrachloroethane	208.8	5.550	4.537	24.24
1,3-Dichlorobenzene	208.8	5.522	4.513	31.09
1,2-Dichlorobenzene	208.8	5.510	4.513	30.80
Nitrobenzene	208.8	5.787	4.761	16.82
Napthalene	208.8	5.378	4.419	25.24
1-Chloronapthalene	208.8	5.052	4.257	23.43
2,6-Dinitrotoluene	208.8	4.995	4.341	20.07
Fluorene	208.8	4.844	4.105	25.91
2,4-Dinitrotoluene	208.8	5.070	4.341	20.17
Hexachlorobenzene	208.8	4.477	3.912	25.07
Phenanthrene	208.8	4.690	4.038	17.81
Fluoranthene	208.8	4.496	3.936	16.59

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 30 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 19 °C AVERAGE AIR
TEMPERATURE, AND 0.9M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	349.5	6.068	9.807	111.86
Chlorobenzene	349.5	5.933	9.839	109.11
Ethylbenzene	349.5	5.673	9.312	107.20
Tetrachloroethane	349.5	5.554	9.415	64.24
1,3-Dichlorobenzene	349.5	5.522	9.366	99.16
1,2-Dichlorobenzene	349.5	5.510	9.366	97.38
Nitrobenzene	349.5	5.786	9.877	37.22
Napthalene	349.5	5.378	9.173	69.67
1-Chloronapthalene	349.5	5.052	8.817	63.11
2,6-Dinitrotoluene	349.5	4.995	9.010	49.32
Fluorene	349.5	4.839	8.534	76.85
2,4-Dinitrotoluene	349.5	5.070	9.010	49.68
Hexachlorobenzene	349.5	4.476	8.124	75.21
Phenanthrene	349.5	4.659	8.381	42.68
Fluoranthene	349.5	4.496	8.169	39.14

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 90 G/L, 33°C AVERAGE WATER
TEMPERATURE, 18°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	247.8	6.067	5.925	49.76
Chlorobenzene	247.8	5.932	5.944	49.04
Ethylbenzene	247.8	5.673	5.626	47.52
Tetrachloroethane	247.8	5.554	5.689	33.61
1,3-Dichlorobenzene	247.8	5.521	5.659	45.32
1,2-Dichlorobenzene	247.8	5.510	5.659	44.80
Nitrobenzene	247.8	5.787	5.970	22.07
Napthalene	247.8	5.380	5.543	35.41
1-Chloronapthalene	247.8	5.052	5.327	32.60
2,6-Dinitrotoluene	247.8	4.997	5.443	27.22
Fluorene	247.8	4.838	5.156	37.09
2,4-Dinitrotoluene	247.8	5.070	5.443	27.37
Hexachlorobenzene	247.8	4.476	4.908	35.98
Phenanthrene	247.8	4.659	5.064	23.92
Fluoranthene	247.8	4.496	4.935	22.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 150 G/L, 33°C AVERAGE WATER
TEMPERATURE, 18°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.068	4.725	33.83
Chlorobenzene	208.8	5.932	4.740	33.46
Ethylbenzene	208.8	5.674	4.480	32.27
Tetrachloroethane	208.8	5.550	4.537	24.24
1,3-Dichlorobenzene	208.8	5.522	4.513	31.09
1,2-Dichlorobenzene	208.8	5.510	4.513	30.80
Nitrobenzene	208.8	5.787	4.761	16.82
Napthalene	208.8	5.378	4.419	25.24
1-Chloronapthalene	208.8	5.052	4.257	23.43
2,6-Dinitrotoluene	208.8	4.995	4.341	20.07
Fluorene	208.8	4.844	4.105	25.91
2,4-Dinitrotoluene	208.8	5.070	4.341	20.17
Hexachlorobenzene	208.8	4.477	3.912	25.07
Phenanthrene	208.8	4.690	4.038	17.81
Fluoranthene	208.8	4.496	3.936	16.59

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 30 G/L, 34°C AVERAGE WATER
TEMPERATURE, 19°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	349.5	6.068	9.807	111.86
Chlorobenzene	349.5	5.933	9.839	109.11
Ethylbenzene	349.5	5.673	9.312	107.20
Tetrachloroethane	349.5	5.554	9.415	64.24
1,3-Dichlorobenzene	349.5	5.522	9.366	99.16
1,2-Dichlorobenzene	349.5	5.510	9.366	97.38
Nitrobenzene	349.5	5.786	9.877	37.22
Napthalene	349.5	5.378	9.173	69.67
1-Chloronapthalene	349.5	5.052	8.817	63.11
2,6-Dinitrotoluene	349.5	4.995	9.010	49.32
Fluorene	349.5	4.839	8.534	76.85
2,4-Dinitrotoluene	349.5	5.070	9.010	49.68
Hexachlorobenzene	349.5	4.476	8.124	75.21
Phenanthrene	349.5	4.659	8.381	42.68
Fluoranthene	349.5	4.496	8.169	39.14

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 90 G/L, 33 °C AVERAGE WATER
TEMPERATURE, 18 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.8	6.067	5.925	49.76
Chlorobenzene	247.8	5.932	5.944	49.04
Ethylbenzene	247.8	5.673	5.626	47.52
Tetrachloroethane	247.8	5.554	5.689	33.61
1,3-Dichlorobenzene	247.8	5.521	5.659	45.32
1,2-Dichlorobenzene	247.8	5.510	5.659	44.80
Nitrobenzene	247.8	5.787	5.970	22.07
Napthalene	247.8	5.380	5.543	35.41
1-Chloronapthalene	247.8	5.052	5.327	32.60
2,6-Dinitrotoluene	247.8	4.997	5.443	27.22
Fluorene	247.8	4.838	5.156	37.09
2,4-Dinitrotoluene	247.8	5.070	5.443	27.37
Hexachlorobenzene	247.8	4.476	4.908	35.98
Phenanthrene	247.8	4.659	5.064	23.92
Fluoranthene	247.8	4.496	4.935	22.21

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 5 °C
AIR, 150 G/L, 33 °C AVERAGE WATER
TEMPERATURE, 18 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	208.8	6.068	4.725	33.83
Chlorobenzene	208.8	5.932	4.740	33.46
Ethylbenzene	208.8	5.674	4.480	32.27
Tetrachloroethane	208.8	5.550	4.537	24.24
1,3-Dichlorobenzene	208.8	5.522	4.513	31.09
1,2-Dichlorobenzene	208.8	5.510	4.513	30.80
Nitrobenzene	208.8	5.787	4.761	16.82
Napthalene	208.8	5.378	4.419	25.24
1-Chloronapthalene	208.8	5.052	4.257	23.43
2,6-Dinitrotoluene	208.8	4.995	4.341	20.07
Fluorene	208.8	4.844	4.105	25.91
2,4-Dinitrotoluene	208.8	5.070	4.341	20.17
Hexachlorobenzene	208.8	4.477	3.912	25.07
Phenanthrene	208.8	4.690	4.038	17.81
Fluoranthene	208.8	4.496	3.936	16.59

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 15 °C
AIR, 30 G/L, 34°C AVERAGE WATER
TEMPERATURE, 24°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	349.4	6.215	9.806	113.40
Chlorobenzene	349.4	6.078	9.743	110.20
Ethylbenzene	349.4	5.811	9.222	107.50
Tetrachloroethane	349.4	5.690	9.416	68.82
1,3-Dichlorobenzene	349.4	5.656	9.366	101.60
1,2-Dichlorobenzene	349.4	5.643	9.366	100.00
Nitrobenzene	349.4	5.929	9.878	40.26
Napthalene	349.4	5.513	9.173	73.42
1-Chloronapthalene	349.4	5.177	8.835	67.03
2,6-Dinitrotoluene	349.4	5.204	9.010	52.08
Fluorene	349.4	4.958	8.534	79.51
2,4-Dinitrotoluene	349.4	5.193	9.010	52.42
Hexachlorobenzene	349.4	4.586	8.045	77.54
Phenanthrene	349.4	4.805	8.293	47.29
Fluoranthene	349.4	4.609	8.090	43.76

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 90 G/L, 33°C AVERAGE WATER
TEMPERATURE, 24°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.9	6.214	5.927	50.22
Chlorobenzene	247.9	6.078	5.946	49.68
Ethylbenzene	247.9	5.791	5.629	47.92
Tetrachloroethane	247.9	5.790	5.691	35.37
1,3-Dichlorobenzene	247.9	5.656	5.607	45.62
1,2-Dichlorobenzene	247.9	5.642	5.607	45.61
Nitrobenzene	247.9	5.300	5.973	23.57
Napthalene	247.9	5.513	5.544	36.77
1-Chloronapthalene	247.9	5.175	5.340	34.09
2,6-Dinitrotoluene	247.9	5.200	5.445	28.39
Fluorene	247.9	4.958	5.158	38.99
2,4-Dinitrotoluene	247.9	5.193	5.446	28.54
Hexachlorobenzene	247.9	4.587	4.910	36.95
Phenanthrene	247.9	4.796	5.066	26.03
Fluoranthene	247.9	4.609	4.938	24.37

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 150 G/L, 33 °C AVERAGE WATER
TEMPERATURE, 24 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.215	4.725	34.07
Chlorobenzene	208.8	6.078	4.740	33.79
Ethylbenzene	208.8	5.812	4.486	32.48
Tetrachloroethane	208.8	5.699	4.536	25.30
1,3-Dichlorobenzene	208.8	5.656	4.513	31.49
1,2-Dichlorobenzene	208.8	5.643	4.513	31.23
Nitrobenzene	208.8	5.923	4.760	17.83
Napthalene	208.8	5.508	4.419	26.04
1-Chloronapthalene	208.8	5.177	4.257	24.29
2,6-Dinitrotoluene	208.8	5.204	4.341	20.82
Fluorene	208.8	4.958	4.112	26.44
2,4-Dinitrotoluene	208.8	5.195	4.341	20.92
Hexachlorobenzene	208.8	4.586	3.914	25.63
Phenanthrene	208.8	4.805	4.034	19.12
Fluoranthene	208.8	4.609	3.936	18.00

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 15 °C
AIR, 30 G/L, 33 °C AVERAGE WATER
TEMPERATURE, 24 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	349.4	6.215	9.806	113.40
Chlorobenzene	349.4	6.078	9.743	110.20
Ethylbenzene	349.4	5.811	9.222	107.50
Tetrachloroethane	349.4	5.690	9.416	68.82
1,3-Dichlorobenzene	349.4	5.656	9.366	101.60
1,2-Dichlorobenzene	349.4	5.643	9.366	100.00
Nitrobenzene	349.4	5.929	9.878	40.26
Napthalene	349.4	5.513	9.173	73.42
1-Chloronapthalene	349.4	5.177	8.835	67.03
2,6-Dinitrotoluene	349.4	5.204	9.010	52.08
Fluorene	349.4	4.958	8.534	79.51
2,4-Dinitrotoluene	349.4	5.193	9.010	52.42
Hexachlorobenzene	349.4	4.586	8.045	77.54
Phenanthrene	349.4	4.805	8.293	47.29
Fluoranthene	349.4	4.609	8.090	43.76

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 90 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 24 °C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.9	6.214	5.927	50.22
Chlorobenzene	247.9	6.078	5.946	49.68
Ethylbenzene	247.9	5.791	5.629	47.92
Tetrachloroethane	247.9	5.790	5.691	35.37
1,3-Dichlorobenzene	247.9	5.656	5.607	45.62
1,2-Dichlorobenzene	247.9	5.642	5.607	45.61
Nitrobenzene	247.9	5.300	5.973	23.57
Napthalene	247.9	5.513	5.544	36.77
1-Chloronapthalene	247.9	5.175	5.340	34.09
2,6-Dinitrotoluene	247.9	5.200	5.445	28.39
Fluorene	247.9	4.958	5.158	38.99
2,4-Dinitrotoluene	247.9	5.193	5.446	28.54
Hexachlorobenzene	247.9	4.587	4.910	36.95
Phenanthrene	247.9	4.796	5.066	26.03
Fluoranthene	247.9	4.609	4.938	24.37

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 150 G/L, 33°C AVERAGE WATER
TEMPERATURE, 23°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.215	4.725	34.07
Chlorobenzene	208.8	6.078	4.740	33.79
Ethylbenzene	208.8	5.812	4.486	32.48
Tetrachloroethane	208.8	5.699	4.536	25.30
1,3-Dichlorobenzene	208.8	5.656	4.513	31.49
1,2-Dichlorobenzene	208.8	5.643	4.513	31.23
Nitrobenzene	208.8	5.923	4.760	17.83
Napthalene	208.8	5.508	4.419	26.04
1-Chloronapthalene	208.8	5.177	4.257	24.29
2,6-Dinitrotoluene	208.8	5.204	4.341	20.82
Fluorene	208.8	4.958	4.112	26.44
2,4-Dinitrotoluene	208.8	5.195	4.341	20.92
Hexachlorobenzene	208.8	4.586	3.914	25.63
Phenanthrene	208.8	4.805	4.034	19.12
Fluoranthene	208.8	4.609	3.936	18.00

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 15 °C
AIR, 30 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 24 °C AVERAGE AIR
TEMPERATURE, AND 1.2M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	349.4	6.215	9.806	113.40
Chlorobenzene	349.4	6.078	9.743	110.20
Ethylbenzene	349.4	5.811	9.222	107.50
Tetrachloroethane	349.4	5.690	9.416	68.82
1,3-Dichlorobenzene	349.4	5.656	9.366	101.60
1,2-Dichlorobenzene	349.4	5.643	9.366	100.00
Nitrobenzene	349.4	5.929	9.878	40.26
Napthalene	349.4	5.513	9.173	73.42
1-Chloronapthalene	349.4	5.177	8.835	67.03
2,6-Dinitrotoluene	349.4	5.204	9.010	52.08
Fluorene	349.4	4.958	8.534	79.51
2,4-Dinitrotoluene	349.4	5.193	9.010	52.42
Hexachlorobenzene	349.4	4.586	8.045	77.54
Phenanthrene	349.4	4.805	8.293	47.29
Fluoranthene	349.4	4.609	8.090	43.76

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 90 G/L, 33°C AVERAGE WATER
TEMPERATURE, 24°C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.9	6.214	5.927	50.22
Chlorobenzene	247.9	6.078	5.946	49.68
Ethylbenzene	247.9	5.791	5.629	47.92
Tetrachloroethane	247.9	5.790	5.691	35.37
1,3-Dichlorobenzene	247.9	5.656	5.607	45.62
1,2-Dichlorobenzene	247.9	5.642	5.607	45.61
Nitrobenzene	247.9	5.300	5.973	23.57
Napthalene	247.9	5.513	5.544	36.77
1-Chloronapthalene	247.9	5.175	5.340	34.09
2,6-Dinitrotoluene	247.9	5.200	5.445	28.39
Fluorene	247.9	4.958	5.158	38.99
2,4-Dinitrotoluene	247.9	5.193	5.446	28.54
Hexachlorobenzene	247.9	4.587	4.910	36.95
Phenanthrene	247.9	4.796	5.066	26.03
Fluoranthene	247.9	4.609	4.938	24.37

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 15 °C
AIR, 150 G/L, 33 °C AVERAGE WATER
TEMPERATURE, 23 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.215	4.725	34.07
Chlorobenzene	208.8	6.078	4.740	33.79
Ethylbenzene	208.8	5.812	4.486	32.48
Tetrachloroethane	208.8	5.699	4.536	25.30
1,3-Dichlorobenzene	208.8	5.656	4.513	31.49
1,2-Dichlorobenzene	208.8	5.643	4.513	31.23
Nitrobenzene	208.8	5.923	4.760	17.83
Napthalene	208.8	5.508	4.419	26.04
1-Chloronapthalene	208.8	5.177	4.257	24.29
2,6-Dinitrotoluene	208.8	5.204	4.341	20.82
Fluorene	208.8	4.958	4.112	26.44
2,4-Dinitrotoluene	208.8	5.195	4.341	20.92
Hexachlorobenzene	208.8	4.586	3.914	25.63
Phenanthrene	208.8	4.805	4.034	19.12
Fluoranthene	208.8	4.609	3.936	18.00

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C
AIR, 30 G/L, 34°C AVERAGE WATER
TEMPERATURE, 29°C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^{3}$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^{5}$)	K_1a (1/hr)
Toluene	349.5	6.366	9.807	114.70
Chlorobenzene	349.5	6.226	9.839	113.00
Ethylbenzene	349.5	5.953	9.312	109.70
Tetrachloroethane	349.5	5.829	9.416	73.14
1,3-Dichlorobenzene	349.5	5.793	9.366	103.70
1,2-Dichlorobenzene	349.5	5.882	9.366	102.60
Nitrobenzene	349.5	6.076	9.878	43.38
Napthalene	349.5	5.648	9.173	76.92
1-Chloronapthalene	349.5	5.288	8.835	70.57
2,6-Dinitrotoluene	349.5	5.419	9.010	54.78
Fluorene	349.5	5.081	8.533	81.94
2,4-Dinitrotoluene	349.5	5.323	9.010	55.12
Hexachlorobenzene	349.5	4.704	8.124	80.58
Phenanthrene	349.5	4.923	8.381	52.22
Fluoranthene	349.5	4.720	8.169	48.85

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 25°C
AIR, 90 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 29 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient (m/sec x 10^3)	Liquid Phase Mass Transfer Coefficient (m/sec x 10^5)	K_1a (1/hr)
Toluene	247.9	6.366	5.928	50.58
Chlorobenzene	247.9	6.226	5.946	50.17
Ethylbenzene	247.9	5.955	5.629	48.24
Tetrachloroethane	247.9	5.829	5.619	36.95
1,3-Dichlorobenzene	247.9	5.793	5.661	46.68
1,2-Dichlorobenzene	247.9	5.883	5.661	46.34
Nitrobenzene	247.9	6.076	5.970	25.03
Napthalene	247.9	5.648	5.544	37.99
1-Chloronapthalene	247.9	5.306	5.340	35.40
2,6-Dinitrotoluene	247.9	5.419	5.446	29.52
Fluorene	247.9	5.081	5.158	38.76
2,4-Dinitrotoluene	247.9	3.233	5.446	29.66
Hexachlorobenzene	247.9	4.702	4.910	37.78
Phenanthrene	247.9	4.923	5.061	27.96
Fluoranthene	247.9	4.727	4.938	26.41

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C
AIR, 150 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 28 °C AVERAGE AIR
TEMPERATURE, AND 0.6 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.365	4.725	34.26
Chlorobenzene	208.8	6.225	4.740	34.06
Ethylbenzene	208.8	5.955	4.487	32.65
Tetrachloroethane	208.8	5.805	4.537	26.32
1,3-Dichlorobenzene	208.8	5.805	4.513	31.83
1,2-Dichlorobenzene	208.8	5.883	4.513	31.64
Nitrobenzene	208.8	6.076	4.759	18.83
Napthalene	208.8	5.635	4.419	26.75
1-Chloronapthalene	208.8	5.304	4.257	25.07
2,6-Dinitrotoluene	208.8	5.417	4.341	21.53
Fluorene	208.8	5.081	4.111	26.88
2,4-Dinitrotoluene	208.8	5.323	4.341	21.62
Hexachlorobenzene	208.8	4.697	3.913	26.09
Phenanthrene	208.8	4.929	4.038	20.36
Fluoranthene	208.8	4.720	3.936	19.29

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C AIR, 30 G/L, 34°C AVERAGE WATER TEMPERATURE, 29°C AVERAGE AIR TEMPERATURE, AND 0.9 M BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	349.5	6.366	9.807	114.70
Chlorobenzene	349.5	6.226	9.839	113.00
Ethylbenzene	349.5	5.953	9.312	109.70
Tetrachloroethane	349.5	5.829	9.416	73.14
1,3-Dichlorobenzene	349.5	5.793	9.366	103.70
1,2-Dichlorobenzene	349.5	5.882	9.366	102.60
Nitrobenzene	349.5	6.076	9.878	43.38
Napthalene	349.5	5.648	9.173	76.92
1-Chloronapthalene	349.5	5.288	8.835	70.57
2,6-Dinitrotoluene	349.5	5.419	9.010	54.78
Fluorene	349.5	5.081	8.533	81.94
2,4-Dinitrotoluene	349.5	5.323	9.010	55.12
Hexachlorobenzene	349.5	4.704	8.124	80.58
Phenanthrene	349.5	4.923	8.381	52.22
Fluoranthene	349.5	4.720	8.169	48.85

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35°C WATER, 25°C
AIR, 90 G/L, 34°C AVERAGE WATER
TEMPERATURE, 29°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	247.9	6.366	5.928	50.58
Chlorobenzene	247.9	6.226	5.946	50.17
Ethylbenzene	247.9	5.955	5.629	48.24
Tetrachloroethane	247.9	5.829	5.619	36.95
1,3-Dichlorobenzene	247.9	5.793	5.661	46.68
1,2-Dichlorobenzene	247.9	5.883	5.661	46.34
Nitrobenzene	247.9	6.076	5.970	25.03
Napthalene	247.9	5.648	5.544	37.99
1-Chloronapthalene	247.9	5.306	5.340	35.40
2,6-Dinitrotoluene	247.9	5.419	5.446	29.52
Fluorene	247.9	5.081	5.158	38.76
2,4-Dinitrotoluene	247.9	3.233	5.446	29.66
Hexachlorobenzene	247.9	4.702	4.910	37.78
Phenanthrene	247.9	4.923	5.061	27.96
Fluoranthene	247.9	4.727	4.938	26.41

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C
AIR, 150 G/L, 33°C AVERAGE WATER
TEMPERATURE, 28°C AVERAGE AIR
TEMPERATURE, AND 0.9 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	208.8	6.365	4.725	34.26
Chlorobenzene	208.8	6.225	4.740	34.06
Ethylbenzene	208.8	5.955	4.487	32.65
Tetrachloroethane	208.8	5.805	4.537	26.32
1,3-Dichlorobenzene	208.8	5.805	4.513	31.83
1,2-Dichlorobenzene	208.8	5.883	4.513	31.64
Nitrobenzene	208.8	6.076	4.759	18.83
Napthalene	208.8	5.635	4.419	26.75
1-Chloronapthalene	208.8	5.304	4.257	25.07
2,6-Dinitrotoluene	208.8	5.417	4.341	21.53
Fluorene	208.8	5.081	4.111	26.88
2,4-Dinitrotoluene	208.8	5.323	4.341	21.62
Hexachlorobenzene	208.8	4.697	3.913	26.09
Phenanthrene	208.8	4.929	4.038	20.36
Fluoranthene	208.8	4.720	3.936	19.29

ESTIMATED OVERALL MASS TRANSFER COEFFICIENTS (K_1a)
USING ONDA CORRELATIONS FOR 35 °C WATER, 25 °C
AIR, 30 G/L, 34 °C AVERAGE WATER
TEMPERATURE, 29 °C AVERAGE AIR
TEMPERATURE, AND 1.2 M
BED DEPTH

Compound	Interfacial Area per Unit Bed Volume (1/m)	Gas Phase Mass Transfer Coefficient ($m/sec \times 10^3$)	Liquid Phase Mass Transfer Coefficient ($m/sec \times 10^5$)	K_1a (1/hr)
Toluene	349.5	6.366	9.807	114.70
Chlorobenzene	349.5	6.226	9.839	113.00
Ethylbenzene	349.5	5.953	9.312	109.70
Tetrachloroethane	349.5	5.829	9.416	73.14
1,3-Dichlorobenzene	349.5	5.793	9.366	103.70
1,2-Dichlorobenzene	349.5	5.882	9.366	102.60
Nitrobenzene	349.5	6.076	9.878	43.38
Napthalene	349.5	5.648	9.173	76.92
1-Chloronapthalene	349.5	5.288	8.835	70.57
2,6-Dinitrotoluene	349.5	5.419	9.010	54.78
Fluorene	349.5	5.081	8.533	81.94
2,4-Dinitrotoluene	349.5	5.323	9.010	55.12
Hexachlorobenzene	349.5	4.704	8.124	80.58
Phenanthrene	349.5	4.923	8.381	52.22
Fluoranthene	349.5	4.720	8.169	48.85

APPENDIX E

COMPARISON OF MEASURED OVERALL MASS TRANSFER COEFFICIENTS (K_1a) WITH BOTH ONDA AND REFERENCE METHOD AT ALL COMBINATIONS OF WATER TEMPERATURES, GAS-TO-LIQUID RATIOS, AIR TEMPERATURES, AND BED DEPTHS

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	90.13	58.76	37.88	-34.81	-57.97
Chlorobenzene	68.91	57.48	33.12	-16.59	-51.94
Ethylbenzene	64.18	56.18	35.44	-12.46	-44.78
Tetrachloroethane	15.67	36.96	21.89	136.3	39.69
1,3-Dichlorobenzene	70.70	52.84	29.04	-25.26	-58.92
1,2-Dichlorobenzene	58.48	51.94	28.81	-11.19	-50.74
Nitrobenzene	5.19	24.34	18.59	368.9	258.1
Napthalene	28.82	40.22	26.80	39.56	-7.09
1-Chloronapthalene	29.81	36.30	22.99	21.77	-22.88
2,6-Dinitrotoluene	5.47	32.04	19.86	485.7	263.0
Fluorene	12.70	43.07	25.74	239.1	102.6
2,4-Dinitrotoluene	4.80	31.49	19.66	556.0	309.6
Hexachlorobenzene	12.51	41.44	19.82	231.3	58.43
Phenanthrene	10.90	24.86	17.95	128.1	64.67
Fluoranthene	24.52	22.65	16.11	-7.62	-34.30

* 5 °C nitrogen, 81.0 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15°C WATER, 5 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	30.37	25.87	15.46	-14.81	-49.09
Chlorobenzene	27.81	25.47	13.53	-8.41	-51.34
Ethylbenzene	28.93	24.68	14.48	-14.69	-49.95
Tetrachloroethane	6.55	18.78	8.95	186.7	36.64
1,3-Dichlorobenzene	34.58	23.77	11.86	-31.26	-65.70
1,2-Dichlorobenzene	31.73	23.57	11.77	-25.72	-62.91
Nitrobenzene	1.66	13.88	7.59	736.1	357.2
Napthalene	19.62	19.70	10.95	-0.40	-44.19
1-Chloronapthalene	16.91	18.12	9.75	-7.16	-42.34
2,6-Dinitrotoluene	2.42	16.65	8.11	588.0	235.1
Fluorene	9.36	20.16	10.51	115.4	12.28
2,4-Dinitrotoluene	2.99	16.44	8.03	449.8	168.7
Hexachlorobenzene	4.98	19.34	8.10	288.4	62.65
Phenanthrene	5.62	13.51	7.33	140.4	30.42
Fluoranthene	5.09	12.50	6.58	145.58	29.27

* 5°C nitrogen, 86.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	21.43	17.52	9.42	-18.24	-56.04
Chlorobenzene	20.44	17.35	8.24	-15.11	-59.69
Ethylbenzene	18.05	16.69	8.82	-7.53	-51.13
Tetrachloroethane	4.01	13.36	5.42	233.2	35.36
1,3-Dichlorobenzene	19.31	16.22	7.22	-16.10	-62.61
1,2-Dichlorobenzene	20.42	16.09	7.19	-21.21	-64.79
Nitrobenzene	1.30	10.34	4.63	695.4	256.15
Napthalene	14.50	13.86	6.67	-4.41	-54.00
1-Chloronapthalene	13.78	12.82	5.72	-6.97	-58.49
2,6-Dinitrotoluene	1.86	11.97	5.00	543.5	168.8
Fluorene	6.26	13.93	6.40	122.5	2.24
2,4-Dinitrotoluene	2.25	11.84	4.89	426.2	117.3
Hexachlorobenzene	3.56	13.36	4.93	275.3	38.48
Phenanthrene	3.66	9.90	4.46	170.5	21.86
Fluoranthene	4.00	9.21	4.01	130.3	0.25

* 5 °C nitrogen, 87.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	58.76	-	-	-
Chlorobenzene	72.53	57.48	25.88	-20.75	-64.33
Ethylbenzene	61.50	56.18	26.25	-8.65	-57.32
Tetrachloroethane	19.30	36.96	21.02	91.50	8.91
1,3-Dichlorobenzene	69.72	52.84	22.74	-24.21	-67.38
1,2-Dichlorobenzene	60.07	51.94	22.58	-13.53	-62.41
Nitrobenzene	4.98	24.34	15.10	388.8	203.2
Napthalene	31.45	40.22	21.30	27.88	-32.27
1-Chloronapthalene	38.39	36.30	18.48	-5.44	-51.86
2,6-Dinitrotoluene	4.28	32.04	15.74	648.6	276.8
Fluorene	19.95	43.07	20.32	115.9	2.36
2,4-Dinitrotoluene	14.12	31.49	15.65	123.0	10.84
Hexachlorobenzene	23.30	41.44	15.62	77.85	-32.96
Phenanthrene	21.29	24.86	14.83	6.77	-30.34
Fluoranthene	24.93	22.65	13.44	-9.15	-46.09

* 5 °C nitrogen, 78.0 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	25.87	-	-	-
Chlorobenzene	29.63	25.47	9.83	-14.03	-66.83
Ethylbenzene	25.06	24.68	10.52	-1.52	-58.02
Tetrachloroethane	5.46	18.78	6.50	243.9	19.05
1,3-Dichlorobenzene	30.00	23.77	8.62	-20.77	-71.27
1,2-Dichlorobenzene	29.44	23.57	8.55	-19.94	-70.96
Nitrobenzene	1.18	13.88	5.52	1076.	367.8
Napthalene	14.17	19.70	7.96	39.03	-43.82
1-Chloronapthalene	14.51	18.12	6.82	24.88	-53.00
2,6-Dinitrotoluene	1.92	16.65	5.90	767.1	207.2
Fluorene	7.28	20.16	7.64	176.9	4.94
2,4-Dinitrotoluene	2.78	16.44	5.83	491.3	109.7
Hexachlorobenzene	6.33	19.34	5.88	205.5	-7.11
Phenanthrene	7.99	13.51	5.32	69.09	-33.42
Fluoranthene	8.43	12.50	4.78	48.27	-43.30

* 5°C nitrogen, 88.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.52	-	-	-
Chlorobenzene	21.58	17.35	5.96	-19.60	-73.28
Ethylbenzene	16.32	16.69	6.38	2.81	-60.91
Tetrachloroethane	3.91	13.36	3.49	241.6	-10.74
1,3-Dichlorobenzene	21.88	16.22	5.23	-25.87	-76.10
1,2-Dichlorobenzene	19.89	16.09	5.19	-19.10	-73.91
Nitrobenzene	1.38	10.34	5.68	649.2	311.5
Napthalene	9.03	13.86	4.83	53.49	-46.51
1-Chloronapthalene	4.10	12.82	4.14	212.6	0.97
2,6-Dinitrotoluene	1.51	11.97	3.58	692.7	137.0
Fluorene	5.01	13.93	4.63	178.0	-7.58
2,4-Dinitrotoluene	1.99	11.84	3.54	494.9	77.89
Hexachlorobenzene	3.81	13.36	3.57	250.6	-6.30
Phenanthrene	5.36	9.90	3.23	84.70	-39.74
Fluoranthene	4.02	9.21	3.05	129.1	-24.13

* 5°C nitrogen, 89.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 5 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	58.76	-	-	-
Chlorobenzene	70.74	57.48	20.41	-18.74	-71.14
Ethylbenzene	52.69	56.18	21.84	6.62	-58.55
Tetrachloroethane	14.04	39.96	13.50	184.6	-3.85
1,3-Dichlorobenzene	65.04	52.84	17.90	-18.76	-72.48
1,2-Dichlorobenzene	58.14	51.94	17.76	-10.66	-69.45
Nitrobenzene	3.64	24.34	11.46	568.6	214.8
Napthalene	32.07	40.22	16.51	25.41	-48.52
1-Chloronapthalene	6.61	36.30	14.17	449.1	114.3
2,6-Dinitrotoluene	7.41	32.04	12.14	332.3	63.83
Fluorene	13.83	43.07	15.86	211.4	14.68
2,4-Dinitrotoluene	7.22	31.49	12.12	336.1	67.87
Hexachlorobenzene	17.58	41.44	12.21	135.7	-30.55
Phenanthrene	16.81	24.86	11.06	47.89	-34.20
Fluoranthene	14.76	22.65	9.03	53.45	-38.82

* 5°C nitrogen, 86.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15°C WATER, 5 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	25.87	-	-	-
Chlorobenzene	20.03	25.47	8.16	-27.16	-59.26
Ethylbenzene	20.51	25.68	8.73	25.21	-57.43
Tetrachloroethane	3.87	18.78	5.40	385.2	39.53
1,3-Dichlorobenzene	22.80	23.77	7.15	4.25	-68.64
1,2-Dichlorobenzene	20.70	23.55	7.10	13.77	-65.70
Nitrobenzene	1.26	13.88	4.58	100.5	263.4
Napthalene	10.88	19.70	6.60	81.07	-39.34
1-Chloronapthalene	11.43	18.12	5.66	58.53	-50.48
2,6-Dinitrotoluene	1.81	16.65	4.89	819.8	170.1
Fluorene	5.77	20.16	6.34	249.3	9.88
2,4-Dinitrotoluene	2.42	16.44	4.84	579.3	100.0
Hexachlorobenzene	5.16	19.34	4.88	274.8	-5.43
Phenanthrene	6.16	13.51	4.42	119.3	-28.25
Fluoranthene	6.43	12.50	3.97	94.40	-38.26

* 5°C nitrogen, 90.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT
(K_1a) FOR 15 °C WATER, 5 °C AIR, 150 G/L
AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.52	-	-	-
Chlorobenzene	18.26	17.35	4.95	-4.98	-72.89
Ethylbenzene	12.88	16.69	5.30	29.59	-58.85
Tetrachloroethane	3.17	13.36	3.27	321.4	3.15
1,3-Dichlorobenzene	16.63	16.22	4.34	-2.47	-73.90
1,2-Dichlorobenzene	15.05	16.09	4.31	6.91	-71.36
Nitrobenzene	1.20	10.34	2.78	761.6	131.6
Napthalene	7.76	13.86	4.01	78.61	-48.32
1-Chloronapthalene	7.08	12.82	3.43	81.09	-51.55
2,6-Dinitrotoluene	1.47	11.97	2.97	741.2	102.0
Fluorene	3.83	13.93	3.85	263.7	0.52
2,4-Dinitrotoluene	1.73	11.84	2.94	584.4	69.94
Hexachlorobenzene	2.80	13.36	2.96	377.1	5.71
Phenanthrene	4.12	9.90	2.68	140.2	-34.95
Fluoranthene	3.90	9.21	2.41	136.1	-38.21

* 5°C nitrogen, 91.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	91.91	59.41	40.57	-35.36	-55.86
Chlorobenzene	82.58	58.42	35.60	29.26	-56.89
Ethylbenzene	73.26	56.76	37.97	-22.52	-48.17
Tetrachloroethane	25.66	39.60	24.22	54.33	-5.61
1,3-Dichlorobenzene	75.55	53.94	31.28	-28.60	-58.60
1,2-Dichlorobenzene	76.42	53.29	31.07	-30.20	-59.34
Nitrobenzene	11.11	26.38	20.78	137.4	87.03
Napthalene	54.79	42.07	29.30	-23.22	-46.52
1-Chloronapthalene	56.96	38.65	25.42	-32.14	-55.37
2,6-Dinitrotoluene	5.72	33.30	21.64	482.1	287.3
Fluorene	24.40	44.29	27.83	81.52	14.06
2,4-Dinitrotoluene	7.76	32.97	21.53	324.8	177.4
Hexachlorobenzene	14.85	42.72	21.49	187.6	44.71
Phenanthrene	19.16	27.73	20.41	44.72	6.52
Fluoranthene	30.00	25.44	18.50	-15.20	-38.33

* 15 °C nitrogen, 82.8% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	35.96	26.05	15.90	-27.39	-55.78
Chlorobenzene	28.01	25.56	14.67	-8.75	-47.63
Ethylbenzene	28.91	24.87	14.88	-13.97	-48.52
Tetrachloroethane	8.19	19.63	9.50	139.6	15.95
1,3-Dichlorobenzene	33.97	24.10	12.26	-29.06	-63.91
1,2-Dichlorobenzene	31.67	23.92	12.18	-24.47	-61.54
Nitrobenzene	3.79	14.67	8.14	287.0	114.7
Napthalene	20.78	20.31	11.48	-2.26	-44.75
1-Chloronapthalene	20.65	18.93	9.96	-8.40	-51.77
2,6-Dinitrotoluene	2.71	17.13	8.48	5.32	212.9
Fluorene	10.28	20.53	10.90	99.71	6.03
2,4-Dinitrotoluene	3.26	16.32	8.44	400.6	158.9
Hexachlorobenzene	6.48	19.72	8.42	204.3	29.94
Phenanthrene	6.25	14.68	8.00	134.8	28.00
Fluoranthene	6.81	13.67	7.25	100.0	6.46

* 15 °C nitrogen, 86.7 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	25.77	17.63	9.17	-31.59	-64.41
Chlorobenzene	21.35	17.51	8.04	-17.99	-62.34
Ethylbenzene	19.77	16.79	8.58	-15.07	-56.60
Tetrachloroethane	6.10	13.87	5.47	127.3	-10.32
1,3-Dichlorobenzene	19.89	16.41	7.07	-17.50	-64.45
1,2-Dichlorobenzene	19.36	16.31	7.02	-15.75	-63.74
Nitrobenzene	2.03	10.86	4.70	434.9	131.5
Napthalene	14.09	14.21	6.62	0.85	-53.02
1-Chloronapthalene	13.82	13.31	5.53	-3.69	-60.00
2,6-Dinitrotoluene	1.86	12.27	4.89	559.6	162.9
Fluorene	6.41	14.15	6.29	120.7	-1.87
2,4-Dinitrotoluene	2.34	12.20	4.87	421.3	108.1
Hexachlorobenzene	4.76	13.61	4.86	185.9	2.10
Phenanthrene	4.30	10.64	4.61	147.4	7.21
Fluoranthene	4.20	9.97	4.18	137.3	-0.48

* 15 °C nitrogen, 86.7 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	59.41	-	-	-
Chlorobenzene	74.20	58.42	20.19	-21.27	-72.79
Ethylbenzene	64.32	56.76	21.61	-11.79	-66.40
Tetrachloroethane	21.98	39.60	13.27	80.16	-39.62
1,3-Dichlorobenzene	71.31	53.94	17.70	-24.36	-75.18
1,2-Dichlorobenzene	63.53	53.29	14.00	-16.11	-77.96
Nitrobenzene	5.19	26.38	11.33	408.2	118.3
Napthalene	35.22	42.07	16.33	19.44	-53.63
1-Chloronapthalene	40.32	38.65	14.01	-4.14	-65.25
2,6-Dinitrotoluene	4.17	33.30	12.58	698.5	201.6
Fluorene	16.66	44.29	15.69	165.8	-5.82
2,4-Dinitrotoluene	7.23	32.97	11.98	356.0	65.70
Hexachlorobenzene	16.30	42.72	12.08	162.0	-25.89
Phenanthrene	17.97	27.73	17.56	54.31	-2.28
Fluoranthene	24.34	25.44	9.82	4.52	-147.8

* 15 °C nitrogen, 85.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	26.05	-	-	-
Chlorobenzene	34.56	25.56	10.89	-26.04	-68.49
Ethylbenzene	27.44	24.87	11.62	-9.37	-57.65
Tetrachloroethane	6.97	19.63	7.41	181.6	6.31
1,3-Dichlorobenzene	34.35	24.10	9.57	-29.84	-72.14
1,2-Dichlorobenzene	32.28	23.92	9.51	-25.89	-70.54
Nitrobenzene	2.44	14.67	8.97	501.2	267.6
Napthalene	19.76	20.31	7.78	2.78	-60.63
1-Chloronapthalene	17.09	18.93	6.62	10.77	-61.26
2,6-Dinitrotoluene	2.46	17.13	8.52	596.3	246.3
Fluorene	8.32	20.53	6.59	146.7	-20.79
2,4-Dinitrotoluene	4.77	16.32	6.57	242.1	37.74
Hexachlorobenzene	7.04	19.72	6.24	180.1	-11.36
Phenanthrene	9.32	14.68	6.36	57.51	-31.76
Fluoranthene	8.91	13.67	5.66	53.42	-36.48

* 15 °C nitrogen, 90.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.63	-	-	-
Chlorobenzene	21.58	17.51	6.41	-18.86	-70.30
Ethylbenzene	16.43	16.79	6.84	2.19	-58.36
Tetrachloroethane	6.74	13.81	4.37	104.9	-35.16
1,3-Dichlorobenzene	21.78	16.41	5.64	-24.65	-74.10
1,2-Dichlorobenzene	19.78	16.31	5.60	-17.54	-71.69
Nitrobenzene	1.76	10.86	3.74	517.0	112.5
Napthalene	13.14	14.21	5.28	8.14	-59.82
1-Chloronapthalene	12.97	13.31	4.58	2.62	-64.69
2,6-Dinitrotoluene	1.56	12.27	3.90	686.5	150.0
Fluorene	7.26	14.15	5.01	94.90	-30.99
2,4-Dinitrotoluene	3.19	12.20	3.88	282.0	21.63
Hexachlorobenzene	4.39	13.61	3.87	210.0	-11.83
Phenanthrene	6.49	10.64	3.68	63.94	-43.20
Fluoranthene	5.91	9.97	3.28	68.70	-44.50

* 15°C nitrogen, 91.0% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	59.41	-	-	-
Chlorobenzene	61.80	58.42	21.11	-5.47	-65.84
Ethylbenzene	65.86	56.76	22.51	-13.82	-65.82
Tetrachloroethane	14.49	39.60	14.37	173.2	-0.83
1,3-Dichlorobenzene	60.62	53.49	18.55	-11.76	-69.40
1,2-Dichlorobenzene	58.04	53.29	18.42	-8.18	-68.26
Nitrobenzene	4.45	26.38	12.32	492.8	176.8
Napthalene	39.33	42.07	17.38	6.97	-55.81
1-Chloronapthalene	38.83	38.65	15.07	-0.46	-61.19
2,6-Dinitrotoluene	10.19	33.30	12.84	226.8	26.00
Fluorene	23.19	44.29	16.50	90.99	-28.85
2,4-Dinitrotoluene	13.53	32.97	12.77	143.6	-5.62
Hexachlorobenzene	17.39	42.72	12.74	146.0	-26.74
Phenanthrene	15.23	27.73	12.10	82.07	-20.55
Fluoranthene	24.18	25.44	10.99	5.21	-54.54

* 15°C nitrogen, 87.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	26.05	-	-	-
Chlorobenzene	23.45	25.56	7.42	-9.00	-68.36
Ethylbenzene	23.70	24.87	7.91	4.85	-66.62
Tetrachloroethane	7.94	19.63	5.05	147.2	-36.40
1,3-Dichlorobenzene	24.93	24.10	6.52	-3.33	-73.85
1,2-Dichlorobenzene	23.99	23.92	6.47	-0.29	-73.03
Nitrobenzene	2.53	14.67	4.29	479.8	60.01
Napthalene	12.44	20.31	6.11	63.26	-50.88
1-Chloronapthalene	12.72	18.93	5.30	48.82	-58.33
2,6-Dinitrotoluene	2.71	17.13	4.51	532.1	66.42
Fluorene	7.15	20.53	5.80	187.1	-18.88
2,4-Dinitrotoluene	3.16	16.32	4.49	416.4	42.09
Hexachlorobenzene	5.71	19.72	4.48	245.3	-21.54
Phenanthrene	6.31	14.68	4.25	132.6	-32.64
Fluoranthene	6.57	13.67	3.85	108.0	-41.40

* 15 °C nitrogen, 88.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 15 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.63	-	-	-
Chlorobenzene	16.92	17.51	4.51	3.48	-73.34
Ethylbenzene	15.37	16.79	4.48	9.23	-70.85
Tetrachloroethane	5.08	13.87	3.07	173.0	-38.58
1,3-Dichlorobenzene	17.30	16.41	3.96	-5.14	-77.11
1,2-Dichlorobenzene	15.47	16.31	3.93	5.43	-74.60
Nitrobenzene	1.34	10.86	2.63	710.4	96.27
Napthalene	10.10	14.21	3.71	40.69	-63.26
1-Chloronapthalene	9.42	13.31	3.22	41.29	-65.82
2,6-Dinitrotoluene	1.54	12.27	2.74	696.7	77.92
Fluorene	5.22	14.15	3.52	171.0	-32.57
2,4-Dinitrotoluene	2.19	12.20	2.73	457.0	24.66
Hexachlorobenzene	3.25	13.61	2.72	318.7	-16.31
Phenanthrene	5.10	10.64	2.58	108.6	-49.41
Fluoranthene	4.77	9.97	2.34	116.3	-54.36

* 15°C nitrogen, 89.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	117.2	59.96	40.60	-48.83	-65.36
Chlorobenzene	86.00	59.20	35.71	-31.16	-58.48
Ethylbenzene	74.07	57.23	37.97	-22.73	-48.74
Tetrachloroethane	33.27	41.78	24.93	25.58	-25.07
1,3-Dichlorobenzene	76.18	54.85	31.44	-28.00	-58.73
1,2-Dichlorobenzene	74.39	54.27	31.26	-27.05	-57.98
Nitrobenzene	14.12	28.22	21.66	99.86	53.40
Napthalene	57.00	43.74	29.86	-23.26	-47.61
1-Chloronapthalene	57.26	40.44	25.98	-29.37	-54.63
2,6-Dinitrotoluene	7.95	34.23	22.00	330.5	176.7
Fluorene	23.88	45.38	28.07	90.00	17.54
2,4-Dinitrotoluene	7.56	34.40	21.99	3.55	190.8
Hexachlorobenzene	20.74	44.05	21.71	112.3	4.67
Phenanthrene	28.20	30.29	21.48	7.41	-23.82
Fluoranthene	35.35	28.11	19.63	-20.84	-44.47

* 25 °C nitrogen, 82.7% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	47.63	26.18	16.51	-45.03	-65.33
Chlorobenzene	30.83	26.01	14.52	-15.63	-52.90
Ethylbenzene	29.18	24.94	15.44	-14.53	-47.09
Tetrachloroethane	8.57	20.37	10.13	137.6	18.20
1,3-Dichlorobenzene	36.55	24.35	12.78	-33.37	-65.03
1,2-Dichlorobenzene	36.38	24.18	14.00	-33.53	-61.52
Nitrobenzene	3.80	15.46	8.81	306.8	136.8
Napthalene	22.87	20.85	12.41	-8.83	-45.74
1-Chloronapthalene	23.40	19.52	10.56	-16.58	-54.87
2,6-Dinitrotoluene	3.19	17.46	8.94	447.3	180.2
Fluorene	10.80	20.85	11.41	93.06	5.64
2,4-Dinitrotoluene	3.93	17.53	8.94	346.0	127.4
Hexachlorobenzene	7.74	20.07	8.28	159.3	6.98
Phenanthrene	6.87	15.67	8.73	128.0	27.07
Fluoranthene	6.83	14.70	11.93	65.97	74.67

* 25 °C nitrogen, 87.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	31.13	17.69	9.78	-43.17	-68.58
Chlorobenzene	20.42	17.61	8.60	-13.76	-57.88
Ethylbenzene	19.38	16.80	9.15	-13.31	-52.78
Tetrachloroethane	6.00	14.30	6.00	138.3	0.00
1,3-Dichlorobenzene	22.52	16.54	7.58	-26.64	-66.34
1,2-Dichlorobenzene	22.06	16.45	7.53	-25.34	-65.87
Nitrobenzene	2.91	11.37	5.22	290.7	79.38
Napthalene	14.56	14.51	7.19	-0.34	-50.62
1-Chloronapthalene	13.86	13.65	6.26	-1.51	-54.83
2,6-Dinitrotoluene	2.82	12.47	5.30	342.2	87.94
Fluorene	7.06	14.33	6.76	102.9	-4.25
2,4-Dinitrotoluene	4.46	12.51	5.30	180.4	18.83
Hexachlorobenzene	4.18	13.76	5.23	229.1	25.12
Phenanthrene	4.46	11.23	5.18	151.7	16.14
Fluoranthene	3.15	10.61	4.73	236.8	50.15

* 25 °C nitrogen, 87.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT
(K_1a) FOR 15 °C WATER, 25 °C AIR, 30 G/L
AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	59.96	-	-	-
Chlorobenzene	66.95	59.20	25.71	-11.57	-61.60
Ethylbenzene	60.20	57.23	27.34	-4.93	-54.58
Tetrachloroethane	22.13	41.78	17.94	88.79	-18.93
1,3-Dichlorobenzene	65.36	54.85	22.64	-16.08	-65.36
1,2-Dichlorobenzene	56.50	54.27	22.51	-3.95	-60.16
Nitrobenzene	10.68	28.22	15.60	162.5	46.07
Napthalene	30.60	43.74	21.50	42.94	-29.74
1-Chloronapthalene	35.78	40.44	18.71	13.02	-47.71
2,6-Dinitrotoluene	8.01	34.23	15.85	327.3	97.88
Fluorene	18.44	45.38	20.21	146.1	9.60
2,4-Dinitrotoluene	16.11	34.40	15.84	113.5	-1.68
Hexachlorobenzene	25.29	44.05	15.63	74.18	-38.20
Phenanthrene	29.13	30.29	15.47	3.98	-46.89
Fluoranthene	27.28	28.11	14.14	3.04	-48.17

* 25°C nitrogen, 88.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	26.18	-	-	-
Chlorobenzene	34.61	26.01	10.53	-24.84	-69.57
Ethylbenzene	28.78	24.94	11.20	-13.34	-61.08
Tetrachloroethane	9.36	20.37	7.35	117.6	-21.47
1,3-Dichlorobenzene	34.18	24.35	9.27	-28.76	-72.88
1,2-Dichlorobenzene	32.88	24.18	9.22	-26.45	-71.96
Nitrobenzene	2.42	15.46	6.39	538.8	164.0
Napthalene	19.57	20.85	8.81	6.54	-54.98
1-Chloronapthalene	16.76	19.52	7.66	16.54	-54.30
2,6-Dinitrotoluene	2.25	17.46	6.49	676.0	188.4
Fluorene	5.60	20.85	8.28	272.3	47.86
2,4-Dinitrotoluene	4.03	17.53	6.49	334.9	61.04
Hexachlorobenzene	8.19	20.07	6.40	145.0	-21.86
Phenanthrene	9.23	15.67	6.34	69.77	-31.31
Fluoranthene	9.84	14.70	5.79	49.39	-41.16

* 25 °C nitrogen, 84.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 150 G/L AND 0.9M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.69	-	-	-
Chlorobenzene	23.17	17.61	6.41	-24.00	-72.33
Ethylbenzene	18.86	16.80	6.82	-10.92	-63.84
Tetrachloroethane	7.00	14.30	4.47	104.2	-36.14
1,3-Dichlorobenzene	22.75	16.54	5.64	-27.30	-75.21
1,2-Dichlorobenzene	22.08	16.45	5.61	-25.50	-74.59
Nitrobenzene	1.83	11.37	3.89	521.3	112.5
Napthalene	14.34	14.51	5.36	1.18	-62.62
1-Chloronapthalene	13.70	13.65	4.66	-0.36	-65.99
2,6-Dinitrotoluene	1.60	12.47	3.95	6.79	146.8
Fluorene	7.22	14.33	5.04	98.47	-30.19
2,4-Dinitrotoluene	3.03	12.51	3.95	312.8	-30.36
Hexachlorobenzene	4.50	13.76	3.90	205.7	-13.33
Phenanthrene	5.91	11.23	3.85	90.00	-34.86
Fluoranthene	5.80	10.61	3.52	82.93	-39.31

* 25 °C nitrogen, 89.7 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	59.96	-	-	-
Chlorobenzene	90.66	59.20	16.58	-34.70	-81.71
Ethylbenzene	105.6	57.23	17.64	-45.80	-83.29
Tetrachloroethane	23.79	41.78	11.57	75.62	-51.37
1,3-Dichlorobenzene	115.5	54.85	14.60	-52.51	-87.36
1,2-Dichlorobenzene	82.41	54.27	14.51	-34.15	-82.33
Nitrobenzene	18.49	28.22	10.06	52.62	-45.59
Napthalene	66.64	43.74	13.87	-34.37	-79.19
1-Chloronapthalene	75.58	40.44	12.07	-46.49	-84.03
2,6-Dinitrotoluene	14.08	34.23	10.22	143.1	-27.41
Fluorene	30.68	45.38	13.04	47.91	-57.50
2,4-Dinitrotoluene	17.15	34.40	10.21	100.5	-40.47
Hexachlorobenzene	21.58	44.05	10.08	104.1	-53.29
Phenanthrene	22.07	30.29	9.98	37.24	-54.78
Fluoranthene	26.09	28.11	9.11	7.74	-65.08

* 25°C nitrogen, 90.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	26.18	-	-	-
Chlorobenzene	29.42	26.01	7.70	-11.59	-73.83
Ethylbenzene	27.09	24.94	8.19	-7.93	-69.77
Tetrachloroethane	8.95	20.37	5.37	127.60	-40.00
1,3-Dichlorobenzene	27.78	24.35	6.78	-12.34	-75.59
1,2-Dichlorobenzene	28.69	24.18	6.74	-15.72	-76.50
Nitrobenzene	2.56	15.46	4.67	503.9	82.42
Napthalene	16.51	20.85	6.44	26.29	-60.99
1-Chloronapthalene	15.81	19.52	5.60	23.47	-64.58
2,6-Dinitrotoluene	3.14	17.46	4.74	456.0	50.96
Fluorene	8.35	20.85	6.06	149.7	-27.42
2,4-Dinitrotoluene	4.12	17.53	4.74	325.4	15.05
Hexachlorobenzene	6.49	20.07	4.70	209.2	-27.59
Phenanthrene	6.82	15.67	4.63	129.7	-32.11
Fluoranthene	7.27	14.70	4.23	102.2	-41.82

* 25°C nitrogen, 90.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 15 °C WATER, 25 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	17.69	-	-	-
Chlorobenzene	16.34	17.61	5.07	7.77	-68.97
Ethylbenzene	15.45	16.80	5.39	8.73	-65.11
Tetrachloroethane	5.27	14.30	3.54	171.3	-32.83
1,3-Dichlorobenzene	16.87	16.54	4.46	-1.96	-73.58
1,2-Dichlorobenzene	16.95	16.45	4.44	-2.95	-73.80
Nitrobenzene	1.80	11.37	3.08	531.6	71.11
Napthalene	10.48	14.51	4.24	38.45	-59.54
1-Chloronapthalene	10.60	13.65	3.69	28.77	-65.19
2,6-Dinitrotoluene	2.35	12.47	3.12	430.6	32.77
Fluorene	5.47	14.33	3.99	161.9	-27.06
2,4-Dinitrotoluene	2.37	12.51	3.12	427.8	31.65
Hexachlorobenzene	4.14	13.76	3.08	232.3	-25.60
Phenanthrene	5.49	11.23	3.05	104.5	-44.44
Fluoranthene	4.64	10.61	2.79	128.6	-39.87

* 25 °C nitrogen, 80.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	166.6	111.8	49.59	-32.85	-72.63
Chlorobenzene	137.5	109.1	43.61	-20.64	-68.28
Ethylbenzene	142.4	107.2	46.36	-24.72	-67.44
Tetrachloroethane	105.1	64.24	30.42	-38.87	-71.06
1,3-Dichlorobenzene	137.6	99.16	38.39	-27.93	-72.10
1,2-Dichlorobenzene	144.0	97.38	38.17	-32.38	-73.49
Nitrobenzene	35.78	37.22	26.54	4.02	-25.82
Napthalene	148.7	69.67	36.46	-53.14	-75.48
1-Chloronapthalene	174.5	63.11	31.73	-63.83	-81.82
2,6-Dinitrotoluene	8.09	49.32	26.87	509.6	232.1
Fluorene	32.47	76.85	34.28	136.6	5.57
2,4-Dinitrotoluene	8.99	49.68	26.86	452.0	198.4
Hexachlorobenzene	18.69	75.21	26.51	302.4	41.84
Phenanthrene	20.88	42.68	26.23	104.4	26.10
Fluoranthene	22.20	39.14	23.97	76.3	7.97

* 5°C nitrogen, 89.0 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	58.04	49.76	17.00	-14.26	-70.71
Chlorobenzene	45.05	49.04	14.95	8.86	-66.81
Ethylbenzene	49.44	47.52	15.90	-3.88	-67.84
Tetrachloroethane	36.68	33.61	10.43	-8.37	-71.56
1,3-Dichlorobenzene	46.74	45.32	13.16	-3.08	-71.84
1,2-Dichlorobenzene	43.25	44.80	13.09	3.58	-69.73
Nitrobenzene	8.71	22.07	9.07	153.3	4.13
Napthalene	43.92	35.41	12.50	-19.37	-71.54
1-Chloronapthalene	45.18	32.60	10.88	-27.84	-75.92
2,6-Dinitrotoluene	2.55	27.22	9.22	967.4	261.5
Fluorene	17.67	37.09	11.75	109.9	-33.50
2,4-Dinitrotoluene	5.19	27.37	9.21	427.3	77.46
Hexachlorobenzene	5.49	35.98	9.09	555.3	65.57
Phenanthrene	8.90	23.92	8.99	168.7	1.01
Fluoranthene	5.91	22.21	8.22	275.8	39.08

* 5 °C nitrogen, 92.0 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT
(K_1a) FOR 35 °C WATER, 5 °C AIR, 150 G/L
AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	49.26	33.83	10.57	-31.32	-78.54
Chlorobenzene	29.70	33.46	9.30	12.66	-68.68
Ethylbenzene	31.12	32.27	9.89	3.70	-68.22
Tetrachloroethane	21.47	24.24	6.49	12.90	-69.77
1,3-Dichlorobenzene	27.89	31.09	8.19	11.47	-70.63
1,2-Dichlorobenzene	26.26	30.80	8.14	17.29	-69.00
Nitrobenzene	4.91	16.82	5.64	242.5	14.57
Napthalene	26.46	25.24	7.77	-4.61	-70.63
1-Chloronapthalene	25.26	23.43	6.92	-7.24	-72.60
2,6-Dinitrotoluene	2.75	20.07	5.73	629.8	108.3
Fluorene	10.60	25.91	7.31	144.4	-31.13
2,4-Dinitrotoluene	2.54	20.17	5.73	694.0	125.5
Hexachlorobenzene	5.42	25.07	5.65	362.5	4.24
Phenanthrene	5.50	17.81	5.59	223.8	1.64
Fluoranthene	4.22	16.59	5.11	293.1	21.09

* 5 °C nitrogen, 88.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	111.8	-	-	-
Chlorobenzene	130.2	109.1	37.31	-16.20	-71.34
Ethylbenzene	105.8	107.2	39.69	1.32	-62.49
Tetrachloroethane	100.5	64.24	26.04	-36.11	-74.10
1,3-Dichlorobenzene	135.2	99.16	32.85	-26.66	-75.07
1,2-Dichlorobenzene	134.0	97.38	32.66	-27.37	-75.64
Nitrobenzene	29.28	37.22	22.63	27.11	-22.71
Napthalene	143.6	69.67	31.20	-51.48	-78.28
1-Chloronapthalene	135.1	63.11	27.15	-53.29	-79.90
2,6-Dinitrotoluene	8.90	49.32	23.00	454.2	158.4
Fluorene	33.44	76.85	29.33	129.0	-12.29
2,4-Dinitrotoluene	15.70	49.68	22.98	216.4	46.37
Hexachlorobenzene	15.80	75.21	22.68	376.0	43.54
Phenanthrene	24.93	42.68	22.44	71.20	-9.99
Fluoranthene	24.31	39.14	20.51	61.00	-15.63

* 25 °C nitrogen, 88.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	49.76	-	-	-
Chlorobenzene	50.13	49.04	13.00	-2.17	-74.07
Ethylbenzene	40.81	47.52	13.82	16.44	-66.13
Tetrachloroethane	27.72	33.61	9.07	21.24	-67.28
1,3-Dichlorobenzene	55.21	45.32	11.44	-17.91	-79.28
1,2-Dichlorobenzene	52.78	44.80	11.37	-15.21	-78.46
Nitrobenzene	7.58	22.07	7.88	191.6	3.96
Napthalene	47.88	35.41	10.86	-26.04	-77.32
1-Chloronapthalene	49.13	32.60	13.30	-33.65	-72.93
2,6-Dinitrotoluene	3.67	27.22	8.00	641.7	118.0
Fluorene	11.88	37.09	10.21	212.2	-14.06
2,4-Dinitrotoluene	5.87	27.36	8.00	366.1	36.29
Hexachlorobenzene	8.14	35.98	7.90	342.0	-2.95
Phenanthrene	6.76	23.92	7.82	253.9	15.68
Fluoranthene	7.18	22.21	7.14	209.3	-0.56

* 5 °C nitrogen, 90.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	33.83	-	-	-
Chlorobenzene	19.55	33.46	8.10	71.15	-58.57
Ethylbenzene	18.40	32.27	8.62	75.38	-53.15
Tetrachloroethane	10.47	24.24	5.65	131.5	-46.04
1,3-Dichlorobenzene	24.11	31.09	7.13	28.95	-70.43
1,2-Dichlorobenzene	21.80	30.80	7.09	41.28	-67.48
Nitrobenzene	3.63	16.82	4.92	363.4	35.35
Napthalene	20.29	25.42	6.78	25.28	-66.58
1-Chloronapthalene	19.59	23.43	5.90	19.60	-69.88
2,6-Dinitrotoluene	2.30	20.07	4.99	772.6	117.4
Fluorene	5.62	25.91	6.37	361.0	13.34
2,4-Dinitrotoluene	2.50	20.17	4.99	706.8	100.0
Hexachlorobenzene	4.07	25.07	4.93	516.0	21.11
Phenanthrene	3.02	17.81	4.86	489.7	-60.93
Fluoranthene	3.23	16.59	4.45	413.6	37.77

* 5 °C nitrogen, 93.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	111.8	-	-	-
Chlorobenzene	113.3	109.1	17.65	-3.70	-84.42
Ethylbenzene	85.46	107.2	18.78	25.44	-78.02
Tetrachloroethane	100.7	64.24	12.32	-36.21	-87.77
1,3-Dichlorobenzene	106.0	99.16	14.00	-6.45	-86.79
1,2-Dichlorobenzene	113.4	97.38	15.45	-14.13	-86.38
Nitrobenzene	23.01	37.22	10.71	61.76	-53.46
Napthalene	112.50	69.67	14.76	-38.07	-86.88
1-Chloronapthalene	112.40	63.11	13.30	-43.85	-88.17
2,6-Dinitrotoluene	15.84	49.32	10.88	211.4	-31.31
Fluorene	17.44	76.85	13.88	339.1	-20.41
2,4-Dinitrotoluene	15.87	49.68	10.87	213.0	-31.51
Hexachlorobenzene	17.29	75.21	10.73	335.0	-37.94
Phenanthrene	21.31	42.68	10.62	100.3	-50.16
Fluoranthene	28.05	39.14	9.70	39.54	-65.44

* 5 °C nitrogen, 93.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35°C WATER, 5 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	49.76	-	-	-
Chlorobenzene	44.58	49.04	6.01	10.00	-86.51
Ethylbenzene	45.39	47.52	6.40	4.69	-85.90
Tetrachloroethane	29.35	33.61	4.20	14.51	-85.69
1,3-Dichlorobenzene	42.50	45.32	4.00	6.63	-90.59
1,2-Dichlorobenzene	44.64	44.80	5.26	0.36	-88.21
Nitrobenzene	6.50	22.07	3.65	239.5	-43.85
Napthalene	37.80	35.41	5.03	-5.52	-86.69
1-Chloronapthalene	37.08	32.60	4.37	-12.08	-88.22
2,6-Dinitrotoluene	4.84	27.22	3.71	462.4	-23.35
Fluorene	10.41	37.09	4.73	256.3	-54.56
2,4-Dinitrotoluene	4.87	27.37	3.71	462.0	-23.77
Hexachlorobenzene	8.66	35.98	2.86	315.5	-66.97
Phenanthrene	5.12	23.92	3.62	367.4	-29.30
Fluoranthene	5.82	22.21	3.31	281.6	-43.13

* 5 °C nitrogen, 95.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 5 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	33.83	-	-	-
Chlorobenzene	25.38	33.46	3.89	31.86	-84.67
Ethylbenzene	23.69	32.27	4.14	36.22	-82.52
Tetrachloroethane	22.47	24.24	2.72	7.88	-87.89
1,3-Dichlorobenzene	26.69	31.09	3.43	16.49	-87.15
1,2-Dichlorobenzene	27.21	30.80	3.41	13.91	-87.47
Nitrobenzene	4.09	16.82	2.36	311.2	-42.30
Napthalene	20.58	25.24	3.26	22.64	-84.61
1-Chloronapthalene	20.78	23.43	2.83	12.75	-86.38
2,6-Dinitrotoluene	2.63	20.07	2.40	663.1	-8.74
Fluorene	5.86	25.91	3.06	3.42	-47.78
2,4-Dinitrotoluene	3.31	20.17	2.40	509.4	-27.29
Hexachlorobenzene	4.13	25.07	2.37	507.2	-42.62
Phenanthrene	3.47	17.81	2.34	413.6	-32.56
Fluoranthene	3.38	16.59	2.14	390.8	-36.69

* 5 °C nitrogen, 82.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	210.6	113.4	41.52	-46.10	-80.28
Chlorobenzene	139.8	110.2	36.55	-21.17	-73.86
Ethylbenzene	145.6	107.5	38.65	-26.17	-73.45
Tetrachloroethane	208.3	68.82	26.07	-66.96	-87.48
1,3-Dichlorobenzene	145.0	101.6	32.00	-29.93	-77.93
1,2-Dichlorobenzene	147.0	100.0	31.80	-31.97	-78.37
Nitrobenzene	42.48	40.26	22.98	-5.25	-45.95
Napthalene	272.5	73.42	30.98	-73.06	-88.63
1-Chloronapthalene	342.1	67.03	27.03	-80.41	-92.10
2,6-Dinitrotoluene	15.00	52.08	22.82	247.2	52.13
Fluorene	38.26	79.51	28.89	107.8	-24.49
2,4-Dinitrotoluene	10.59	52.42	22.90	395.0	116.2
Hexachlorobenzene	20.25	77.54	22.36	282.9	10.42
Phenanthrene	51.11	47.29	22.92	-7.47	-55.16
Fluoranthene	31.74	43.76	21.08	37.87	-33.59

* 15°C nitrogen, 82.2% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	73.53	50.22	16.62	-31.70	-77.40
Chlorobenzene	48.56	49.68	14.64	2.23	-69.85
Ethylbenzene	54.82	47.92	15.54	-12.59	-71.65
Tetrachloroethane	36.82	35.37	10.44	-3.93	-71.64
1,3-Dichlorobenzene	47.65	45.62	12.91	-4.26	-72.91
1,2-Dichlorobenzene	41.32	45.61	12.85	10.38	-68.90
Nitrobenzene	7.98	23.57	9.20	195.4	15.29
Napthalene	45.86	36.77	12.41	-19.82	-72.94
1-Chloronapthalene	45.02	34.09	10.83	-24.28	-75.94
2,6-Dinitrotoluene	5.61	28.39	9.14	406.1	62.92
Fluorene	16.46	38.99	11.57	136.9	-29.71
2,4-Dinitrotoluene	5.82	28.54	9.17	390.4	57.56
Hexachlorobenzene	9.42	36.95	8.96	292.2	-4.88
Phenanthrene	9.42	26.03	9.18	176.3	-2.54
Fluoranthene	7.22	24.37	8.44	237.5	16.90

* 15 °C nitrogen, 85.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	49.88	34.07	10.05	-31.69	-79.85
Chlorobenzene	33.23	33.79	8.86	1.68	-73.34
Ethylbenzene	32.72	32.48	9.40	-0.73	-71.27
Tetrachloroethane	21.36	25.30	6.32	18.44	-70.44
1,3-Dichlorobenzene	30.81	31.49	7.75	2.20	-74.84
1,2-Dichlorobenzene	34.89	32.23	7.77	-7.62	-77.33
Nitrobenzene	4.25	17.83	5.68	319.5	33.65
Napthalene	27.63	26.04	7.51	-5.75	-72.82
1-Chloronapthalene	26.53	24.29	6.55	-8.53	-75.31
2,6-Dinitrotoluene	3.06	20.82	5.53	580.4	80.72
Fluorene	11.18	26.44	7.00	136.5	-37.40
2,4-Dinitrotoluene	3.04	20.92	5.55	588.2	82.57
Hexachlorobenzene	5.91	25.63	5.42	333.8	8.29
Phenanthrene	6.69	19.12	5.55	185.8	-17.04
Fluoranthene	4.44	18.00	5.11	305.4	15.09

* 15 °C nitrogen, 83.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	113.4	-	-	-
Chlorobenzene	114.3	110.2	25.19	-3.58	-77.96
Ethylbenzene	169.7	107.5	26.64	-36.65	-84.30
Tetrachloroethane	169.8	68.82	17.96	-59.47	-89.42
1,3-Dichlorobenzene	137.8	101.6	22.21	-26.26	-83.88
1,2-Dichlorobenzene	133.8	100.0	22.10	-25.26	-83.48
Nitrobenzene	34.57	40.26	15.83	16.45	-54.21
Napthalene	223.9	73.42	21.34	-67.21	-90.47
1-Chloronapthalene	237.6	67.03	18.63	-71.79	-92.16
2,6-Dinitrotoluene	10.78	52.08	15.73	383.2	45.92
Fluorene	25.91	79.51	19.90	206.9	-23.20
2,4-Dinitrotoluene	21.47	52.42	15.78	144.2	-26.50
Hexachlorobenzene	17.68	77.54	15.41	338.6	12.84
Phenanthrene	39.35	47.29	15.79	20.18	-59.87
Fluoranthene	31.96	43.76	14.52	36.92	-54.57

* 15 °C nitrogen, 87.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15°C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	50.22	-	-	-
Chlorobenzene	53.92	49.68	10.47	-7.86	-80.58
Ethylbenzene	42.97	47.92	11.03	11.51	-74.33
Tetrachloroethane	27.15	35.37	7.42	30.27	-72.67
1,3-Dichlorobenzene	55.70	45.62	9.17	-18.10	-83.54
1,2-Dichlorobenzene	53.48	45.61	9.13	-14.71	-82.93
Nitrobenzene	6.45	23.57	6.54	265.4	1.39
Napthalene	42.93	36.77	8.82	-14.34	-79.45
1-Chloronapthalene	42.68	34.09	7.69	-20.12	-81.98
2,6-Dinitrotoluene	4.68	28.39	6.50	506.6	38.89
Fluorene	11.09	38.99	8.22	251.6	-25.88
2,4-Dinitrotoluene	5.41	28.54	6.52	427.5	20.50
Hexachlorobenzene	6.69	36.95	6.36	452.3	-4.93
Phenanthrene	7.02	26.03	6.52	270.8	-7.12
Fluoranthene	8.17	24.37	5.99	198.3	-26.56

* 15 °C nitrogen, 86.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	34.07	-	-	-
Chlorobenzene	31.54	33.79	6.56	7.13	-79.20
Ethylbenzene	28.52	32.48	6.96	13.88	-75.60
Tetrachloroethane	14.28	25.30	4.67	77.17	-67.30
1,3-Dichlorobenzene	32.00	31.49	5.78	-1.59	-81.93
1,2-Dichlorobenzene	32.58	31.23	5.76	-4.14	-82.32
Nitrobenzene	3.36	17.83	4.12	430.7	22.62
Napthalene	24.69	26.04	5.56	5.47	-77.48
1-Chloronapthalene	24.11	24.29	4.80	0.75	-80.09
2,6-Dinitrotoluene	2.92	20.82	4.10	613.0	40.41
Fluorene	6.80	26.44	5.19	288.8	-23.67
2,4-Dinitrotoluene	3.95	20.92	4.11	429.6	4.05
Hexachlorobenzene	4.25	25.63	4.01	503.1	-5.64
Phenanthrene	3.89	19.12	4.11	391.5	5.66
Fluoranthene	4.39	18.00	3.86	310.0	12.07

* 15°C nitrogen, 84.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	113.4	-	-	-
Chlorobenzene	97.23	110.2	14.22	-13.34	-85.37
Ethylbenzene	88.87	107.5	15.10	20.96	-83.00
Tetrachloroethane	159.0	68.82	10.14	-56.71	-93.62
1,3-Dichlorobenzene	102.6	101.6	12.54	-0.97	-87.78
1,2-Dichlorobenzene	94.57	100.0	12.48	5.74	-86.80
Nitrobenzene	25.93	40.26	8.94	55.26	-65.52
Napthalene	251.4	73.42	12.06	-70.80	-95.20
1-Chloronapthalene	217.7	67.03	10.52	-69.20	-95.17
2,6-Dinitrotoluene	16.25	52.08	8.88	220.5	-45.35
Fluorene	23.43	79.51	11.24	239.4	-52.03
2,4-Dinitrotoluene	15.98	52.42	8.91	228.0	-44.24
Hexachlorobenzene	20.87	77.54	8.70	271.5	-58.31
Phenanthrene	36.26	47.29	8.92	30.42	-75.40
Fluoranthene	31.92	43.76	8.20	37.09	-74.31

* 15 °C nitrogen, 89.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	50.22	-	-	-
Chlorobenzene	41.28	49.68	6.19	20.34	-85.00
Ethylbenzene	38.27	47.92	6.57	25.21	-82.83
Tetrachloroethane	40.95	35.37	4.41	-13.63	-89.23
1,3-Dichlorobenzene	44.97	45.62	5.46	1.44	-87.86
1,2-Dichlorobenzene	36.29	45.61	5.43	25.68	-85.04
Nitrobenzene	8.25	23.57	3.89	185.7	-52.58
Napthalene	40.93	36.77	5.25	-10.16	-87.17
1-Chloronapthalene	34.26	34.09	4.58	-0.50	-86.63
2,6-Dinitrotoluene	4.00	28.39	3.87	609.7	-3.25
Fluorene	10.70	38.99	4.84	264.4	-54.77
2,4-Dinitrotoluene	3.68	28.54	3.88	675.5	5.43
Hexachlorobenzene	7.59	36.95	3.79	386.8	-50.07
Phenanthrene	5.99	26.03	3.88	333.8	-35.33
Fluoranthene	5.99	24.37	3.57	306.2	-40.50

* 15°C nitrogen, 91.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 15 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	34.07	-	-	-
Chlorobenzene	23.89	33.79	4.20	41.44	-82.42
Ethylbenzene	27.43	32.48	4.43	18.41	-83.85
Tetrachloroethane	19.98	25.30	2.97	-27.37	-85.14
1,3-Dichlorobenzene	25.28	31.49	3.68	24.56	-85.44
1,2-Dichlorobenzene	24.52	31.23	3.66	27.36	-85.07
Nitrobenzene	6.66	17.83	2.62	167.7	-60.66
Napthalene	23.88	26.04	3.53	9.04	-85.22
1-Chloronapthalene	22.10	24.29	3.09	9.91	-86.01
2,6-Dinitrotoluene	3.06	20.82	2.60	580.4	-15.03
Fluorene	5.29	26.44	3.30	399.8	-37.62
2,4-Dinitrotoluene	3.15	20.92	2.61	564.2	-17.14
Hexachlorobenzene	6.62	25.63	2.55	287.1	-61.48
Phenanthrene	4.44	19.12	2.61	330.6	-41.22
Fluoranthene	4.40	18.00	2.40	309.1	-45.45

* 15°C nitrogen, 95.1% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	284.3	114.7	39.68	-59.66	-86.04
Chlorobenzene	135.4	113.0	35.01	-16.54	-74.14
Ethylbenzene	140.0	109.7	37.10	-21.64	-73.50
Tetrachloroethane	267.8	73.14	45.44	-72.69	-83.03
1,3-Dichlorobenzene	144.2	103.7	30.92	-28.09	-78.56
1,2-Dichlorobenzene	109.8	102.6	30.77	-6.56	-71.98
Nitrobenzene	37.96	43.38	22.74	-14.28	-40.09
Napthalene	193.7	76.92	30.04	-60.29	-84.49
1-Chloronapthalene	155.0	70.57	26.28	-54.47	-83.04
2,6-Dinitrotoluene	23.80	54.78	22.12	130.1	-7.06
Fluorene	48.25	81.94	27.18	69.82	-43.67
2,4-Dinitrotoluene	24.73	55.12	22.29	122.9	-9.87
Hexachlorobenzene	20.37	80.58	21.53	295.6	5.65
Phenanthrene	38.70	52.22	22.75	34.93	-41.21
Fluoranthene	36.83	48.85	21.02	32.63	-42.93

* 25°C nitrogen, 82.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	94.09	50.58	14.25	-46.24	-84.82
Chlorobenzene	60.61	50.17	12.57	-17.22	-79.26
Ethylbenzene	80.23	48.24	11.26	-39.87	-85.96
Tetrachloroethane	112.7	36.95	9.14	-67.22	-91.89
1,3-Dichlorobenzene	55.83	46.68	11.10	-16.38	-80.12
1,2-Dichlorobenzene	51.43	46.34	11.06	-9.72	-78.50
Nitrobenzene	8.19	25.03	8.17	205.6	-0.24
Napthalene	47.46	37.99	10.79	-19.93	-77.26
1-Chloronapthalene	43.69	35.40	9.44	-18.97	-78.93
2,6-Dinitrotoluene	6.32	29.52	7.95	367.1	125.9
Fluorene	14.53	38.76	9.98	166.8	-31.31
2,4-Dinitrotoluene	6.89	29.66	8.00	330.5	16.11
Hexachlorobenzene	10.39	37.78	7.74	263.6	-25.50
Phenanthrene	9.20	27.96	8.17	203.9	11.20
Fluoranthene	8.97	26.41	7.55	194.4	-15.83

* 25 °C nitrogen, 87.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	34.26	-	-	-
Chlorobenzene	34.58	34.06	9.91	-1.50	-71.34
Ethylbenzene	38.06	32.65	10.05	-14.21	-73.59
Tetrachloroethane	22.43	26.32	7.20	-17.34	-67.90
1,3-Dichlorobenzene	31.33	31.83	8.75	1.60	-72.07
1,2-Dichlorobenzene	31.00	31.64	8.71	2.06	-71.90
Nitrobenzene	5.81	18.83	15.30	44.62	163.3
Napthalene	29.01	26.75	8.50	-7.79	-70.70
1-Chloronapthalene	28.05	25.07	7.43	-10.62	-73.51
2,6-Dinitrotoluene	3.90	21.53	6.26	452.0	60.51
Fluorene	10.84	26.88	7.87	148.0	-27.40
2,4-Dinitrotoluene	5.06	21.62	6.31	327.3	24.70
Hexachlorobenzene	4.74	26.09	6.09	450.4	28.48
Phenanthrene	5.62	20.36	6.43	267.1	14.41
Fluoranthene	6.14	19.29	5.95	214.2	-3.09

* 25°C nitrogen, 81.8% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	114.7	-	-	-
Chlorobenzene	121.5	113.0	26.34	-7.00	-78.32
Ethylbenzene	115.8	109.7	27.91	-5.27	-75.90
Tetrachloroethane	185.0	73.41	19.14	-60.32	-89.65
1,3-Dichlorobenzene	129.8	103.7	23.26	-20.10	-82.08
1,2-Dichlorobenzene	122.6	102.6	23.16	-16.31	-81.11
Nitrobenzene	35.68	43.38	17.11	21.58	-52.04
Napthalene	203.7	76.92	22.60	-62.32	-88.90
1-Chloronapthalene	255.2	70.57	19.77	-72.34	-92.25
2,6-Dinitrotoluene	16.11	54.78	16.65	240.0	3.35
Fluorene	32.62	81.94	20.92	151.2	-35.87
2,4-Dinitrotoluene	28.27	55.12	16.77	94.98	-40.68
Hexachlorobenzene	17.86	80.58	16.20	354.8	-9.29
Phenanthrene	34.95	52.22	17.11	49.41	-51.04
Fluoranthene	51.81	48.85	15.81	-5.71	-69.48

* 25 °C nitrogen, 83.4 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	50.58	-	-	-
Chlorobenzene	54.30	50.17	9.52	-7.60	-78.32
Ethylbenzene	45.31	48.24	10.09	6.47	-77.73
Tetrachloroethane	28.74	36.95	6.92	28.56	-75.92
1,3-Dichlorobenzene	54.64	46.68	8.41	-14.57	-84.61
1,2-Dichlorobenzene	52.52	46.34	8.38	-11.77	-84.04
Nitrobenzene	7.05	25.03	6.19	255.0	-12.19
Napthalene	40.97	37.99	8.17	-7.24	-80.06
1-Chloronapthalene	42.59	35.40	7.15	-16.88	-83.21
2,6-Dinitrotoluene	5.29	29.52	6.02	458.0	13.80
Fluorene	10.73	38.76	7.56	261.2	-29.54
2,4-Dinitrotoluene	6.31	29.66	6.06	370.0	-3.96
Hexachlorobenzene	8.00	37.78	5.86	372.2	-26.75
Phenanthrene	7.26	27.96	6.19	285.1	-14.74
Fluoranthene	8.28	26.41	5.72	316.9	-30.92

* 25°C nitrogen, 91.2% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	34.26	-	-	-
Chlorobenzene	31.88	34.06	6.30	6.84	-80.23
Ethylbenzene	30.50	32.65	6.67	7.05	-78.13
Tetrachloroethane	16.11	26.32	4.58	63.37	-71.57
1,3-Dichlorobenzene	33.68	31.83	5.56	-5.49	-83.49
1,2-Dichlorobenzene	34.52	31.64	5.54	-8.34	-83.95
Nitrobenzene	3.85	18.83	4.09	79.55	6.23
Napthalene	25.60	26.75	5.41	4.49	-78.78
1-Chloronapthalene	26.96	25.07	4.73	-7.01	-82.45
2,6-Dinitrotoluene	3.40	21.53	3.98	533.2	17.05
Fluorene	7.71	26.88	5.01	248.6	-35.02
2,4-Dinitrotoluene	3.77	21.62	4.01	473.5	6.37
Hexachlorobenzene	5.90	26.09	3.87	342.2	34.41
Phenanthrene	4.11	20.36	4.09	395.4	-0.49
Fluoranthene	4.47	19.29	3.78	331.5	-15.44

* 25 °C nitrogen, 85.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	114.7	-	-	-
Chlorobenzene	99.66	113.0	22.25	13.39	-77.67
Ethylbenzene	101.9	109.7	23.58	7.65	-76.86
Tetrachloroethane	169.9	73.14	16.17	-56.79	-90.48
1,3-Dichlorobenzene	109.1	103.7	19.65	-4.94	-81.99
1,2-Dichlorobenzene	105.5	102.6	19.57	-2.74	-81.47
Nitrobenzene	21.70	43.38	14.45	100.0	-33.41
Napthalene	166.1	76.92	19.09	-53.69	-88.51
1-Chloronapthalene	179.4	70.57	16.70	-60.66	-90.69
2,6-Dinitrotoluene	16.05	54.78	14.07	241.3	-12.33
Fluorene	24.45	81.94	17.67	235.1	-27.73
2,4-Dinitrotoluene	16.61	55.12	14.17	231.8	-14.69
Hexachlorobenzene	20.35	80.58	13.69	296.0	-32.72
Phenanthrene	41.42	52.22	14.46	26.07	-65.08
Fluoranthene	66.47	48.85	13.36	26.51	-79.90

* 25°C nitrogen, 86.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	50.58	-	-	-
Chlorobenzene	47.78	50.17	7.62	5.00	-84.05
Ethylbenzene	39.16	48.24	8.07	23.19	-79.39
Tetrachloroethane	37.07	36.95	5.54	-0.32	-85.06
1,3-Dichlorobenzene	39.53	46.68	6.73	18.09	-82.97
1,2-Dichlorobenzene	47.81	46.34	6.70	-3.07	-85.99
Nitrobenzene	8.63	25.03	4.95	190.0	-42.64
Napthalene	43.64	37.99	6.54	-12.99	-85.01
1-Chloronapthalene	36.80	35.40	5.72	-3.80	-84.46
2,6-Dinitrotoluene	4.07	29.52	4.82	625.3	18.42
Fluorene	8.88	38.76	6.05	336.5	-31.86
2,4-Dinitrotoluene	5.01	29.66	4.85	492.0	-3.19
Hexachlorobenzene	7.77	37.78	4.69	386.2	-39.63
Phenanthrene	5.89	27.96	4.95	374.7	-15.96
Fluoranthene	6.11	26.41	4.58	332.2	-25.04

* 25 °C nitrogen, 90.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 35 °C WATER, 25 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	34.26	-	-	-
Chlorobenzene	28.79	34.06	5.62	-13.58	-80.48
Ethylbenzene	26.09	32.65	5.95	-25.14	-77.19
Tetrachloroethane	30.91	26.32	4.08	-14.84	-86.80
1,3-Dichlorobenzene	24.81	31.83	4.96	28.29	-80.00
1,2-Dichlorobenzene	24.94	31.64	4.94	26.86	-80.19
Nitrobenzene	6.75	18.83	3.65	179.0	-45.92
Napthalene	21.89	26.75	4.82	22.20	-77.98
1-Chloronapthalene	19.72	25.07	4.21	27.13	-78.65
2,6-Dinitrotoluene	3.65	21.53	3.55	490.0	-2.73
Fluorene	6.33	26.88	4.46	324.6	-29.54
2,4-Dinitrotoluene	3.09	21.62	3.57	600.0	15.53
Hexachlorobenzene	7.10	26.09	3.45	267.5	-51.41
Phenanthrene	4.53	20.36	3.65	349.4	-19.42
Fluoranthene	4.34	19.29	3.47	344.5	-20.05

* 25 °C nitrogen, 88.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	192.5	188.7	44.48	-1.97	-76.89
Chlorobenzene	176.2	184.2	39.24	4.54	-77.62
Ethylbenzene	151.2	181.2	41.58	19.84	-72.50
Tetrachloroethane	263.3	102.4	28.52	-61.11	-89.17
1,3-Dichlorobenzene	161.8	166.0	34.66	2.60	-78.58
1,2-Dichlorobenzene	158.0	163.2	34.51	3.29	-78.16
Nitrobenzene	29.50	53.73	25.49	82.11	-13.59
Napthalene	236.1	110.2	33.77	-53.32	-85.70
1-Chloronapthalene	226.5	99.6	29.45	-56.03	-87.00
2,6-Dinitrotoluene	26.38	72.03	24.80	173.0	-5.99
Fluorene	66.98	123.3	31.16	84.08	-53.47
2,4-Dinitrotoluene	17.75	72.58	24.46	308.9	37.80
Hexachlorobenzene	24.90	123.4	24.14	395.6	-3.05
Phenanthrene	23.95	69.07	25.48	188.4	6.38
Fluoranthene	21.73	63.92	23.56	194.2	8.42

* 5 °C nitrogen, 85.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	59.95	69.01	16.58	15.11	-72.34
Chlorobenzene	61.09	67.84	14.61	11.05	-76.08
Ethylbenzene	59.95	69.95	15.50	16.68	-74.14
Tetrachloroethane	50.69	45.04	10.42	-11.15	-79.44
1,3-Dichlorobenzene	60.17	62.56	12.88	3.97	-78.59
1,2-Dichlorobenzene	63.63	61.55	12.82	-3.27	-79.58
Nitrobenzene	14.54	27.95	9.18	92.22	-36.86
Napthalene	69.13	47.47	12.38	-31.33	-82.09
1-Chloronapthalene	66.53	43.58	10.80	-34.45	-83.77
2,6-Dinitrotoluene	7.40	35.03	9.12	377.0	23.23
Fluorene	9.15	50.26	11.54	449.3	26.12
2,4-Dinitrotoluene	11.54	35.22	9.15	205.2	-20.71
Hexachlorobenzene	9.44	49.15	8.93	420.7	-5.40
Phenanthrene	11.88	32.07	9.16	170.0	-22.89
Fluoranthene	9.23	29.80	8.42	222.9	-8.76

* 5 °C nitrogen, 87.6 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	35.97	44.15	10.01	22.74	-72.17
Chlorobenzene	38.86	43.51	8.80	11.96	-77.35
Ethylbenzene	34.39	39.15	9.36	13.84	-72.78
Tetrachloroethane	29.18	29.76	6.14	1.99	-78.96
1,3-Dichlorobenzene	37.06	40.19	7.75	8.44	-79.09
1,2-Dichlorobenzene	41.22	39.72	7.71	-3.63	-81.30
Nitrobenzene	7.02	19.51	5.34	177.9	-23.93
Napthalene	38.59	31.37	7.36	-18.73	-80.93
1-Chloronapthalene	37.47	28.88	6.41	-22.93	-82.89
2,6-Dinitrotoluene	4.20	24.09	5.43	473.6	29.28
Fluorene	20.15	32.88	6.92	63.18	-65.66
2,4-Dinitrotoluene	3.77	24.21	5.42	542.2	-43.77
Hexachlorobenzene	8.32	31.89	5.42	283.3	-34.85
Phenanthrene	7.61	21.23	5.30	179.2	-30.35
Fluoranthene	6.66	19.65	4.84	193.7	-27.32

* 5°C nitrogen, 88.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	154.0	-	-	-
Chlorobenzene	165.6	150.1	29.62	12.42	-75.64
Ethylbenzene	128.8	147.7	31.44	12.31	-74.20
Tetrachloroethane	94.57	84.46	21.12	19.51	-77.66
1,3-Dichlorobenzene	175.9	135.5	26.12	-22.45	-85.45
1,2-Dichlorobenzene	183.7	132.2	26.00	-28.03	-85.84
Nitrobenzene	23.43	46.05	18.62	96.54	-20.52
Napthalene	249.7	93.53	25.31	-62.54	-89.96
1-Chloronapthalene	179.2	82.68	21.92	-53.86	-87.77
2,6-Dinitrotoluene	18.18	61.79	18.50	239.9	1.76
Fluorene	53.07	102.2	23.43	92.67	55.85
2,4-Dinitrotoluene	14.59	62.22	18.57	326.5	27.28
Hexachlorobenzene	17.85	101.3	18.12	467.5	1.51
Phenanthrene	20.38	56.32	18.59	176.4	-8.87
Fluoranthene	27.68	51.72	17.09	86.85	-38.26

* 5 °C nitrogen, 88.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	68.98	-	-	-
Chlorobenzene	60.44	67.96	14.27	12.44	-76.99
Ethylbenzene	58.69	65.92	15.14	12.13	-74.70
Tetrachloroethane	37.68	45.03	10.18	19.51	-72.98
1,3-Dichlorobenzene	64.58	62.54	12.58	3.16	-80.52
1,2-Dichlorobenzene	51.98	61.56	12.52	18.43	-75.92
Nitrobenzene	13.35	27.94	8.96	109.2	-32.88
Napthalene	52.34	48.19	12.10	-8.11	-76.88
1-Chloronapthalene	63.60	43.57	10.56	-31.49	-83.40
2,6-Dinitrotoluene	5.03	35.02	8.91	596.2	77.14
Fluorene	16.56	50.24	11.27	203.4	-31.94
2,4-Dinitrotoluene	5.09	35.22	8.94	591.9	75.63
Hexachlorobenzene	9.85	49.13	8.73	398.8	-11.37
Phenanthrene	7.59	32.06	8.95	322.4	17.91
Fluoranthene	8.88	29.79	8.23	-33.6	-7.32

* 5 °C nitrogen, 95.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	46.45	-	-	-
Chlorobenzene	39.72	45.74	9.53	15.15	-76.00
Ethylbenzene	37.16	43.32	10.14	-16.58	-72.71
Tetrachloroethane	6.65	30.91	6.65	364.8	0.00
1,3-Dichlorobenzene	32.25	42.19	8.40	30.82	-73.95
1,2-Dichlorobenzene	34.65	41.68	8.35	20.29	-75.90
Nitrobenzene	8.96	20.02	5.79	123.4	-35.38
Napthalene	31.21	32.64	7.98	4.58	-74.43
1-Chloronapthalene	33.67	30.00	6.94	-10.90	-79.39
2,6-Dinitrotoluene	3.04	24.88	5.88	718.4	141.5
Fluorene	14.23	34.37	7.50	141.5	-47.29
2,4-Dinitrotoluene	2.97	25.02	5.87	742.4	-97.64
Hexachlorobenzene	5.95	33.37	5.80	460.8	-2.52
Phenanthrene	4.53	21.91	5.74	383.7	26.71
Fluoranthene	5.29	20.25	5.24	282.3	-0.95

* 5°C nitrogen, 97.2% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT
(K_1a) FOR 55 °C WATER, 5 °C AIR, 30 G/L
AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	154.0	-		
Chlorobenzene	109.2	150.1	17.78	37.45	-91.42
Ethylbenzene	103.2	147.7	18.87	43.12	-81.72
Tetrachloroethane	165.8	84.46	12.68	-49.06	-92.35
1,3-Dichlorobenzene	143.8	135.5	15.68	-5.77	-89.10
1,2-Dichlorobenzene	150.0	132.2	15.60	-11.87	-89.60
Nitrobenzene	25.93	46.05	11.17	77.59	-56.92
Napthalene	307.2	93.53	15.07	-69.55	-95.09
1-Chloronapthalene	229.5	82.68	13.15	-63.97	-94.27
2,6-Dinitrotoluene	18.76	61.79	11.10	229.3	-40.83
Fluorene	40.65	102.2	14.05	61.60	-65.44
2,4-Dinitrotoluene	10.62	62.22	11.14	4.86	4.99
Hexachlorobenzene	23.07	101.3	10.87	339.1	-52.88
Phenanthrene	50.17	56.32	11.14	12.26	-77.79
Fluoranthene	52.72	51.72	10.25	-1.90	-80.56

* 5°C nitrogen, 86.3% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	69.01	-	-	-
Chlorobenzene	41.89	67.84	7.41	61.94	-82.31
Ethylbenzene	40.93	69.95	7.87	70.90	-80.77
Tetrachloroethane	34.00	45.04	5.29	32.47	-84.44
1,3-Dichlorobenzene	47.52	62.56	6.54	31.64	-86.24
1,2-Dichlorobenzene	39.28	61.55	6.50	56.60	-83.45
Nitrobenzene	15.20	27.95	4.66	83.88	-69.34
Napthalene	54.05	47.47	6.28	-12.17	-88.38
1-Chloronapthalene	33.46	43.58	5.48	30.25	-83.62
2,6-Dinitrotoluene	4.22	35.03	4.63	730.1	9.71
Fluorene	21.96	50.26	5.86	128.9	-73.32
2,4-Dinitrotoluene	4.50	35.22	4.64	682.7	3.11
Hexachlorobenzene	8.94	49.15	4.53	449.7	-49.32
Phenanthrene	6.30	32.07	4.65	409.5	-26.19
Fluoranthene	6.60	29.80	4.27	351.5	-35.30

* 5°C nitrogen, 87.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 5 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	46.45	-	-	-
Chlorobenzene	24.77	45.74	5.24	84.66	-78.84
Ethylbenzene	25.31	43.32	5.59	71.16	-77.91
Tetrachloroethane	23.57	30.91	3.66	31.14	-84.47
1,3-Dichlorobenzene	27.67	42.19	4.61	52.48	-83.34
1,2-Dichlorobenzene	25.46	41.68	4.59	63.70	-81.97
Nitrobenzene	7.74	20.02	3.18	158.7	-58.91
Napthalene	29.57	32.64	4.38	10.38	-85.19
1-Chloronapthalene	28.85	30.00	3.81	3.99	-86.79
2,6-Dinitrotoluene	2.88	24.88	3.23	764.8	12.15
Fluorene	14.78	34.37	4.12	132.5	-72.12
2,4-Dinitrotoluene	3.12	25.02	3.23	701.9	3.53
Hexachlorobenzene	6.59	33.37	3.23	406.8	-50.99
Phenanthrene	4.49	21.91	3.15	388.0	-29.84
Fluoranthene	4.13	20.25	2.88	390.3	-30.27

* 5 °C nitrogen, 90.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	217.5	191.5	46.95	-11.95	-78.41
Chlorobenzene	180.4	188.0	41.43	4.21	-77.03
Ethylbenzene	152.8	183.6	43.84	20.16	-71.31
Tetrachloroethane	196.7	109.8	30.60	-44.18	-84.44
1,3-Dichlorobenzene	162.9	170.4	36.63	4.60	-77.52
1,2-Dichlorobenzene	162.5	168.3	36.50	3.56	-77.54
Nitrobenzene	28.79	58.15	27.72	101.9	-3.72
Napthalene	252.4	116.5	35.92	-53.84	-84.90
1-Chloronapthalene	298.4	105.9	31.49	-64.51	-89.44
2,6-Dinitrotoluene	45.72	76.21	26.50	66.67	-42.04
Fluorene	81.46	128.0	33.04	57.13	-59.44
2,4-Dinitrotoluene	22.78	76.80	26.76	237.1	17.48
Hexachlorobenzene	31.31	128.6	25.61	310.7	-18.20
Phenanthrene	22.60	76.53	27.73	238.6	22.70
Fluoranthene	22.36	71.56	25.74	220.0	15.12

* 15°C nitrogen, 86.5 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	71.05	73.17	16.08	2.98	-77.37
Chlorobenzene	64.37	72.30	14.18	12.32	-77.97
Ethylbenzene	60.56	69.92	15.03	15.45	-75.19
Tetrachloroethane	51.72	48.13	10.31	-6.94	-80.07
1,3-Dichlorobenzene	69.69	66.67	12.53	-4.33	-82.02
1,2-Dichlorobenzene	66.51	66.01	12.47	-0.75	-81.25
Nitrobenzene	14.52	30.52	9.21	110.2	-36.57
Napthalene	66.16	51.42	12.17	-22.27	-81.61
1-Chloronapthalene	63.67	47.24	10.65	-25.80	-83.27
2,6-Dinitrotoluene	10.27	37.66	8.97	266.7	-12.66
Fluorene	29.60	53.70	11.26	81.41	-61.96
2,4-Dinitrotoluene	7.46	37.88	9.03	407.8	21.05
Hexachlorobenzene	12.82	52.74	8.73	311.4	-31.90
Phenanthrene	8.64	35.85	9.21	314.9	6.60
Fluoranthene	9.85	33.60	8.52	241.1	-13.50

* 15°C nitrogen, 86.7 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55°C WATER, 15 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	45.44	44.51	10.66	-2.05	-76.54
Chlorobenzene	38.20	44.04	10.29	15.29	-73.06
Ethylbenzene	38.47	39.44	10.90	2.52	-71.67
Tetrachloroethane	36.81	31.30	13.09	-14.97	-64.43
1,3-Dichlorobenzene	42.09	40.83	9.09	-3.00	-78.40
1,2-Dichlorobenzene	40.90	40.31	9.05	-1.88	-77.87
Nitrobenzene	7.23	20.83	6.68	28.16	-7.61
Napthalene	39.80	32.56	8.83	-18.91	-77.81
1-Chloronapthalene	37.07	30.14	7.72	-18.69	-79.17
2,6-Dinitrotoluene	6.61	25.13	6.50	280.2	-1.66
Fluorene	19.47	33.65	8.17	73.80	-58.04
2,4-Dinitrotoluene	5.54	25.25	6.55	355.9	18.23
Hexachlorobenzene	8.74	32.73	6.33	274.5	-27.57
Phenanthrene	7.37	23.00	6.68	212.1	-9.36
Fluoranthene	7.01	21.55	6.18	207.4	-11.84

* 15 °C nitrogen, 92.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	158.3	-	-	-
Chlorobenzene	156.5	155.8	26.36	-0.45	-83.16
Ethylbenzene	143.4	151.5	27.89	5.64	-80.55
Tetrachloroethane	164.8	96.69	19.47	-41.32	-88.19
1,3-Dichlorobenzene	150.1	142.7	23.30	-4.93	-84.47
1,2-Dichlorobenzene	150.3	140.8	23.22	-6.32	-84.55
Nitrobenzene	31.28	53.74	17.64	71.80	-43.61
Napthalene	176.4	101.7	22.86	-42.35	-87.04
1-Chloronapthalene	204.4	92.97	20.04	-54.55	-90.25
2,6-Dinitrotoluene	32.43	68.94	16.86	112.6	-48.01
Fluorene	74.52	109.60	21.02	47.07	-71.79
2,4-Dinitrotoluene	15.78	69.42	17.03	339.9	7.92
Hexachlorobenzene	26.54	109.2	16.29	311.4	-38.62
Phenanthrene	18.40	68.82	17.65	274.0	-4.76
Fluoranthene	26.12	64.42	16.38	146.6	-37.29

* 15 °C nitrogen, 85.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	69.67	-	-	-
Chlorobenzene	61.30	68.84	12.65	12.30	-79.36
Ethylbenzene	63.80	66.49	13.40	4.21	-79.00
Tetrachloroethane	55.37	42.65	9.19	-22.97	-83.40
1,3-Dichlorobenzene	66.12	61.41	11.17	-7.12	-83.11
1,2-Dichlorobenzene	64.40	63.01	11.12	-2.16	-82.73
Nitrobenzene	15.70	29.90	8.12	90.44	-48.28
Napthalene	54.47	49.35	10.85	-9.04	-80.08
1-Chloronapthalene	60.97	45.59	9.49	-25.22	-84.43
2,6-Dinitrotoluene	7.25	36.63	8.00	405.2	10.34
Fluorene	20.18	51.52	10.04	155.3	-50.24
2,4-Dinitrotoluene	6.68	36.83	8.05	451.8	20.51
Hexachlorobenzene	10.70	50.53	7.78	372.2	-27.29
Phenanthrene	8.00	34.85	8.22	332.2	2.75
Fluoranthene	8.62	32.70	7.60	279.4	-11.83

* 15 °C nitrogen, 93.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	47.63	-	-	-
Chlorobenzene	36.25	46.96	7.73	29.54	-78.67
Ethylbenzene	36.45	45.18	8.20	24.08	-77.50
Tetrachloroethane	30.78	34.22	5.62	11.18	-81.74
1,3-Dichlorobenzene	39.48	43.63	6.83	10.51	-82.70
1,2-Dichlorobenzene	42.40	43.30	6.80	2.12	-83.96
Nitrobenzene	9.70	22.89	5.02	135.9	-48.25
Napthalene	29.07	35.25	6.64	21.25	-77.16
1-Chloronapthalene	32.19	32.74	5.81	1.71	-81.95
2,6-Dinitrotoluene	4.02	27.18	4.89	576.1	21.64
Fluorene	13.06	36.10	6.14	176.4	-52.99
2,4-Dinitrotoluene	4.27	27.30	4.92	539.3	15.22
Hexachlorobenzene	6.66	35.09	4.76	426.9	-28.52
Phenanthrene	4.59	25.78	5.02	461.7	9.37
Fluoranthene	4.77	24.30	4.64	409.4	-2.73

* 15°C nitrogen, 94.2 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 30 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	158.3	-	-	-
Chlorobenzene	117.5	155.8	19.12	32.60	-83.73
Ethylbenzene	131.0	151.5	20.27	15.64	-84.53
Tetrachloroethane	167.6	96.69	13.90	-42.31	-91.71
1,3-Dichlorobenzene	154.5	142.7	16.89	-7.64	-89.07
1,2-Dichlorobenzene	132.2	140.8	16.82	6.50	-87.28
Nitrobenzene	31.22	53.74	12.42	71.27	-60.22
Napthalene	335.8	101.7	16.41	-69.71	-95.11
1-Chloronapthalene	297.6	92.97	14.35	-68.76	-95.18
2,6-Dinitrotoluene	32.57	68.94	12.09	111.2	-62.88
Fluorene	33.00	109.6	15.19	232.1	-53.97
2,4-Dinitrotoluene	12.50	69.42	12.18	455.4	-2.56
Hexachlorobenzene	25.40	109.2	11.76	329.9	-53.70
Phenanthrene	38.48	68.82	12.43	78.84	-67.70
Fluoranthene	57.77	64.42	11.48	11.51	-80.13

* 15°C nitrogen, 84.4% oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55°C WATER, 15 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	69.67	-	-	-
Chlorobenzene	48.47	68.84	7.70	42.02	-84.11
Ethylbenzene	43.87	66.49	8.16	51.56	-81.40
Tetrachloroethane	38.53	42.65	5.59	-10.69	-85.49
1,3-Dichlorobenzene	38.60	61.41	6.80	59.09	-82.38
1,2-Dichlorobenzene	41.53	63.01	6.77	51.72	-83.70
Nitrobenzene	16.57	29.90	5.00	80.44	-69.82
Napthalene	49.94	49.35	6.61	-1.18	-86.76
1-Chloronapthalene	51.43	45.59	5.78	-11.36	-88.75
2,6-Dinitrotoluene	5.64	36.63	4.87	549.4	-13.65
Fluorene	23.89	51.52	6.11	115.7	-74.42
2,4-Dinitrotoluene	5.71	36.83	4.90	545.0	-14.19
Hexachlorobenzene	8.27	50.53	4.73	511.0	-42.81
Phenanthrene	6.58	34.85	5.00	425.5	-24.01
Fluoranthene	8.23	32.70	4.62	297.3	-43.86

* 15 °C nitrogen, 88.8 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 15 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	49.38	-	-	-
Chlorobenzene	29.60	48.78	4.68	64.80	-84.19
Ethylbenzene	23.02	47.16	4.99	104.86	-78.28
Tetrachloroethane	27.85	33.88	3.42	21.65	-87.72
1,3-Dichlorobenzene	29.48	45.81	4.16	55.39	-85.89
1,2-Dichlorobenzene	27.22	44.49	4.14	63.44	-84.79
Nitrobenzene	9.81	22.00	3.06	124.3	-68.81
Napthalene	27.29	35.40	4.04	29.72	-85.20
1-Chloronapthalene	25.87	32.70	3.51	26.40	-86.40
2,6-Dinitrotoluene	3.11	26.90	2.98	765.0	-4.18
Fluorene	10.95	36.88	3.74	236.8	-65.84
2,4-Dinitrotoluene	3.30	27.04	2.99	719.4	-9.39
Hexachlorobenzene	6.96	35.94	2.89	416.4	-58.45
Phenanthrene	3.43	24.66	3.06	619.0	-10.79
Fluoranthene	4.41	23.01	2.83	421.7	-35.83

* 15 °C nitrogen, 90.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55°C WATER, 25 °C AIR, 30 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	194.0	-	-	-
Chlorobenzene	170.6	191.4	41.07	12.19	-75.93
Ethylbenzene	152.9	185.8	43.41	21.52	-71.61
Tetrachloroethane	202.6	117.4	30.76	-42.05	-84.82
1,3-Dichlorobenzene	201.3	174.3	36.36	-13.41	-81.94
1,2-Dichlorobenzene	170.2	171.7	36.24	0.88	-78.71
Nitrobenzene	52.82	63.03	28.25	19.32	-46.52
Napthalene	243.6	122.8	35.95	-49.58	-85.24
1-Chloronapthalene	195.2	112.4	31.57	-42.42	-83.83
2,6-Dinitrotoluene	57.53	78.75	26.65	-36.88	-53.68
Fluorene	119.1	132.7	32.99	11.42	-72.61
2,4-Dinitrotoluene	35.02	81.41	26.89	132.5	-23.21
Hexachlorobenzene	35.54	133.5	25.49	275.6	-28.28
Phenanthrene	51.79	84.40	28.20	62.97	-45.55
Fluoranthene	31.38	79.60	26.26	153.7	-16.32

* 25 °C nitrogen, 86.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 90 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	74.03	-	-	-
Chlorobenzene	68.40	74.25	16.06	8.55	-76.52
Ethylbenzene	65.89	70.75	17.00	7.38	-74.20
Tetrachloroethane	66.31	51.95	11.87	-21.66	-82.10
1,3-Dichlorobenzene	76.97	68.02	14.21	-11.63	-81.54
1,2-Dichlorobenzene	69.98	67.55	14.15	-3.47	-79.78
Nitrobenzene	13.11	32.88	10.75	150.8	-18.00
Napthalene	65.88	53.54	13.93	-18.73	-78.86
1-Chloronapthalene	62.40	49.61	12.21	-20.50	-80.43
2,6-Dinitrotoluene	13.77	39.65	10.28	187.9	-25.34
Fluorene	24.27	55.32	12.81	127.9	-47.22
2,4-Dinitrotoluene	12.28	39.87	10.38	224.7	-15.47
Hexachlorobenzene	16.27	54.41	9.93	234.4	-38.97
Phenanthrene	15.24	39.00	10.75	155.9	-29.46
Fluoranthene	10.36	36.82	9.98	255.4	-3.67

* 25 °C nitrogen, 88.7 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 150 G/L AND 0.6 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	45.11	-		
Chlorobenzene	38.49	44.86	9.46	16.55	-75.42
Ethylbenzene	39.55	39.88	10.52	0.83	-73.40
Tetrachloroethane	38.17	33.99	7.35	-10.95	-80.74
1,3-Dichlorobenzene	51.91	41.83	8.80	-19.42	-83.05
1,2-Dichlorobenzene	40.70	41.62	8.76	2.26	-78.47
Nitrobenzene	7.91	23.39	6.66	195.7	-15.80
Napthalene	40.32	34.63	8.62	-14.11	-78.62
1-Chloronapthalene	36.58	32.34	7.56	-11.34	-79.33
2,6-Dinitrotoluene	7.34	27.05	6.36	268.5	-13.35
Fluorene	17.35	34.95	7.93	101.4	-54.29
2,4-Dinitrotoluene	6.97	27.17	6.43	289.8	-7.75
Hexachlorobenzene	9.59	34.16	6.15	256.2	-35.87
Phenanthrene	7.69	26.35	6.66	242.7	-13.39
Fluoranthene	6.98	25.01	6.18	258.3	-11.46

* 25°C nitrogen, 91.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 30 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	160.0	-	-	-
Chlorobenzene	150.5	158.2	26.21	5.12	-82.58
Ethylbenzene	141.4	153.0	27.70	8.20	-80.41
Tetrachloroethane	234.9	102.7	19.64	-56.28	-91.64
1,3-Dichlorobenzene	155.0	145.1	23.12	-6.39	-85.08
1,2-Dichlorobenzene	158.8	143.2	23.13	-9.82	-85.43
Nitrobenzene	45.30	58.04	18.03	28.12	-60.20
Napthalene	206.6	106.6	22.95	-48.40	-88.89
1-Chloronapthalene	183.1	98.02	20.15	-46.46	-89.00
2,6-Dinitrotoluene	39.64	71.05	16.95	79.24	-57.24
Fluorene	80.76	113.1	21.00	40.04	-74.00
2,4-Dinitrotoluene	24.54	73.26	17.16	198.5	-30.07
Hexachlorobenzene	30.01	113.0	16.27	276.7	-47.78
Phenanthrene	35.81	75.29	18.01	110.3	-49.73
Fluoranthene	35.88	71.21	16.77	98.46	-53.26

* 25°C nitrogen, 84.9 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 90 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	70.17	-	-	-
Chlorobenzene	68.03	69.58	10.10	2.28	-85.15
Ethylbenzene	59.80	66.96	10.69	11.97	-82.12
Tetrachloroethane	67.28	49.72	7.46	-26.10	-88.91
1,3-Dichlorobenzene	61.22	64.51	8.93	5.37	-85.41
1,2-Dichlorobenzene	59.38	64.08	8.90	7.91	-85.01
Nitrobenzene	11.47	31.83	6.76	177.5	-41.06
Napthalene	52.78	51.15	8.76	-3.09	-83.40
1-Chloronapthalene	53.18	49.05	7.68	-7.77	-85.58
2,6-Dinitrotoluene	9.28	38.17	6.46	311.3	-30.38
Fluorene	17.77	52.68	8.06	196.4	-54.64
2,4-Dinitrotoluene	7.87	38.37	6.53	387.5	-17.03
Hexachlorobenzene	9.98	51.69	6.24	417.9	-37.47
Phenanthrene	9.95	37.49	6.76	276.8	-32.06
Fluoranthene	7.96	35.54	6.28	346.5	-21.10

* 25 °C nitrogen, 88.3 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 150 G/L AND 0.9 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	47.66	-	-	-
Chlorobenzene	41.32	47.37	6.27	14.64	-84.82
Ethylbenzene	26.45	45.44	6.64	71.79	-74.90
Tetrachloroethane	39.11	35.62	4.63	-8.92	-88.16
1,3-Dichlorobenzene	37.52	44.14	5.55	17.64	-85.21
1,2-Dichlorobenzene	35.44	43.90	5.53	23.87	-84.40
Nitrobenzene	8.33	24.25	4.20	191.2	-49.58
Napthalene	30.94	36.33	5.44	17.42	-82.42
1-Chloronapthalene	30.40	33.89	4.77	11.48	-84.31
2,6-Dinitrotoluene	5.23	28.19	4.01	439.0	-23.33
Fluorene	13.10	36.78	5.00	180.8	-61.83
2,4-Dinitrotoluene	4.64	28.32	4.05	510.3	-12.72
Hexachlorobenzene	6.88	35.90	3.88	421.8	-43.60
Phenanthrene	5.73	27.51	4.20	380.1	-26.70
Fluoranthene	5.01	26.09	3.90	421.8	-22.16

* 25 °C nitrogen, 90.1 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 30 G/L AND 1.2M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	160.03	-	-	-
Chlorobenzene	152.3	158.20	17.94	3.83	-88.22
Ethylbenzene	129.5	153.00	18.98	18.14	-85.34
Tetrachloroethane	248.8	102.70	13.25	-58.72	-94.67
1,3-Dichlorobenzene	166.7	145.10	15.86	-12.78	-90.49
1,2-Dichlorobenzene	148.5	143.20	15.81	-3.69	-89.35
Nitrobenzene	35.54	58.00	12.00	63.30	-66.23
Napthalene	259.2	106.60	15.56	58.87	-94.00
1-Chloronapthalene	229.5	98.02	13.64	-57.29	-94.07
2,6-Dinitrotoluene	26.76	71.15	11.48	165.50	-57.10
Fluorene	93.51	113.10	14.31	20.95	-84.07
2,4-Dinitrotoluene	20.32	73.16	11.59	260.50	-42.96
Hexachlorobenzene	27.99	113.50	11.09	303.60	-60.38
Phenanthrene	55.14	75.09	12.01	36.54	-78.22
Fluoranthene	101.1	71.11	11.15	-88.97	-88.97

* 25 °C nitrogen, 82.4 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 90 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	70.17	-	-	-
Chlorobenzene	46.80	69.58	6.12	46.67	-86.92
Ethylbenzene	42.28	66.96	6.48	58.37	-84.67
Tetrachloroethane	43.09	49.72	4.52	15.34	-89.51
1,3-Dichlorobenzene	47.25	64.54	5.41	36.53	-88.55
1,2-Dichlorobenzene	44.57	64.06	5.39	-7.18	-87.91
Nitrobenzene	15.52	31.43	4.10	105.9	-73.57
Napthalene	50.16	51.15	5.31	1.97	-89.41
1-Chloronapthalene	49.59	49.05	4.65	-1.09	-90.62
2,6-Dinitrotoluene	5.58	38.17	3.92	584.0	-29.75
Fluorene	23.92	52.68	4.88	120.2	-79.60
2,4-Dinitrotoluene	6.41	38.37	3.96	498.6	-38.22
Hexachlorobenzene	9.05	51.69	3.78	458.5	-58.23
Phenanthrene	6.73	37.49	4.10	457.1	-39.08
Fluoranthene	8.87	35.54	3.80	106.7	-57.16

* 25°C nitrogen, 82.4 % oxygen removal.

COMPARISON OF OVERALL MASS TRANSFER COEFFICIENT (K_1a) FOR 55 °C WATER, 25 °C AIR, 150 G/L AND 1.2 M BED DEPTH

Compound	Experimental K_1a (1/hr)	Onda K_1a (1/hr)	Reference* K_1a (1/hr)	% Difference Experimental and Onda	% Difference Experimental and Reference
Toluene	-	47.06	-	-	-
Chlorobenzene	27.84	47.30	4.91	70.15	-82.36
Ethylbenzene	25.14	45.40	5.21	80.74	-79.28
Tetrachloroethane	21.73	35.62	3.57	63.92	-83.57
1,3-Dichlorobenzene	25.55	44.14	4.34	72.76	-83.01
1,2-Dichlorobenzene	25.40	43.90	4.32	72.83	-82.99
Nitrobenzene	11.25	24.25	3.19	95.96	-71.64
Napthalene	30.39	36.37	4.22	16.48	-86.11
1-Chloronapthalene	25.56	33.39	3.69	8.80	-85.56
2,6-Dinitrotoluene	3.01	28.19	3.11	836.5	3.32
Fluorene	11.00	36.78	3.90	234.4	-64.54
2,4-Dinitrotoluene	3.54	38.32	3.13	982.5	-11.58
Hexachlorobenzene	7.47	36.90	3.02	380.6	-59.57
Phenanthrene	3.71	27.51	3.19	641.5	-14.02
Fluoranthene	4.68	26.09	2.95	475.5	-36.96

* 25°C nitrogen, 91.1 % oxygen removal.

VITA

Payoungsak Kittikul

Candidate for the Degree of

Doctor of Philosophy

Thesis: STUDY OF HIGH WATER TEMPERATURE EFFECTS ON AIR STRIPPING OF VOLATILE AND SLIGHTLY-VOLATILE ORGANICS FROM WATER

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Chachoensao, Thailand, September 21, 1952, the son of Thomya and Sudjai. Married to Varaporn Kirdsiri on April 14, 1978.

Education: Graduated from Srivikorn High School, Bangkok, Thailand, in May 1969; received Bachelor of Science Degree from Kasetsart University, Bangkok, Thailand, in April 1975; received Bachelor of Science Degree in Engineering Technology from Oklahoma State University in December 1979; received Master of Science Degree from Oklahoma State University in December 1981; completed requirements for the Doctor of Philosophy Degree at Oklahoma State University in July 1987.

Professional Experience: Graduate Research Assistant, Engineering Department, Oklahoma State University, January 1980 - October 1987.