PREDICTING BIOLOGICAL TREATABILITY OF A MULTICOMPONENT WASTEWATER BASED UPON TREATABILITY OF THE INDIVIDUAL COMPONENTS

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Submitted to the Faculty of the Graduate College
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in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1983

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Title of Study: PREDICTING BIOLOGICAL TREATABILITY OF A MULTICOMPONENT WASTEWATER BASED UPON TREATABILITY OF THE INDIVIDUAL COMPONENTS

Pages in Study: 234 Candidate for Degree of Doctor of Philosophy

Major Field: Civil Engineering

Scope and Method of Study: This research was conducted in the hope of finding some predictive technique which could enable the design engineer to determine the activated sludge treatability parameters of a multicomponent waste based upon knowledge of each of the influent constituents. Treatability studies were conducted upon eight individual organic substrates. The results of the individual compound treatability studies were utilized to formulate predictive models. These predictive models were tested upon treatability data collected from multicomponent wastewaters which were composed of mixtures of the same eight organic constituents.

Findings and Conclusions: After screening ten predictive techniques, several showed a certain degree of success in predicting mixed liquor volatile suspended solids and effluent TOC concentrations. Several acceptable methods for predicting specific compound concentrations in treated effluents of test units administered a multisubstrate influent were also found. Settleability, as measured by the sludge volume index test, could not be reliably predicted but dewatering was demonstrated to be predicted reasonably well by a simplistic technique.

ADVISER'S APPROVAL Enos L. Stover

ACKNOWLEDGMENTS

I wish to thank my major advisor, Dr. Enos L. Stover, and my faculty committee members, Dr. Marcia Bates, Dr. Don Kincannon, Dr. George Odell, and Dr. John Veenstra for their advice and assistance. The OSU Department of Biochemistry was most cooperative in facilitating my research and has my deep appreciation.

I would also like to thank my fellow students for their friendship and assistance. A special thanks should be extended to fellow students Ali Fazel, Faramarz Dehkordi, Gomathinayagam Ganapathi, and Mohammed Abdul Hafid who had the often difficult task of working closely with me during our stay at OSU.

Joan Reid and Kim Coleman should be commended for their skillful, accurate and efficient word processing. Had it not been for their diligence, I never could have completed this manuscript in a timely manner.

I should also like to thank my parents, Clarence E. and Dorothy R. McCartney, brothers Mark, Paul, Bob and Ken, as well as my aunt and uncle, Daisy R. and Thomas B. Robinson for their encouragement and support.

The person who deserves most of the credit for the completion of this work, however, would have to be my wife, Shung Ming. Not only did she offer her love and support but she directed the gas chromatography analyses, performed the bulk of the computer analyses, helped with the

plotting and data summary, and did all of the drafting work. This dissertation, surely, is as much hers as mine. I do not think that I could ever thank her enough for her help.

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LIST OF SYMBOLS

BOD_5	Biochemical oxygen demand.
CHO	Carbohydrate (in this case, starch, sucrose).
COD	Chemical oxygen demand.
CST	Capillary suction time.
F	Flow rate.
F/M	Food to microorganism ratio $\frac{FSi}{XV}$.
Fw	Waste sludge flow rate.
K	Lawrence and McCarty maximum substrate utilization rate.
K_B	Kincannon and Stover saturation constant.
Kd	Maintenance energy or decay coefficient.
Ke'	Eckenfelder's second order substrate removal rate constant.
KS_1	Lawrence and McCarty's saturation constant.
KS_2	Modification of Lawrence and McCarty's saturation constant.
km	McKinney's substrate removal rate.
ki	Weston inhibition constant.
MLSS	Mixed liquor suspended solids.
MLVSS	Mixed liquor volatile suspended solids.
N	Sample population used for statistical analyses.
oleic H^+	Oleic acid.
PRO	Protein (in this case, egg albumen).
prop	Propanol.

R_S	Weston substrate removal rate.
S.D.	Standard Deviation.
S_e	Effluent substrate concentration.
S_i	Influent substrate concentration.
SRT	Sludge retention time, Oc.
SVI	Sludge volume index.
t	Hydraulic detention time.
TOC	Total organic carbon.
TSS	Total suspended solids.
U	$\frac{(S_i - S_e)}{Xt}$, specific substrate utilization rate.
U_{max}	Maximum substrate utilization rate.
V	Reactor volume.
VSS	Volatile suspended solids.
X	Biological solids.
X_e	Effluent suspended solids.
X_R	Underflow solids concentration.
Yt	True cell yield.
α	Recycle flow ratio.
Oc	SRT.
μn	Observed growth rate.
μ_{max}	Maximum growth rate.

CHAPTER I

INTRODUCTION

Very rarely, in the field of water pollution control, are wastewaters encountered which are composed of only one organic compound. Rather, most treatment facilities receive wastewaters composed of complex, multicomponent organic constituents. Current methodology for predicting biological treatment feasibility, operating conditions and effluent quality involves costly and time consuming pilot studies. Most often, the primary objective of these studies is to determine the operating conditions necessary to achieve a desired level of effluent biochemical oxygen demand (BOD). Since it has become common to characterize waste streams in terms of their BOD load, problems (as noncompliance with regulatory agency standards) have arisen in the past when wastewaters with equivalent BOD loads were assumed to have similar treatment requirements.

Although effluent BOD discharge limitations have been the cornerstone of government water pollution control policy, it has been realized for quite some time that there are major shortcomings with the BOD test both with the analytical procedure (37) (38) and with the concept of BOD itself (12). A move towards characterizing waste streams in terms of their chemical oxygen demand (COD) and/or organic carbon content (TOC) has done much to eliminate analytical variability but has introduced other problems. One such problem is that neither COD nor TOC distinguishes between biodegradable and nonbiodegradable organic material.

With the issuance of the EPA Consent Decree and the subsequent development of the priority pollutant list, the impetus for characterization of wastewaters with regard to the presence of specific organic compounds has been provided. The work of Banks et al. (1) has indicated that the composition of the influent wastewater will have more influence upon the predominating bacterial populations at a treatment works than will plant operational strategy or design. It is conceivable that if waste streams are characterized in terms of their specific organic constituents rather than for non-specific indicators of pollutant concentration (such as BOD), then similar wastewaters may, indeed, require similar treatment strategies. In light of this, a method for predicting biological treatment parameters (biokinetic constants, settleability, and dewaterability) based upon knowledge of the specific influent organic substrates present would be extremely useful.

For this research, bench scale, external recycle, activated sludge units were operated and received a multicomponent waste composed of sucrose, soluble starch, oleic acid, 2-propanol, egg albumen, 2-nitrophenol, 4-chloro-3-methyl phenol, and Cheer laundry detergent. Various combinations of these substrates were utilized with several solids retention times (SRT) employed for each combination. For the eight individual substrates, separate treatability studies were conducted using internal recycle activated sludge treatment units to determine the biokinetic constants, settleability and dewaterability. The treatability data gathered from the pilot units receiving each of these separate substrates were compared with the performance data collected from the units receiving the combined waste to determine if any predictable trends existed.

CHAPTER II

LITERATURE REVIEW

Terminology used in the field of bioenvironmental engineering oftentimes fails to conform to any generally accepted convention. Therefore a complete list of all symbols discussed in this text as well as their definitions can be found on page xiii.

The recommended method for designing full scale activated sludge biological treatment facilities to treat complex wastewaters is to perform pilot tests upon the wastewater of concern. The data compiled from these pilot tests are generally incorporated into one of several existing models where biokinetic constants are determined. These constants aid the design engineer in sizing of the various unit operations employed. Earlier design techniques employed batch feed pilot studies while later work was concerned more with continuous flow studies. Some of the batch techniques were later modified to continuous flow (43). For nearly all of the design models, several biological units must be operated at several conditions of solids retention time or F/M ratios. However, it has been noted that biological constants developed in batch studies do not always correspond to the constants developed in continuous flow chemostats subjected to the same wastewater (2) (5). It would therefore, seem more prudent to engage in the continuous flow studies since this operational mode more nearly simulates full scale operation.

Some of the more notable activated sludge design models that have been developed are the models of Eckenfelder, McKinney, Weston, Lawrence and McCarty, and Gaudy (18) (39) (40) (48). The biokinetic constants which must be determined are biomass yield (Y_t), biomass decay or maintenance rate (k_d) and an expression to describe the rate of substate removal.

Most of the models employ the same means for determining Y_t and k_d which is to plot the compiled pilot data in terms of the reciprocal of solids retention time (u_n) versus the specific substrate utilization rate $(\frac{Si - Se}{Xt})$. Here, the slope represents the yield while changing the sign of the intercept allows one to obtain the decay coefficient (k_d).

There appears to be more disagreement concerning the application of an expression to describe soluble substrate removal in the activated sludge process. Table I excerpted from Stover and Gomathinayagam (41) shows the substrate removal rate expressions utilized by the previously mentioned researchers. Certain similarities may be observed when comparing these expressions. For example, it has been observed that McKinney's k_m is a function of mixed liquor suspended solids concentration. Plotting k_m as a function of X results in another constant which is very similar to Eckenfelder's k_e (first order model). Thus, McKinney's k_m can be expressed as the product of mixed liquor suspended solids concentration and some constant. The resultant expression for McKinney's substrate removal rate then becomes identical to Eckenfelder's first order expression. Another similarity between models is seen in that Gaudy as well as Lawrence and McCarty both employ a Monod type expression for substrate removal rate. Gaudy actually works in terms of microbial growth rate which can be converted to substrate

TABLE I

KINETIC EXPRESSIONS FOR SUBSTRATE REMOVAL DUE TO GROWTH EMPLOYED FOR VARIOUS MODELS

Eckenfelder	First Order	$(dS/dt)_g = k_e XS_e$
McKinney		$(dS/dt)_g = k_m S_e$
Eckenfelder	Second Order	$(dS/dt)_g = (k'_e S_e X)/Si$
Weston		$(dS/dt)_g = R_S S_e \ (X/Si)^{ki}$
Lawrence and McCarty		$(dS/dt)_g = (kXS_e)/(K_s+S_e)$
Gaudy		$(dS/dt)_g = (\mu_{max} XS_e)/(Y_t(K_s+S_e))$

removal rate by dividing through by Y_t. Eckenfelder's second order equation representing the substrate removal rate is similar to Weston's expression if the Weston inhibition constant, k_i, is equivalent to one (no inhibition). Basically, then, these six substrate removal rate expressions can be divided into three groups: 1) First order (Eckenfelder's first order expression and McKinney; 2) Second order (Eckenfelder's second order and Weston; and 3) Monod type (Lawrence/McCarty and Gaudy).

Once these researchers have chosen their substrate removal rate expressions, they proceeded to write mass balances for biomass and substrate. These balances are presented in Tables II and III which have been excerpted from Kincannon and Gaudy (20) and Stover and Gomathinayagam (40). It can be seen that the Gaudy and Weston mass balances are drawn only around the aeration basin while the others draw their mass balances around both the aeration basin and the clarifier. It is contended that including the additional parameters of recycle solids concentration and rate by drawing the mass balances only around the aeration basin enables the engineer to gauge the effect of these two controllable parameters on the performance of the proposed design (18). Assuming steady state operation, the mass balances can be algebraically manipulated so that the design engineer can solve for effluent substrate concentration, mixed liquor suspended solids, aeration basin volume and excess sludge production. These expressions are presented in Table IV. It is interesting to note that influent substrate concentration has no effect upon the prediction of effluent substrate concentration in both the Gaudy and Lawrence/McCarty models. Yet, several researchers (3) (28) have indicated that influent substrate concentration may impact effluent substrate concentrations.

TABLE II

MATERIALS BALANCE FOR BIOMASS (X) DEVELOPED FOR THE VARIOUS MODELS

Balance Model	Mass Rate of Change		Mass Rate due to Inflow		Mass Rate due to Growth		Mass Rate due to Autodigestion		Mass Rate due to Outflow (Overflow & Underflow)
Eckenfelder	$\frac{dX}{dt}.V$	=	FX_o	+	$Y_t k_e S_e XV$	-	$k_d XV$	-	$(F-F_W)X_e - F_W X_R$
McKinney	$\frac{dX}{dt}.V$	=	FX_o	+	$Y_t k_m S_e V$	-	$k_d XV$	-	$(F-F_W)X_e - F_W X_R$
Eckenfelder (2nd Order)	$\frac{dX}{dt}.V$	=	FX_o	+	$Y_t k_e' S_e XV/S_i$	-	$k_d XV$	-	$(F-F_W)X_e - F_W X_R$
Weston	$\frac{dX}{dt}.V$	=	$FX_o+\alpha FX_R$	+	$Y_t R_S S_e (X/S_i)^{ki} V$	-	$k_d XV$	-	$F(1+\alpha)X$
Lawrence-McCarty	$\frac{dX}{dt}.V$	=	FX_o	+	$VY_t KS_e X/(K_s+S_e)$	-	$k_d XV$	-	$(F-F_W)X_e - F_W X_R$
Gaudy	$\frac{dX}{dt}.V$	=	$FX_o+\alpha FX_R$	+	$V\mu_{max} XS_e/(K_s+S_e)$	-	$k_d XV$	-	$F(1+\alpha)X$

TABLE III

MATERIALS BALANCE FOR SUBSTRATES DEVELOPED FOR THE VARIOUS MODELS

Model	Mass Rate of Change		Mass Rate due to Inflow		Mass Rate due to Outflow		Mass Rate due to Metabolism
Eckenfelder (First Order)	$\frac{dS}{dt}.V$	=	FS_i	-	FS_e	-	k_eXS_eV
McKinney	$\frac{dS}{dt}.V$	=	FS_i	-	FS_e	-	k_mS_eV
Eckenfelder (Second Order)	$\frac{dS}{dt}.V$	=	FS_i	-	FS_e	-	$\frac{k'_eS_eXV}{S_i}$
Weston	$\frac{dS}{dt}.V$	=	$FS_i+\alpha FS_e$	-	$F(1+\alpha)S_e$	-	$VR_sS_e\left(\frac{X}{(S_i)}\right)^{k_i}$
Lawrence-McCarty	$\frac{dS}{dt}.V$	=	FS_i	-	FS_e	-	$kX\frac{S_e}{K_s+S_e}V$
Gaudy	$\frac{dS}{dt}.V$	=	$FS_i+\alpha FS_e$	-	$F(1+\alpha)S_e$	-	$\alpha_{max}\frac{X}{Y_t}\frac{S_e}{(K_s+S_e)}V$

TABLE IV

DESIGN FORMULAS FOR STEADY STATE IN S_e AND X

Design Approach	Effluent S_e	Biomass X
Eckenfelder 1st Order	$S_e = \frac{S_i - S_e}{k_e X t} = \frac{S_i}{k_e X t + 1}$	$X = \frac{Y_t (S_i - S_e)}{\left[\frac{1}{SRT} + k_d\right] t}$
McKinney	$S_e = \frac{S_i}{k_m t + 1} = \frac{S_i - S_e}{k_m t}$	$X = \frac{Y_t (S_i - S_e)}{\left[\frac{1}{SRT} + k_d\right] t}$
Eckenfelder 2nd Order	$S_e = \frac{S_i}{\frac{k_e' X V}{S_i F} + 1}$	$X = \frac{Y_t (S_i - S_e)}{\left[\frac{1}{SRT} + k_d\right] t}$
Weston	$S_e = \frac{F S_i}{F + R_S \left[\frac{X}{S_i}\right] k_i V}$	$X = \frac{Y_t [S_i - (1 + \alpha) S_e]}{(\mu_n + k_d) t}$
Lawrence and McCarty	$S_e = \frac{K_S \left[\frac{1}{SRT} + k_d\right]}{Y_t k - \left[\frac{1}{SRT} + k_d\right]}$	$X = \frac{Y_t (S_i - S_e)}{\left[\frac{1}{SRT} + k_d\right] t}$
Gaudy	$S_e = \frac{K_s (\mu_n + k_d)}{\mu_{max} - (\mu_n + k_d)}$	$X = \frac{Y_t [S_i - (1 + \alpha) S_e]}{(\mu_n + k_d) t}$

Over the years since the development of these activated sludge models, many researchers have made modifications, noted inadequacies or introduced their own theories. For instance, Grady and Roper (14) suggested the addition of a term to account for cell viability. Kargi and Shuler (17) reviewed several expressions for predicting specific growth rate; among them, the Monod, Teisser, Contois and Moser equations. It was found that all of these equations had a common general differentiated form. A screening technique was presented to determine which expression applied for any given situation. Sykes (47) points out shortcomings in the limiting nutrient concept models previously described. For those systems where the components found in the treated effluent are metabolites of the biota rather than constituents of the influent, he states that the limiting nutrient concept is inappropriate. An alternative theory based upon biomass maintenance energy demand is presented. Mikesell (29) presents a mathematical model which accounts for ammonia and dissolved oxygen deficiencies and consists of rate equations for both viable and nonviable cells. These rate equations take the form of differential mass and energy balances for exogeneous soluble substrate, microbial protoplasm, endogeneous glycogen, and endogeneous glucose. To operate at a constant specific growth rate as defined by this model, mixed liquor and underflow respiration rates as well as sludge viability should be closely monitored. Other researchers have treated wastes that were partially strippable, as well as biodegradeable (20) (42). When mass balances were made for substrate, a term for air stripping was incorporated. Various types of inhibition of substrate removal that may occur in the bacterial population comprising the activated sludge system are discussed by Orhon and Tunay (30).

Incorporation of inhibition terms into Monod expressions for μ is shown. Gaudy and Gaudy (13) also present a discussion of inhibition expressions available for use in the kinetic models used to describe the activated sludge process.

Probably the singlemost cited deficiency of the steady-state models most commonly used in the wastewater engineering field is their inability to predict system behavior during transient shock loads. Selna and Schroeder (32) applied Monod kinetics with a correction added to account for "basal" COD concentration to predict system performance during organic transients. Their model was not applicable during "step down" from the shock condition. Daigger and Grady (7) reviewed the literature concerning the dynamics of microbial growth on soluble substrates. They pointed out that researchers have become polarized in that some feel that the microbial response to organic transients is one of storage while others feel that the response is one of growth. An attempt was made to show that either response could occur and that, based upon certain preconditions, the probability of one of these mechanisms being incorporated was greater than that of the other. In an effort to clarify the role of physiological adaptation in determining the transient response, cellular RNA levels were monitored (8). Although cellular RNA concentration did play a role in determining the nature of the response, other unidentified factors were also important. Ekama and Morais (11) presented a comprehensive model considered by them to be an extension of the Lawrence and McCarty model which incorporated terms for carbonaceous substrate removal and nitrification as well as for active, endogeneous and inert biomass fractions. A rational link was provided between carbonaceous oxygen consumption rate and heterotrophic cell synthesis and endogeneous respiration. In order to include general conditions of substrate concentration, the Monod equation was not used in its simplified form. Perdrieux and Therieu (31) used a non-steady-state model which considered soluble and suspended organic substrate concentration, concentration of cellular material and substrate stored in the biomass. When applied to situations where unsteady state operation were to be predicted, advantages of this approach over simple Monod kinetics were discussed. Dennis and Irvine (9) developed a model that also considered cell storage and release of substrates as well as shunted soluble organic components which might occur during transients. Since they indicate that the extent of storage and/or shunting is a function of bacterial population, substrate composition and possibly operational and environmental conditions, the design engineer seems to be faced with a monumental modeling task.

In the laboratories of Oklahoma State University's Bioenvironmental Engineering Department, researchers were afforded the rare opportunity of conducting bench scale activated sludge treatability studies upon thirty-three distinct synthetic wastewaters for the purpose of determining the biokinetic constants for each. The findings of this research (19) were most interesting. Although two months of steady state operational data was collected in terms of BOD, COD, TOC and specific influent substrate analyses, tremendous problems were encountered when the data were applied to Eckenfelder (second order), Lawrence and McCarty, and Gaudy's design models. The data were so badly scattered that meaningful determination of the so-called biokinetic constants was very difficult. Techniques were developed to try to cope with this situation

(36) (23). A most distressing observation was made in that if a statistical analysis of Eckenfelder or Lawrence and McCarty, substrate removal "constants" was performed, one could not state with 95% certainty that the mean value of these constants was different for 32 of the 33 compounds investigated. Clearly, the value of these models as a design tool seems to be limited.

For several years, Kincannon (18) and Stover (45) have advocated design of fixed film biological reactors in terms of total organic loading. Just as activated sludge design processes had evolved from rule of thumb organic loading design approaches to the more sophisticated kinetic designs, research work has been undertaken to upgrade the fixed film design techniques and has resulted in recent publications by Kincannon and Stover (22) (24) (35). A reciprocal plot of mass of substrate removed per media surface area versus mass of substrate applied per media surface area was utilized to develop biokinetic constants from which equations to specify tower or RBC design criteria were developed. These plots fit the data quite well.

Recently, these researchers decided to apply the same design strategy to activated sludge design. A plot of substrate utilization rate (Si - Se/Xt) versus F/M ratio (FSi/XV) was said to be described by a Monod relationship. A reciprocal plot of these two parameters should yield a straight line with an intercept corresponding to the reciprocal of the maximum specific substrate utilization rate and a slope equivalent to K_B/U_{max} (K_B = Kincannon and Stover saturation constant). The substrate removal term (due to growth) is expressed as:

$$\frac{(dS)}{(dt)}_g = U_{max} \frac{FSi/XV}{K_B + FSi/XV}$$

Drawing a mass balance for the aerator-clarifier envelope and assuming steady state operation, the following equations may be developed:

$$Se = Si - \frac{U_{max}\ Si}{K_B + FSi/XV}$$

$$XV = \frac{FSi}{[U_{max}\ Si)/(Si - Se)] - K_B}$$

The Kincannon and Stover model was applied to the bench scale treatability data for the thirty-three wastewaters studied and a very good fit of this model to the data was realized.

A search of the literature showed that Suschka (46), a Polish researcher, independently reached the same conclusion. Using the data collected over many years from laboratory pilot and full scale operations, he applied a Monod equation to describe the relationship between substrate utilization rate and organic load. An excellent fit to the data is also reported. However, neither mass balances nor design equations were presented.

Several researchers have tried to establish techniques to predict the performance of activated sludge systems treating multicomponent wastewaters based upon the treatment characteristics of each individual component. Lackmann et al. (25) conducted studies in which glucose and selected chlorinated organics were subjected to activated sludge treatment. It was demonstrated that the addition of glucose, starch or lactose to microbial populations actively metabolizing 2,4-D caused no decrease in the rate of 2,4-D removal. However, 2,4-D may have had an inhibitory effect on the rate of glucose removal. It was also noted that cells grown upon glucose did possess some potential for 2,4-D metabolism while cultures acclimated to, then deprived of 2,4-D for up to fifty days while still receiving glucose feed retained some of their ability to metabolize 2,4-D. Based upon the results of tests upon wastewaters composed of mixtures of 2,4-D and glucose, it was determined that the growth rate required to reduce 2,4-D concentrations to below 10 μg/L would be significantly less than the growth rates required to achieve typical effluent BOD concentrations. This implies operation at high SRT (energy intensive) in order to reduce 2,4-D concentrations to proposed levels. In that Monod kinetics were employed, influent 2,4-D concentration had no impact upon effluent 2,4-D levels. Kincannon et al. (23) investigated the activated sludge treatability of a mixture of nine organic substrates. Both Eckenfelder's and the Kincannon/Stover biokinetic models were employed to calculate the size of aeration facilities required to achieve a given level of treatment efficiency. Variability observed when determining Eckenfelder's k_e was accounted for by a probabilistic technique described previously (36). Effluent quality was measured in terms of BOD as well as for three specific organic compounds (pentachlorophenol, bis(z-ethylhexyl)phthalate, and trichloroethylene). Since effluent quality is a function of influent substrate concentration for both of the biokinetic models utilized, the influent substrate concentrations were analyzed in terms of their probability of occurrence. Given the influent characteristics and effluent discharge criteria, examples of the calculated aeration volumes for the various effluent constituents and desired probability levels are presented for both models. The point is made that for Eckenfelder's model, variability in influent flow and substrate concentration as well as variability in k_e must be considered, whereas, in the Kincannon/Stover model the variability within the biokinetic constants is negligible leaving only two parameters, flow and influent organic concentration, subject to variability. Kincannon et al. (21) (23) presented a technique for predicting the biokinetic constants for the activated sludge treatability of multicomponent wastewaters (combined systems) based upon the biokinetic constants determined for wastewaters composed of only portions of the components of the multicomponent mixture (single substrate systems). Two methods were utilized to predict the constants which would describe the performance of the combined units. One was to average the biokinetic constants determined for the single substrate systems. The other method incorporated a weighted average technique whereby the biokinetic constants predicted for the combined unit were a function of the biokinetic constants calculated for the single substrate systems and a weighting factor corresponding to the ratio of the concentration of the particular priority pollutant to the sum total ot the priority pollutant concentration in the combined unit. Corrections for air stripping and adsorption were also incorporated. In general, predicting the observed biokinetic constants determined for the combined substrate units in terms of either BOD, TOC or COD using the previously described method was found to be unsatisfactory. However, a much greater degree of success was achieved when predictions of the specific organic constituents in the effluent were made.

Siber and Eckenfelder (33) conducted treatability studies on mixtures of glucose, phenol and sulfanilic acid. Varying the concentrations of the three components while maintaining a relatively constant TOC loading and operating a relatively constant TOC loading and operating at several F/M ratios, these researchers analyzed influent and effluent quality in terms of TOC and specific analyses of the three components. It was concluded that the total substrate removal rate was the sum of the individual substrate removal rates. It should be noted that since the individual substrate removal rates were calculated by converting each specific substrate analysis to its corresponding TOC, this approach ignores the possible production of microbial intermediates. Using Eckenfelder's second order model, effluent TOC concentrations were predicted using the following equation:

$$Se = \frac{Si}{[k'_e \div (F/M)] + 1}$$

The authors also corrected k_e with respect to biodegradeable fraction of the sludge (f) and added a term for non-biodegradeable TOC (S_{NB}) yielding:

$$Se = \frac{Si}{[k'_e f \div (F/M)] + 1} - S_{NB}$$

Remembering that k_e, here, is a composite of the three individual compound removal rates, the predicted effluent TOC values coincided very closely to those observed for the various operating conditions.

It should be pointed out that the activated sludge process employs a dynamic, heterogeneous microbial population. Shifts in predominating species are known to occur, and indeed, may be responsible for the great variability encountered when attempting to determine biokinetic constants (more appropriately, biokinetic coefficients) for any given set of operating conditions. Banks et al. (1) characterized the bacterial populations at ten activated sludge treatment plants and found great differences in the species present at each with an average of one hundred forty isolates per plant. Seventy seven percent of these isolates, however, could be segregated into fifteen groups based upon biochemical tests. These researchers concluded that the type of wastewater rather than the operational mode of the plant had the greatest impact upon the nature of the microbial population. Lester et al. (26) studied mixtures of pure cultures receiving multicomponent substrates at several dilution rates in an effort to simulate activated sludge heterogeneous populations. Enumeration of the various species' populations allowed one to observe the composition of the population. Since tests were conducted for only about eight days, it was not possible to determine whether or not predominance shifts would occur even as steady state conditions of growth rate and qualitative and quantitative organic loading. Other researchers (27) (34) have attempted to account for population shifts when developing kinetic expressions. However, an attempt to monitor dynamic biological systems, as the activated sludge process, in terms of predominating species would demand a greater degree of sophistication than what is currently being applied in the environmental engineering field.

CHAPTER III

MATERIALS AND METHODS

3.1 Description of Bench Scale Reactors

3.1.1 Combination Substrate Studies

Wastewaters composed of combinations of organic compounds (various combinations of sucrose, soluble starch, egg albumen, oleic acid, 2-propanol, 2-nitrophenol, 4-chloro-3-methylphenol and Cheer) were subjected to activated sludge treatment in bench units similar to that depicted in Figure 1. Influent was delivered from a twenty liter carboy (equipped with a mixer) to the glass aeration basin by positive displacement pumps which either operated continuously or were controlled by timers that activated the pumps for a specified time period during each two minute interval. Compressed air passing through diffusers performed the dual function of supplying oxygen to the microbial population and mixing the reactor. Mixed liquor displaced from the aeration basin by incoming wastewater overflowed into a glass clarifier where the sludge settled and was returned to the aeration basin by a pump operated on a timer. Clarified effluent was collected in twenty liter, glass carboys. The clarifier, which was generally subjected to a surface overflow rate of 30 gpd/ft^2 and a solids loading of 0.4 to 3.9 lb/ft^2/day was oversized. An advantage to using an oversized clarifier was that operational problems caused by poor sludge settling characteristics were minimized.

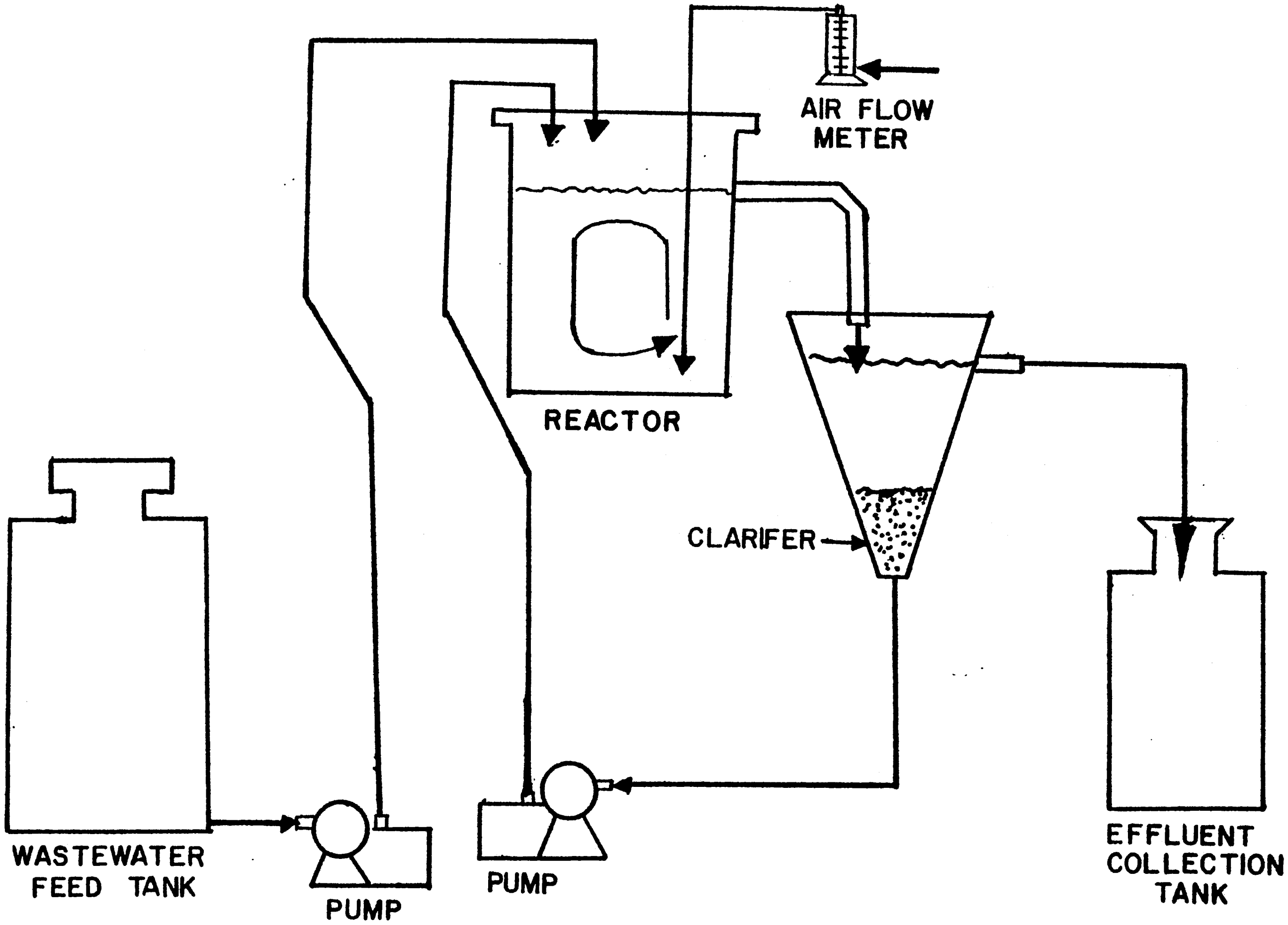

Figure 1. Schematic of External Recycle Reactors Employed for the Combination Substrate Investigations

Clarifier sludge inventories were intentionally kept low and high sludge recycle rates (up to $\alpha = 1.5$) were sometimes used to accomplish this. If necessary, a clarifier rake was installed to enhance thickening and maintain a low clarifier inventory. Tygon tubing was used as conduit to connect the treatment train.

3.1.2 Single Substrate Studies

In addition to the combined substrate investigations, activated sludge treatability studies were conducted for each individual substrate component. Three plexiglass, internal recycle reactors, each operated at a specific solids retention time (SRT), were employed for this phase of the research. All eight of the compounds utilized for the combined substrate studies were each subjected to activated sludge treatment in these internal recycle reactors. When sufficient operating data were collected for the particular compound being tested, the units were shut down and washed out. Upon reseeding, another of the eight compounds was selected and administered as an influent. This procedure was repeated until all eight compounds (sucrose, soluble starch, egg albumen, oleic acid, 2-propanol, 2-nitrophenol, 4-chloro-3-methylphenol or Cheer). Each influent solution was supplemented with yeast extract (2% of the weight of compound added) and appropriate inorganic nutrients (namely ammonia and phosphate).

Figure 2 illustrates the experimental set-up employed for these treatability studies performed on the individual compounds. From a common feed tank constructed of plexiglass, the synthetic wastewater was pumped by positive displacement pumps to each of the reactors. The pumps either operated continuously or were controlled by timers which

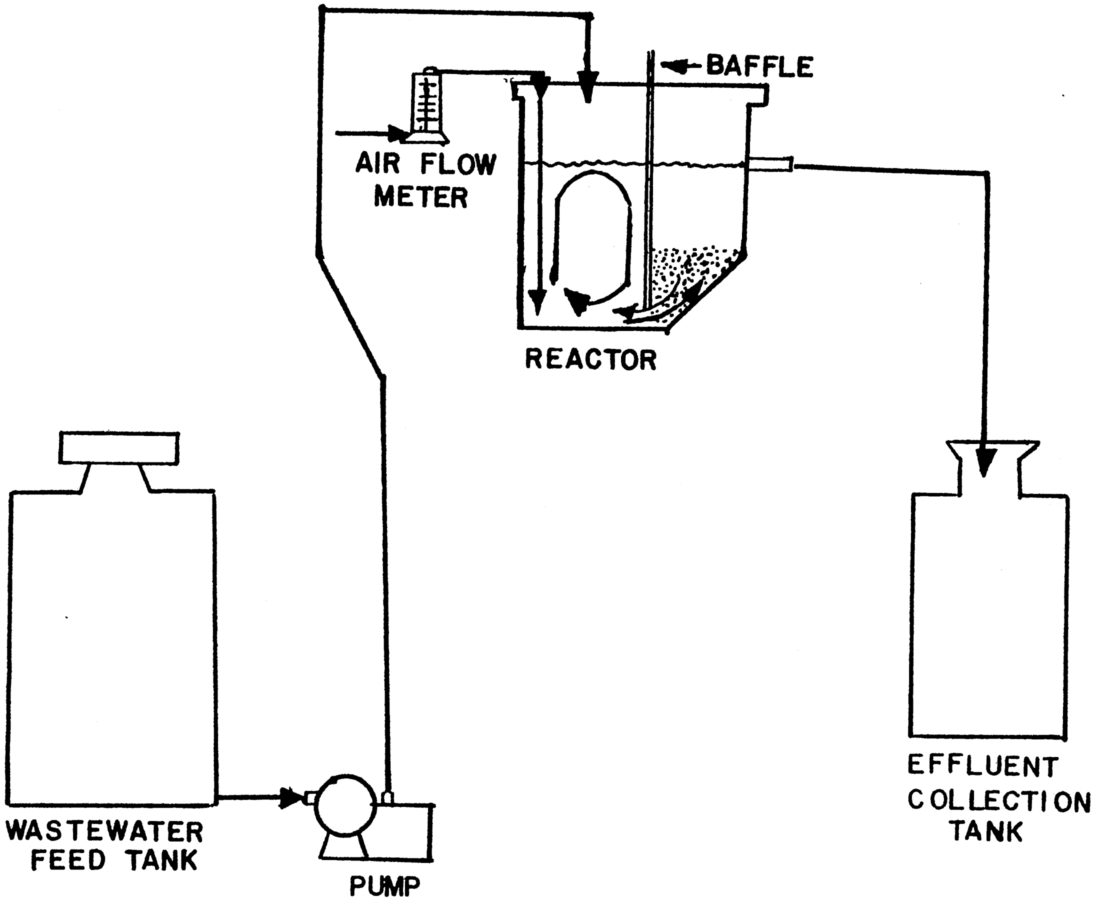

Figure 2. Schematic of Internal Recycle Reactors Employed for the Individual Substrate Investigations

activated them for a specified time period at two or three minute intervals. Compressed air passing through diffusers was used to supply oxygen to the microbial population as well as to mix the reactor contents. An adjustable plexiglass baffle was positioned so as to keep the clarifier sludge from compacting too tightly inside the baffle opening but, at the same time, to allow efficient sludge settling. Clarified effluent was collected in twenty liter, glass carboys. Tygon tubing was used to connect the feed carboy, pump, reactors, and effluent carboy.

3.2 Operation of the Bench Scale Units

Microbial seed organisms were initially obtained from the Tulsa, Oklahoma Municipal Wastewater Treatment Facility (Southside plant) which utilizes activated sludge treatment. Once an acclimated population was developed for the combined substrate unit, this sludge was employed during the entire study period where each of the five combined substrate wastewaters were treated. When conditions of SRT or feed combination were changed, the system was allowed to achieve steady state with respect to mixed liquor suspended solids concentration and effluent substrate concentration before compiling the data that would be utilized in the biokinetic constant, settleability and dewaterability determinations.

For the studies involving the treatability of the individual organic compounds (single substrate studies), microbial seed organisms were acquired from the combined unit wastage and were supplemented with sludge obtained from the Tulsa Plant. Administration of a wastewater containing the particular organic substrate selected for study was initiated. After it was determined that the units were operating at steady state conditions, the data used to determine the treatability of each specific influent compound were collected. When ample data were collected, the units were shut down, cleaned, and started up again in the same manner as stated previously using another organic compound as the organic substrate.

The bench scale units were operated at a constant solids retention time (SRT). Several solids retention times (usually 3) were studied for each compound or combination of compounds investigated. Suspended solids analyses were performed on mixed liquor and effluent samples daily. Solids wastage, based upon that day's suspended solids analyses, was accomplished by removing the appropriate volume from the aeration basin. Influent flow rates were monitored at least once per day and were adjusted to maintain a hydraulic detention time of approximately six hours in the aeration basin. Diffused air flow rates were adjusted to insure that the dissolved oxygen concentration in the reactor was not limiting (greater than 2 mg/L) and, at the same time, prevent sludge from depositing on the reactor floor. An exception to these operational procedures was made when the bench scale treatability study involving detergent (Cheer) was conducted. Here, air flow rates were reduced to prevent excessive foaming. Dissolved oxygen concentrations were kept at approximately 1 to 1.5 mg/L. Mixing was accomplished by placing magnetic stirrers in the aeration basin and placing the reactors on insulated stirring devices. These reactors were operated at a hydraulic retention time of seven hours.

3.3 Synthetic Wastewaters

A time table indicating the period during which each of the units was operated is presented in Figure 3. It should be mentioned that each

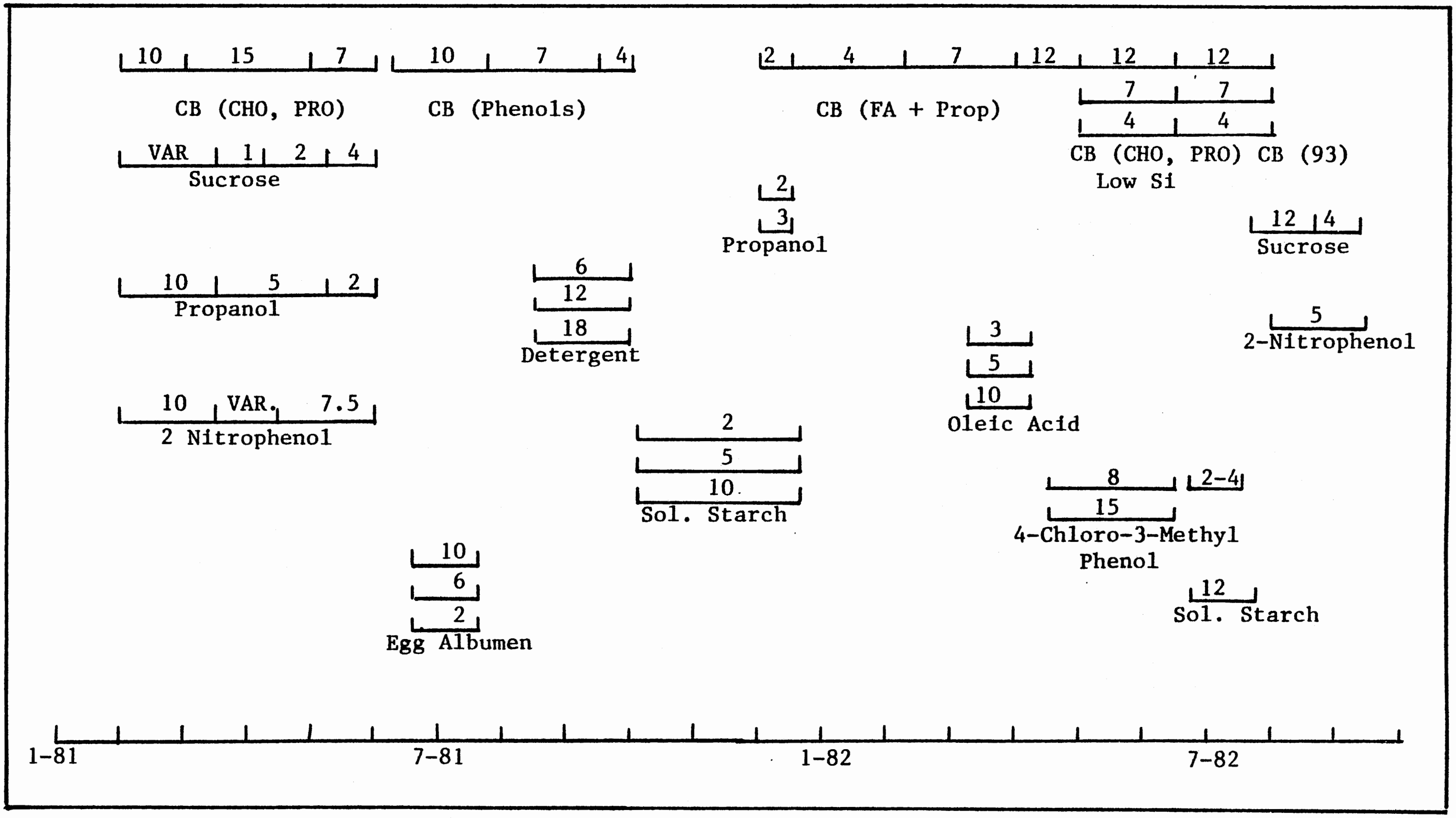

Figure 3. Schedule Depicting the Time Period During Which Each of the Test Units was Operated

of the synthetic wastes was supplemented with nitrogen (ammonium chloride) in order to maintain a COD/N ratio in excess of 40/1. Ammonia analyses of the effluent often indicated that great excesses of ammonia were present. Occasionally, the quantity of nutrient ammonia added was reduced, especially if operational problems, as rising clarifier sludge, were noted but several mg/L of excess ammonia was always allowed to remain. A strong phosphate buffer (.01 M) was provided in the synthetic wastewater to supply phosphorus and, also, to maintain a neutral pH in the biological reactors. To supply trace organic nutrients, yeast extract was administered to the wastewaters containing only single substrates at a concentration of two percent of the compound concentration (this procedure was omitted for the combined wastewaters due to the wide variety of substrates already present). Tap water was used to dilute the synthetic wastewaters to volume.

Tables V to IX list the concentrations of each of the eight organic substrates for the five combined wastewaters studied. The concentration of TOC, COD and BOD contributed by each compound as well as their percent contribution of TOC, COD and BOD to the total influent concentration are also presented. Table X lists the influent concentrations employed for the investigations conducted upon the individual substrates.

Three of the organic substrates studied required the following special preparation procedures:

1. Egg albumen was blended to homogenize the stock solution.
2. Soluble starch was boiled to form a soluble solution.
3. Oleic acid was heated to form a homogeneous solution which could be added to the feed. When oleic acid was used as the

TABLE V

COMBINED SUBSTRATE INFLUENT FOR CONDITION NO. 1 (2/6 - 6/2/81)

		TOC		COD		BOD	
Component	mg/l	mg/l	%	mg/l	%	mg/l	%
Albumen	120	50	11.8	116	10.1	32	6.4
Starch	303	121	28.6	273	23.7	125	25.1
Sucrose	164	70	16.6	163	14.1	95	19.1
2-Propanol	78	44	10.4	163	14.1	46	9.2
Oleic Acid	82	36	8.5	152	13.2	79	15.9
Cheer	731	61	14.5	190	16.5	69	13.9
2-Nitrophenol	62	29	6.9	67	5.8	35	7.0
4-Chloro-3-Methyl Phenol	29	11.1	2.6	29	2.5	17	3.4
Total		422		1,152		498	

TABLE VI

COMBINED SUBSTRATE INFLUENT FOR CONDITION NO. 2 (6/12 - 10/15/81)

		TOC		COD		BOD	
Component	mg/l	mg/l	%	mg/l	%	mg/l	%
Albumen	60	25	6.6	58	5.5	16	3.3
Starch	151	60	15.8	136	13.0	62	12.9
Sucrose	82	35	9.2	81	7.7	47.5	9.9
2-Propanol	63	35	9.2	131	12.5	37	7.7
Oleic Acid	69	30	7.9	128	12.2	66	13.7
Cheer	549	46	12.1	143	13.7	52	10.8
2-Nitrophenol	153	71	18.7	165	15.8	85.5	17.8
4-Chloro-3-Methyl Phenol	140	78	20.5	205	19.6	116	24.1
Total		380		1,047		482	

TABLE VII

COMBINED SUBSTRATE INFLUENT FOR CONDITION NO. 3 (11/28/81 - 5/1/82)

		TOC		COD		BOD	
Component	mg/l	mg/l	%	mg/l	%	mg/l	%
Albumen	20	8.4	4.9	19	3.5	5.4	2.4
Starch	50	20	11.8	45	8.2	20.6	9.0
Sucrose	50	21	12.4	50	9.1	29	12.7
2-Propanol	98	55	32.3	204	37.1	58	25.3
Oleic Acid	80	35	20.6	148	26.9	77	33.6
Cheer	137	11.3	6.6	36	6.5	13	5.7
2-Nitrophenol	21	9.8	5.8	23	4.2	12	5.2
4-Chloro-3-Methyl Phenol	17	9.4	5.5	25	4.5	14	6.1
Total		170		550		229	

TABLE VIII

COMBINED SUBSTRATE INFLUENT FOR CONDITION NO. 4 (5/2 - 6/15/82)

		TOC		COD		BOD	
Component	mg/l	mg/l	%	mg/l	%	mg/l	%
Albumen	90	38	18.8	87	16.8	24	10.6
Starch	146	58	28.7	132	25.5	60	26.5
Sucrose	122	52	25.7	121	23.4	71	31.4
2-Propanol	31	17	8.4	65	12.6	18	8
Oleic Acid	15	6.5	3.2	28	5.4	14	6.2
Cheer	137	11	5.4	36	7	13	5.8
2-Nitrophenol	21	10	5.8	23	4.4	12	5.3
4-Chloro-3-Methyl Phenol	17	9.5	4.7	25	4.8	14	6.2
Total		202		517		226	

TABLE IX

COMBINED SUBSTRATE INFLUENT FOR CONDITION NO. 5 (6/20 - 8/2/82)

Component	mg/l	TOC mg/l	TOC %	COD mg/l	COD %	BOD mg/l	BOD %
Albumen	48	20	10.5	46	8.8	13	5.6
Starch	77	31	16.3	69	13.2	32	13.8
Sucrose	65	28	14.7	64	12.3	38	16.4
2-Propanol	39	22	11.6	81	15.5	23	9.9
Oleic Acid	3	13	6.8	56	10.7	29	12.5
Cheer	290	24	12.6	75	14.4	27	11.6
2-Nitrophenol	63	29	15.3	68	13.1	35	15.1
4-Chloro-3-Methyl Phenol	42	23	12.1	62	11.9	35	15.1
Total		190		521		232	

TABLE X

SINGLE SUBSTRATE TREATABILITY STUDIES: INFLUENT SUBSTRATE CONCENTRATIONS USED IN BENCH SCALE TESTING

Organic Feed Constituent	Influent Concentration mg/l
Egg Albumen	500
*Sol. Starch	500
Sol. Starch	200
*Sucrose	850
Sucrose	200
2-Propanol	300
Oleic Acid	350
Cheer	470
2-Nitrophenol	250
4-Chloro-3-Methyl Phenol	100

*Several Influent Concentrations Were Studies for These Compounds.

sole substrate, the tap water was softened to minimize the formation of insoluble calcium oleate.

3.4 Analytical Techniques

Analyses performed upon the biological reactors, influents and effluents as well as the procedures utilized are presented in Table XI.

Activated sludge mixed liquor and effluent suspended solids concentrations were monitored daily. Volatile suspended solids of the mixed liquor were monitored periodically in order that the ratio of volatile to total suspended solids could be determined. Mixed liquor temperature, pH, and dissolved oxygen concentration were monitored to insure that an environment conducive to biological activity was maintained. The temperature of the room in which the reactors were located was controlled to keep the mixed liquor temperatures at 25 ±2°C.

When the biological units under investigation were determined to have reached steady-state, influent and effluent samples were regularly analyzed for total organic carbon (TOC), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) concentrations. Only soluble (passing through Reeve Angel 934-AH filters) effluent TOC, COD, and BOD were considered for modeling purposes.

To determine what portion of the residual effluent TOC, COD and BOD was due to any unmetabolized components of the influent and what portion was due to microbial byproducts resulting from the metabolism of the feed constituents, it was attempted to perform analyses upon each of the eight specific substrates at least once during every operating condition of SRT and influent composition. The test procedures utilized in these investigations are also summarized in Table XI. To increase the sensitivity of the protein and carbohydrate test procedures, soluble effluent

TABLE XI

ANALYTICAL TECHNIQUES EMPLOYED IN THESE INVESTIGATIONS

Analysis	Technique	Source
Suspended Solids	Samples were filtered through a dried, preweighed glass fiber filter (Reeve Angel 934-AH) and dried in a 103°C oven.	
Volatile Suspended Solids	Following suspended solids analyses, the filters were combusted to 550°C for twenty minutes then reweighed.	
pH	Orion Research Model 701 pH meter and combination electrode probe.	
Dissolved Oxygen Concentration and Uptake	Orion Research Model ___ Probe; reduction of oxygen concentration monitored with time.	
TOC	Beckman Model 915 TOC Analyzer; Sample response compared to standard solution response curve.	
COD	Hach Chemical Company	Hach Chemical Co. Manual (15)
BOD	Standard Methods Technique with modified seed correction; Orion Research D.O. probe utilized.	Standard Methods for the Examination of Water & Wastewater, 14th Ed., (37)
Ammonia	Hach Chemical Company	Hach Chemical Co. Manual (15)

TABLE XI (Continued)

Analysis	Technique	Source
Nitrate	Hach Chemical Company	Hach Chemical Co. Manual (15)
Egg Albumen	Colorometric; Coomassie dye binding technique on effluent samples concentrated by lyophilization.	Biorad Biochemical Co. (4)
Soluble Starch and Sucrose	Effluent samples concentrated by lyophilization were hyrolized at 100°C in a IN H_2SO_4 solution (3-6 hrs.); After neutralization, enzymatic, colorometric, glucose analyses were performed (ultramicro technique) and compared to standard solutions.	Worthington Biochemical Corp.
2-Propanol	Using a Tekmar LSC-1 Concentrator, a sample was heated to 90°C and purged for ten minutes. The purge gas was passed through a Tenax GC/silica gel trap where volatile organic compounds were adsorbed. The trap was then heated and the trap effluent directed into an F&M Gas Chromatograph employing a Carbopak C/0.2% Carbowax 1500, 80/100 mesh column, flame ionization detector and an integrator. Sample response was compared to that of known standards.	

TABLE XI (Continued)

Analysis	Technique	Source
Oleic Acid	Samples were acidified (less than pH = 2) and extracted with hexane. Concentrated samples were transesterified and analyzed on a Perkin-Elmer gas chromatograph employing a column of 20% DEGS and flame ionization detector. Sample response was compared to that of known standards.	Performed in accordance with the techniques employed by the OSU biochemistry department.
Detergent	Hach Chemical Company - methylene blue technique.	Hach Chemical Co. Manual (15)
2-Nitrophenol and 4-Chloro-3-Methyl Phenol	Samples were acidified and extracted with methylene chloride. Concentrated samples were analyzed using either a Hewlett Packard or a Perkin-Elmer gas chromatograph both equipped with a 1% SP-1240-DA or 100/120 Supalcoport column, flame ionization detectors and integrators. Sample responses were compared to those of known standards.	U. S. Environmental Protection Agency. *Sampling and Analysis Procedures for Screening Industrial Wastewaters for Priority Pollutants*. Cincinnati, Ohio: Environmental Monitoring and Support Laboratory, April, 1977.
Sludge Settleability	One liter mixed liquor samples at various suspended solids concentrations were placed in one liter, glass graduated cylinders (not stirred) and allowed to settle. Solid/supernatant interface height was recorded versus time.	

TABLE XI (Continued)

Analysis	Technique	Source
Sludge Settleability	Sludge samples thickened to 8,000 mg/l were placed into a capillary suction time apparatus. The amount of time required for the filtrate to traverse the gauged field was recorded.	

samples were lyophilized. Although excellent recovery was obtained for sucrose, protein and starch recovery was low and in the final analysis, lyophilization did little to increase the sensitivity of the test for these compounds. Due to the nature of the carbohydrate analyses (hydrolisis to the glucose component), it was not possible to distinguish between starch and sucrose and results are reported in terms of glucose. If all the carbohydrate remaining was due to starch, the residual starch concentration would correspond to the glucose value reported. However, if all the residual carbohydrate remaining was sucrose, the actual sucrose concentration remaining would be twice the glucose concentration reported.

A tentative procedure was utilized for 2-propanol analyses. The procedure (Table XI) yielded reasonable results part of the time but on other occasions, resolution of a sharp peak was not possible. Limited 2-propanol results were available to report. It should be noted that samples were not filtered to minimize 2-propanol volatilization.

More reliable gas chromatographic techniques were employed for 2-nitrophenol, 4-chloro-3-methylphenol and oleic acid analysis. These effluent samples were not filtered and care was taken to rinse the glass sample bottles with the appropriate solvent to remove any of the compound that may have adhered to the glass. Since identical techniques were used to analyze 2-nitrophenol and 4-chloro-3-methylphenol, the same sample was analyzed simultaneously for both compounds.

The detergent analytical procedure utilized was a Hach Chemical Company spectrophotometric procedure employing a methylene blue color development step followed by benzene extraction. This procedure was subject to interference by phenols.

Sludge settleability and dewaterability data were collected utilizing the techniques outlined in Table XI. It was attempted to analyze the sludge under investigation several times during the steady state period in order to account for any variations that would occur with time.

CHAPTER IV

RESULTS

The list of symbols appearing on page XIII should be referred to when reviewing the results and discussion sections of this research.

4.1 Operational Data

Operational data for all test runs were compiled and entered onto a computer file. An example of a typical test run is shown in Figure 4. Here, an activated sludge reactor was maintained at a solids retention time (SRT) of two days. The influent consisted of egg albumen administered at a concentration of 500 mg/L plus appropriate nutrients. Hydraulic retention time and SRT were maintained at fairly constant values of .25 and two days, respectively. Mixed liquor suspended solids concentrations usually ranged between 1200 and 1700 mg/L. Effluent suspended solids concentrations were sometimes as high as 100 mg/L. These effluent suspended solids concentrations would have to be considered as some of the higher values observed during the treatability studies (refer to Section 4.6.1). Influent TOC concentrations were relatively constant with the exception of July 12 and 13 during which Si values were quite high. F/M values for TOC generally ranged between .8 to 1.2 except during the two days when Si was so high. Effluent soluble TOC concentrations fluctuated between 20 and 50 mg/L except, again, for the period when Si was unusually high. It should be added that the

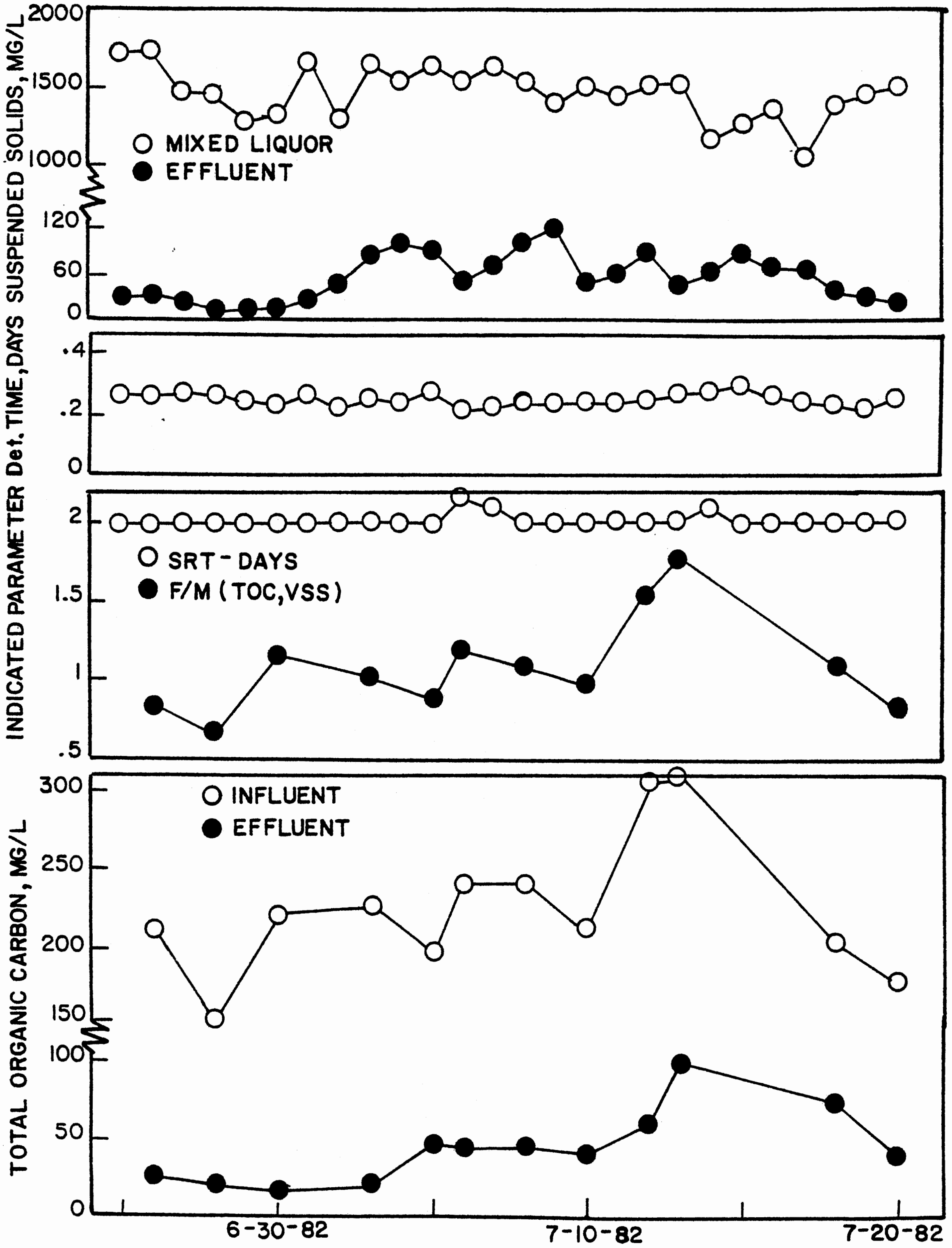

Figure 4. Operational Data for an Activated Sludge Reactor Maintained at an SRT = 2 Days Receiving a Wastewater Composed of Egg Albumen

residual effluent TOC measured for many test runs were much lower than those observed for egg albumen at SRT = 2 days. Due to problems encountered in preparing a homogeneous feed solution and taking a representative influent sample, influent TOC concentrations did fluctuate somewhat. Feed preparation and/or sampling problems were encountered with several compounds (egg albumen, oleic acid, and Cheer) and measures had to be incorporated to mitigate these difficulties (heat solublization, feed water softening, mixing and immediate analysis).

4.2 Operational Data Summary and Kinetic Constant Determination

Tables XII and XIII as well as Figure 5 summarize the test results for the individual compound units and combination units, respectively. Figure 5 presents mean values (dark line) and one standard deviation from the mean (shaded area) for the analytical results obtained from each operating condition. These data were then utilized to determine the biokinetic constants for the Kincannon and Stover, Eckenfelder, and Lawrence and McCarty models. An example of one set of plots used to calculate these biokinetic constants can be found in Figures 6, 7, 8 and 9. Eckenfelder's model was selected as a representative second order model while Lawrence and McCarty's model was selected to represent the Monod type models. The Kincannon and Stover model, having shown promise in other research (19) (41), was also used. The data presented in these figures were taken from the activated sludge systems subjected to a wastewater consisting of 2-propanol and were analyzed in terms of the substrate parameter TOC. All of the plots utilized to determine the biological constants for the bench scale studies performed upon all

TABLE XII

SUMMARY OF THE RESULTS OF BENCH SCALE TREATABILITY STUDIES FOR SINGLE SUBSTRATE INFLUENTS

			TOC						COD						BOD					
Wastewater Composition	Nom. SRT	Stat. Param.	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Egg Albumen	10	$\bar{X}$	11	.25	9.57	202.1	3,463	15.3	3	.25	8.36	666	3,510	3.5		.25	9.9	187	3,169	2.17
		S.D.		.01	1.55	24.8	627	6.96		0	2.98	109	636	14.1		.01	.18	83	298	.23
	6	$\bar{X}$	14	.26	5.96	207.5	2,918	17	3	.27	5.98	666	3,048	36	5	.26	5.76	257	2,777	3.58
		S.D.		.01	.22	26.05	540	5.3		0	.05	109.7	709	17		.01	.57	112	344	2.6
	2	$\bar{X}$	15	.25	2.04	225	859	48	4	.25	2.02	710	857	130	3	.26	2.01	187	904	53.7
		S.D.		.01	.17	53	126	23		0	.02	131.6	103	70		.01	.01	83	136	42.7
Starch	2	$\bar{X}$	8	.248	2	200	1,425	15.7	5	.248	2	497	1,544	12.8		.247	2	227	1,550	0.53
		S.D.		.003	0	11.6	241.8	2.8		.003	0	36	234	8.2		.002	0.02	39.6	205	0.57
	5	$\bar{X}$	4	.25	4.3	200	1,894	14.5	0						1	.242	5	179	270	2.4
		S.D.		0	1.4	11.4	131	3.11												
	12	$\bar{X}$	10	.27	12.05	88.6	1,850	10.5	6	.257	12	254	1,820	30	6	.257	12	109.6	1,820	4.6
		S.D.		.03	.15	22.7	100	5.38		.01	0	32.2	94	14.5		.01	0	36	94	4.7
Sucrose	12	$\bar{X}$	7	.27	11.38	93.8	2,004	4.6	4	.26	10.7	264.5	1,986	12	2	.26	9.4	170	2,079	5.3
		S.D.		.02	.81	20.5	126	2.44		.02	1.67	24	112	7.5		.02	1.28	4.2	24.8	3.1
	4	$\bar{X}$	8	.26	3.91	72.6	867	4.16	4	.26	3.96	289	900	35	1	.25	4	170	1,024	4.8
		S.D.		.01	.22	20.5	83	3.3		.02	.07	6.6	89	19						
	4	$\bar{X}$	6	.27	4.32	403	5,590	40.3	2	.27	5.6	875	5,879	80	2	.27	5.63	408	5,879	29
		S.D.		.01	1.49	19.6	635	7.87		.02	.02	7.07	480	5.66		.02	.02	32.5	480	12.7

TABLE XII (Continued)

			TOC						COD						BOD					
Wastewater Composition	Nom. SRT	Stat. Param.	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Sucrose (Continued)	1	$\bar{X}$	5	.24	1	345	1,573	16.1	2	.25	1	905	1,615	50	1	.24	1.13	477	1,294	6.6
		S.D.		0	0	19	134	4.5		0	0	7	221	15.5						
	2	$\bar{X}$	4	.25	2.1	346	2,603	39	2	.26	2	885	2,741	111	2	.25	2	420	2,587	52
		S.D.		.01	.21	6	481	6.1		0	0	7.07	589	58		.01	0	2.8	371	28.3
2-Propanol	10	$\bar{X}$	5	.25	10	220	4,057	11.3	2	.26	10	957	4,237	34	2	.25	10	279	4,161	1.8
		S.D.		.01	.01	45.3	271	3.58		.01	.01	46	122	8.5		.01	.01	84	14	0.85
	5	$\bar{X}$	5	.25	4.89	243	2,433	38.6	2	.26	5	890	3,439	96	2	.27	5	288	2,686	28.5
		S.D.		.01	.24	9.7	902	24.8		.01	0	0	470	5.6		.02	0	49.5	593	23
	2	$\bar{X}$	7	.26	2	254	1,050	34	2	.28	2	985	1,033	64.5	2	.28	2	233	1,033	25
		S.D.		.02	0	4.96	90.7	17.6		.05	0	134	116	55.8		.05	0	138.6	116	28
	2	$\bar{X}$	4	.24	2.02	234	1,391	22.7	1	.25	2	737	1,368	20	2	.24	2	233	1,630	21.5
		S.D.		.01	.04	13.8	346	4.57								0	0	109	364	6.3
	3	$\bar{X}$	4	.24	3.01	234	2,016	17.7	1	.25	2.99	737	2,207	27		.243				
		S.D.		.01	.02	13.8	240	2.14								0				
Oleic Acid	3	$\bar{X}$	17	.25	2.9	159	1,306	26.4	7	.25	2.93	608	1,187	58	5	.25	2.9	315	1,253	4.8
		S.D.		.01	.18	14.4	319.6	10.6		.01	.19	0	309	31.3		.01	.23	29	321	1.8
	5	$\bar{X}$	13	.25	4.5	159	1,509	23.5		.25	4.4	608	1,469	39	5	.26	4.36	315	1,463	3.5
		S.D.		.01	1.02	13	374	12.5		.01	1.3	0	199.4	15		.03	1.3	29.4	246	3.2

TABLE XII (Continued)

			TOC						COD						BOD					
Wastewater Composition	Nom. SRT	Stat. Param.	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Oleic Acid (Continued)	10	$\bar{X}$	14	.25	9.76	157	2,301	27	6	.25	9.9	608	2,320	44	5	.25	9.4	315	2,279	2.44
		S.D.		.01	.47	14.2	249	6.97		.01	.19	0	195	16		.01	1.1	29	157	1.5
4C-3MP	8	$\bar{X}$	13	.26	7.99	63.5	949	12.4	3	.24	8.01	145	865	22.3	5	.26	8.19	81.8	800	1.62
		S.D.		.04	.04	8.7	199	9.7		.01	0	18	189	16		.03	.41	10.4	161	.38
	15	$\bar{X}$	13	.23	15.1	63.5	1,529	9.83	5	.22	15.2	141.6	1,404	18.6	5	.23	15.2	82	1,435	2.18
		S.D.		.03	.3	8.7	212.8	5.1		.02	.48	18.2	234	14		.03	.49	10.43	216.6	0.9
2-Nitrophenol	#1 5	$\bar{X}$	6	.49	5.04	121	365.7	8.97	3	.49	4.99	274.6	377	17.6	3	.49	4.99	180	377	5.6
		S.D.		.01	.25	34.7	46	1.07		.01	.02	6.43	55.5	6.3		.01	.02	12	55.5	1.29
	#2 5	$\bar{X}$	7	.24	5.2	80.5	791	3.9	4	.24	5.23	318	764	24.7	1	.23	5	116	826	2.9
		S.D.		.01	.43	3.87	48.4	2.89		.01	.45	30.6	47.8	6.13						
	10	$\bar{X}$	7	.24	9.63	103.5	1,183	6.4	3	.24	9.16	361	1,172	19.3	3	.24	9.16	189	1,172	1.43
		S.D.		.01	.81	19	10	3.17		.01	1.17	28.4	41	1.53		.01	1.17	5.6	40.8	0.67
Cheer	12	$\bar{X}$	7	.28	12.58	46.7	550	29.3	5	.28	12.8	162	543	79	3	.28	12	59	545	9.2
		S.D.		.01	1.56	4.54	24.9	2.1		.01	1.84	4.8	22.5	11		.02	.01	6.2	21.8	4.2
	18	$\bar{X}$	11	.29	17.5	50	1,030	27		.3	17.8	179	1,071	58	3	.3	18.01	59	1,113.7	5.07
		S.D.		.01	1.14	12.3	170	5		.01	.49	42.6	225	14		.01	.02	6.2	323	3.1

TABLE XII (Continued)

			TOC						COD						BOD					
Wastewater Composition	Nom. SRT	Stat. Param.	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Cheer	6	$\bar{X}$	11	.3	5.77	45.8	290	30	6	.29	6.32	162	284	83	3	.29	6.02	59	308	12
(Continued)		S.D.		.02	1.53	4.4	63	4.38		.01	1.79	4.3	75	12		.02	.03	6.24	111	1.8

TABLE XIII

SUMMARY OF THE RESULTS OF BENCH SCALE TREATABILITY STUDIES FOR COMBINED SUBSTRATE INFLUENTS

Wastewater Composition	Nom SRT	Stat. Param	TOC						COD						BOD					
			N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Comb. Cond. NO #1; PRO/CHO High S_i	7	$\bar{X}$	6	.254	6.8	401.8	4,795	21.3	2	.26	7	1,055	5,041	69	2	.26	7.01	499	5,041	3.2
		S.D.		.02	.489	37	729	3.27		.01	0	210	438.7	14.8		.01	0	0	439	.2
	10	$\bar{X}$	9	.256	10	423.7	12,089	50.7	3	.254	10	1,493	12,092	96.7	2	.254	10	599	1,157	5.45
		S.D.		.005	0	52.9	842	11.1		0	0	208	926	14		0	0	7.07	28.4	1.2
	15	$\bar{X}$	8	.25	15	371	17,337	23	3	.25	15	1,206	16,615	74	2	.25	15	472	16,524	10.7
		S.D.		.01	.08	19	1,638	9.9		.01	.02	141	1,427	27		0	0	38	1,638	11.1
Comb. Cond. NO #2; Phenols; High S_i	10	$\bar{X}$	13	.25	9.82	412	6,598	22	3	.25	9.22	1,313	6,604	64.6	4	.25	9.66	486	6,563	1.6
		S.D.		.01	.37	65	320	6.2		0	.28	176	508.9			0	.4	41	381	.61
	7	$\bar{X}$	5	.26	7.01	369	3,908	25.5	5	.26	7.01	1,359	3,998	55	4	.26	7.01	481	3,750	2.3
		S.D.		0	.03	17.8	698	13.2		.01	.03	211	621	4.6		.01	.03	58.5	324	1.57
	4	$\bar{X}$	6	.25	4.05	385	3,039	30	3	.24	4.08	1,210	2,527	80	1	.26	4	573	2,495	2.6
		S.D.		.01	.09	47	564	9.4		.02	.14	132	27.9	17.4						
Comb. Cond. NO #3; Oleic H+/2-Prop; Low S_i	4	$\bar{X}$	8	.25	3.99	187.7	2,126	22	4	.25	4	603	2,082	72.7	7	.25	3.99	180	2,145	9.6
		S.D.		.01	.02	12.8	257	4.48		0	.01	95.8	302	8.5		.01	.02	37.5	271	6.7
	7	$\bar{X}$	11	.25	6.98	161	3,514	21.4	7	.25	6.99	503.5	3,314	60.5	5	.24	7	152.6	3,639	5.02
		S.D.		.01	.49	7.04	336	10.9		.01	.1	24.5	325	9.02		.01	.02	16.21	374	3.39
	12	$\bar{X}$	11	.24	11.99	180	4,552	18.3	4	.24	11.98	562	4,638	61.2	4	.24	11.98	288	4,633	3.5
		S.D.		.01	.02	25.3	217.9	4.05		0	.01	27.4	223	38.8		0	.01	5.44	223	.37

TABLE XIII (Continued)

			TOC						COD						BOD					
Wastewater Composition	Nom SRT	Stat. Param	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm	N	Det. Time days	SRT day	S_i ppm	VSS ppm	S_e ppm
Comb. Cond. NO #4; PRO/CHO #2; Low S_i	4	$\bar{X}$	8	.24	3.96	173.6	1,784	23.09	3	.23	4	442	1,879	57	3	.23	4	239	1,879	10.9
		S.D.		.01	.13	33.9	257	10.2		0	0	79.7	168	13		0	0	71	168	3.95
	7	$\bar{X}$	10	.23	6.91	172	3,226	11	5	.22	6.99	466	3,400	26.4	5	.22	6.99	219.8	3,400	6.28
		S.D.		.02	.15	30.1	399	8.1		.02	.02	67.6	413	7.89		.02	.02	65.4	413	3.37
	12	$\bar{X}$	10	.24	11.9	172	4,636	12.1	5	.24	12	466	4,695	41	4	.24	12.01	199	4,652	2.08
		S.D.		.01	.31	30	263	6.96		.01	.02	67.6	187	10.7		.01	.02	53.7	186	.3
Comb. Cond. NO #5; 93 mg/l COD for each component, Low S_i	4	$\bar{X}$	10	.23	3.99	186	2,178	23.8	4	.23	3.98	549	2,249	47	6	.23	3.99	206	2,217	10.2
		S.D.		.01	.02	17	231	9.15		.01	.03	12.2	281	7.3		.01	.02	26.6	238	4.74
	7	$\bar{X}$	8	.2	7.18	185	3,940	21.6	4	.21	7.36	549	4,289	33.7	6	.21	7.24	206	3,854	9.35
		S.D.		.01	.54	16.5	741	12.4		0	.76	12.25	633	2.99		.01	.62	26.6	833	4.28
	12	$\bar{X}$	12	.24	12.03	186.8	4,528	12.3	5	.23	12	549	4,684	43.4	5	.24	12.01	209.6	4,386	3.8
		S.D.		.02	.1	15.2	574	4.4		.01	.02	10.6	644	22.07		.01	.01	28.4	339	1.2

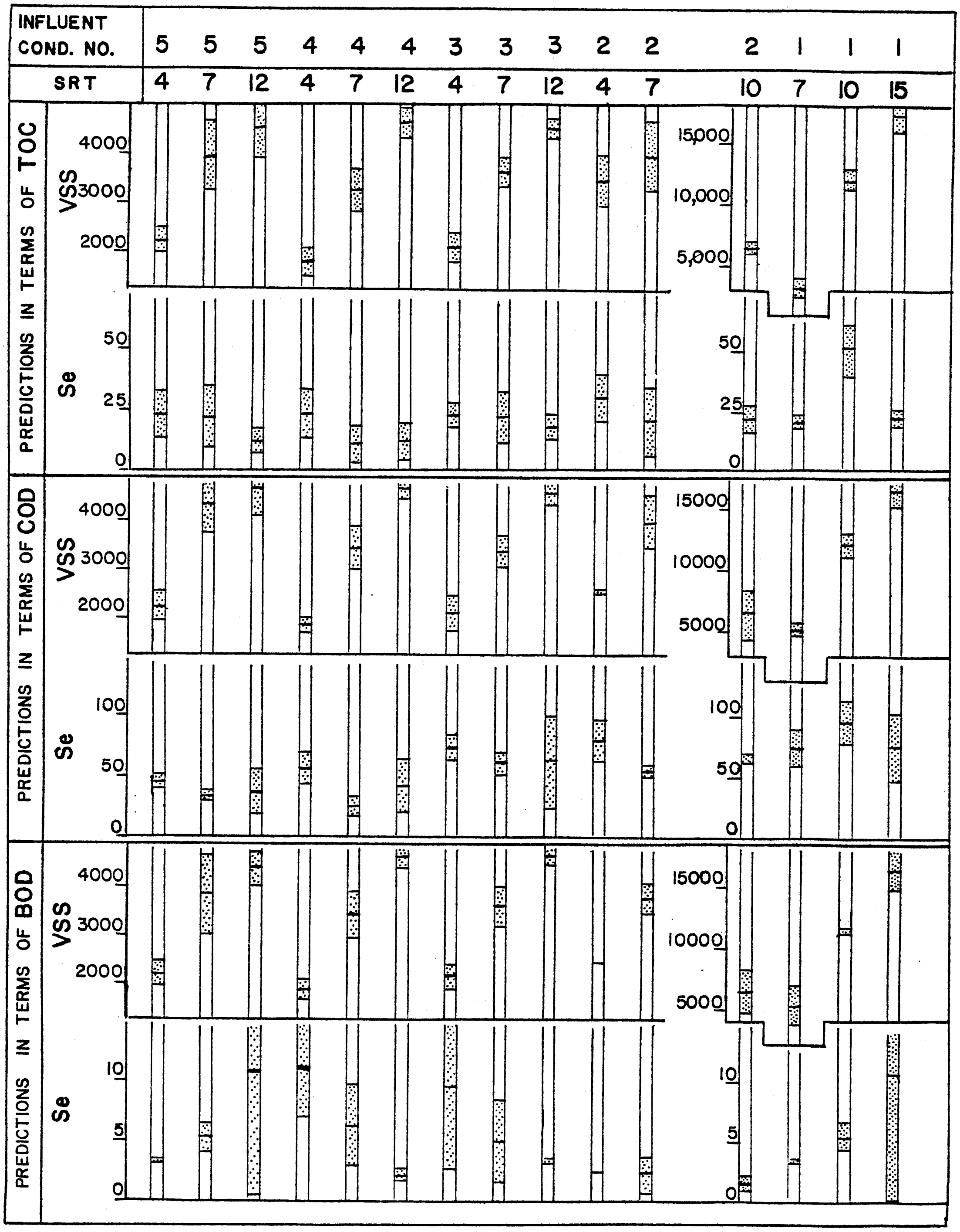

Figure 5. Bar Graph Depicting Observed Mean Value (Dark Bar) and One Standard Deviation From the Mean Value (Shaded Area) for Mixed Liquor Volatile Suspended Solids and Effluent Substrate Concentration for all Combined Substrate Influents and Operating Conditions. Concentrations are Reported as MG/L.

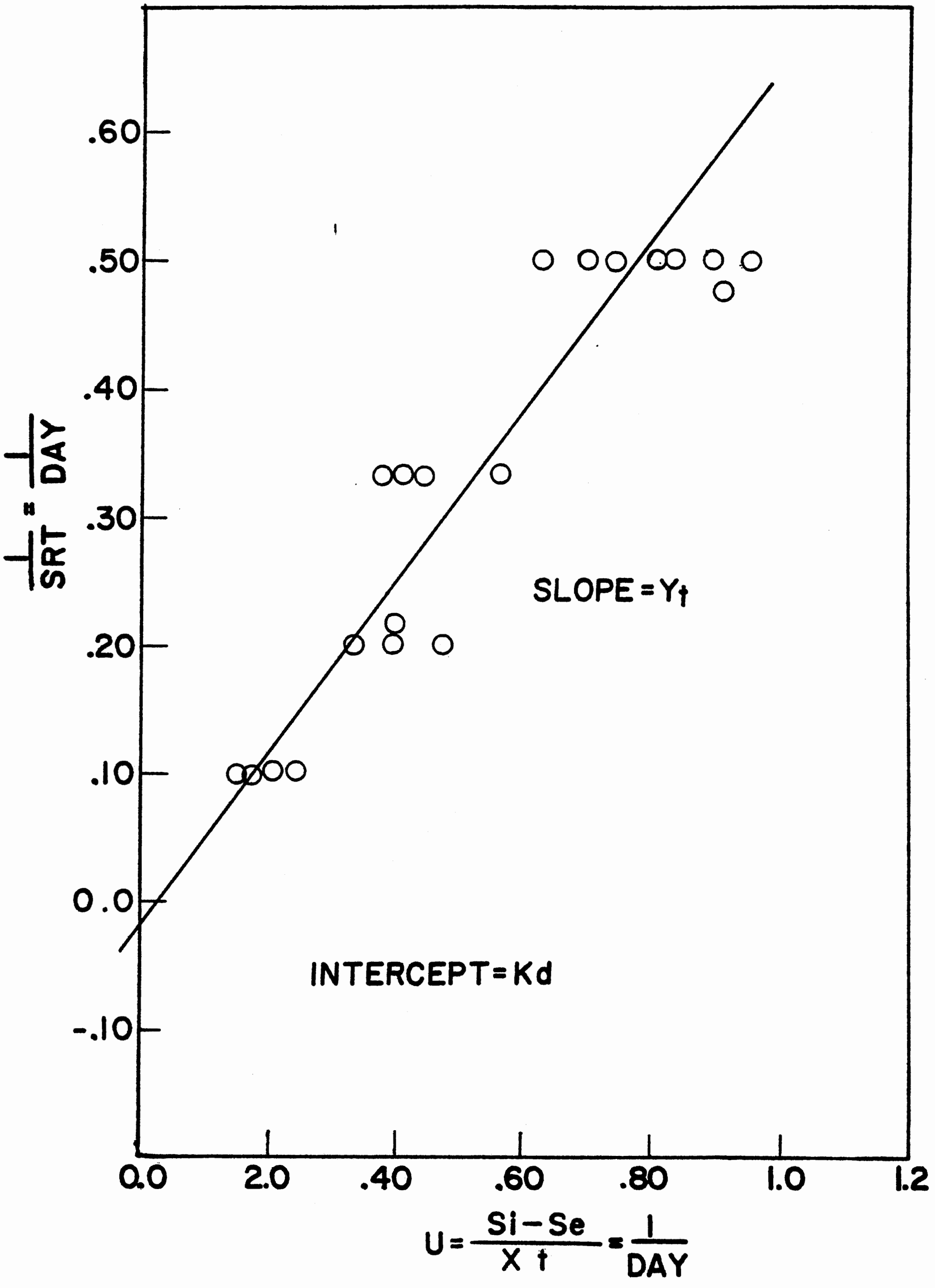

Figure 6. Plot Utilized to Determine the Biokinetic Constants, k_d and Y_t for a 2-Propanol Influent

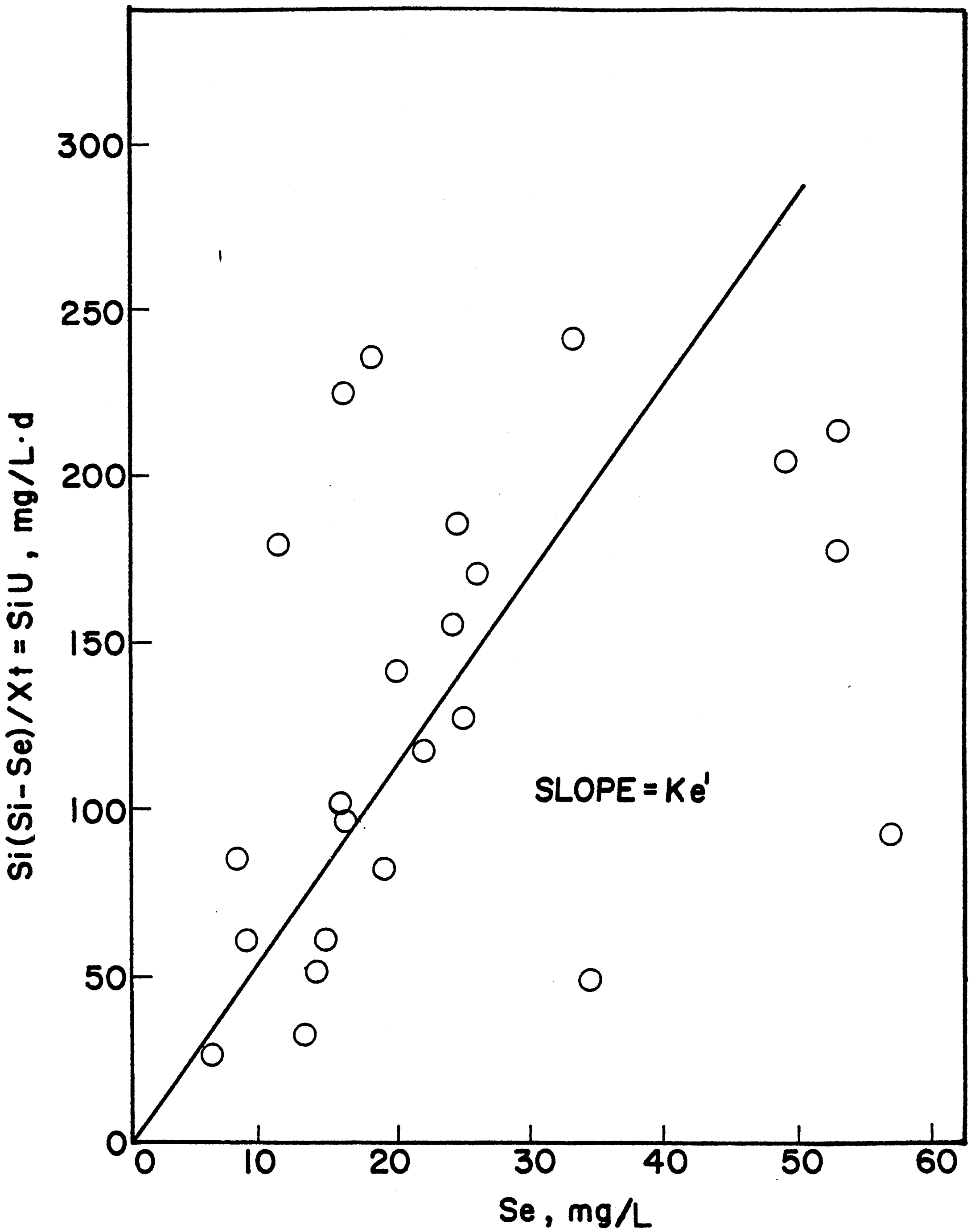

Figure 7. Plot Utilized to Determine the Biokinetic Constant, k'_e for Eckenfelder's Second Order Model and a 2-Propanol Influent

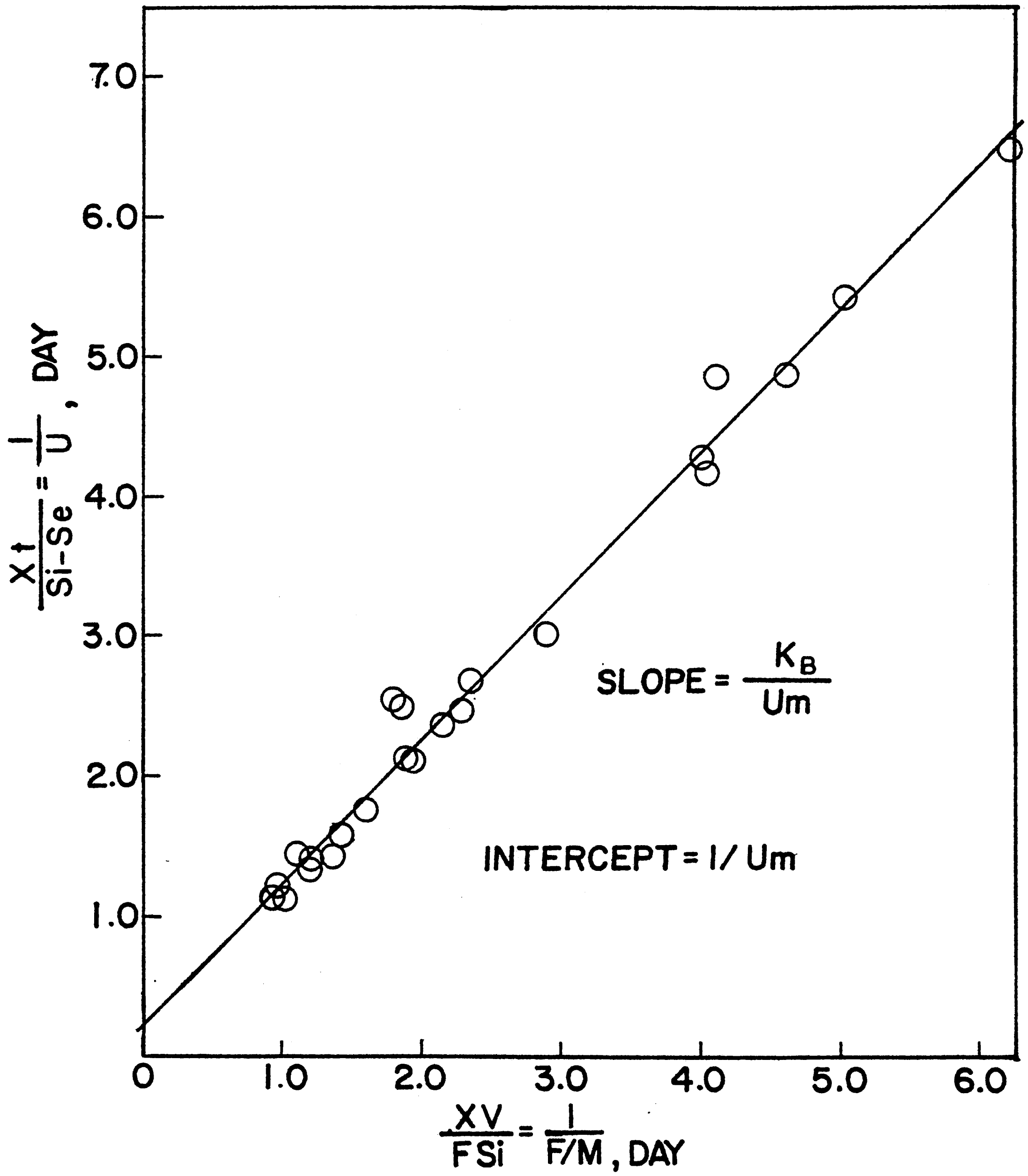

Figure 8. Plot Utilized to Determine the Biokinetic Constants, U_{max} and K_B for the Kincannon/Stover Model and a 2-Propanol Influent

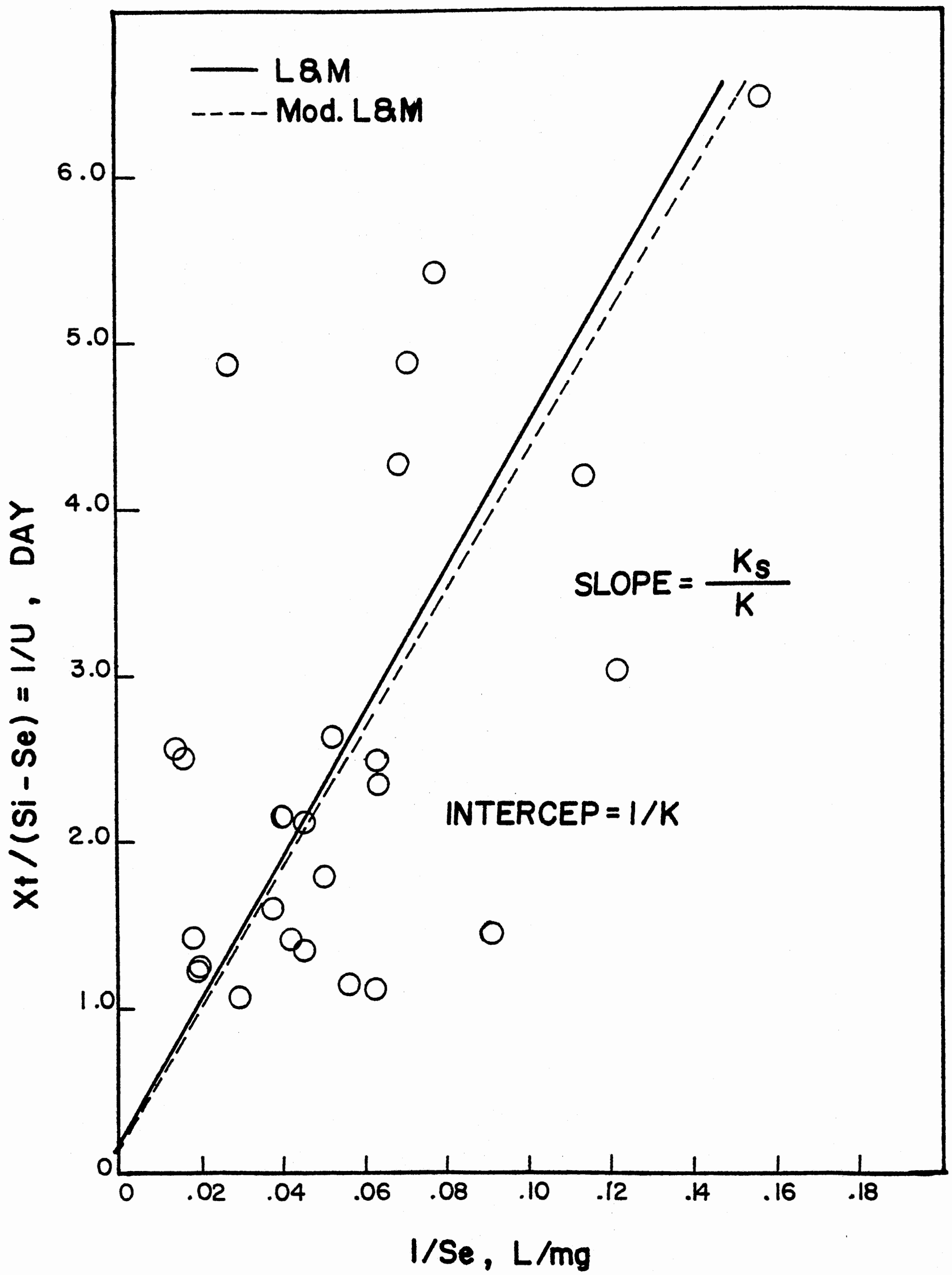

Figure 9. Plot Utilized to Determine the Biokinetic Constants, k and k_s for the Lawrence/McCarty Model and a 2-Propanol Influent

influents (single and combined substrate) and for all three substrate parameters (TOC, COD and BOD) are presented in Appendix A. This author has intentionally included all of the valid data collected when developing the plots presented in these figures. After years of research in the laboratories of the Bioenvironmental Engineering Department at Oklahoma State University, researchers have experienced various degrees of data scatter when attempting to fit pilot data to the existing models of Eckenfelder, Weston, McKinney, Lawrence and McCarty, and Gaudy. The plots shown here and in Appendix A are representative of those generated from studies involving other wastewaters. This data scatter is particularly difficult to cope with in the Lawrence and McCarty model where both an intercept and slope must be determined. Eckenfelder's model is generally easier to evaluate if one is certain that the organic substrate utilized is completely biodegradeable (intercept of zero). It can be seen, however, that the model of Kincannon and Stover shows considerably less data scatter with linear regression correlation coefficients of the data generally exceeding 0.9.

The biokinetic constants determined for the individual compound treatability and combined substrate treatability studies can be found in Tables XIV and XV respectively. Lawrence and McCarty's K_s is denoted as KS1, while KS2 is used to represent the term K_s in the modified Lawrence and McCarty model. This modified model is discussed further in Section 4.3.

4.3 Predictive Equations

The objective of this research was to estimate operational parameters (as mixed liquor volatile suspended solids and effluent substrate

TABLE XIV

BIOKINETIC CONSTANTS DETERMINED FOR THE SINGLE SUBSTRATE WASTEWATERS

	In Terms of TOC							
	Y_t	k_d days^{-1}	k_e' days^{-1}	U_{max} days^{-1}	K_B days^{-1}	k days^{-1}	K_{S1} Judgment mg/L	K_{S2} Assume U_m=k mg/L
Egg Albumen	.635	.025	4.32	4.46	4.6	2.86	146	233
Starch	1.04	.080	4.4	10.0	10.95	4.55	199	370
Sucrose	1.265	.115	5.22	11.9	12.51	2.5	63.1	366
2-Propanol	.673	.019	5.75	5.94	6.15	4.65	197	245
Oleic Acid	.944	.082	2.35	7.14	8.29	1.03	48.4	517
Cheer	1.14	.029	.184	0.537	1.08	.699	121	96.2
2-Nitrophenol	.668	.126	6.25	7.35	7.38	2.0	23.3	99.8
4-Chloro-3 Methyl Phenol	.897	.074	1.27	1.45	1.51	.769	23.8	54.9

	In Terms of COD							
	Y_t	k_d days^{-1}	k_e' days^{-1}	U_{max} days^{-1}	K_B days^{-1}	k days^{-1}	K_{S1} Judgment mg/L	K_{S2} Assume U_m=k mg/L
Egg Albumen	.245	.065	15.25	15.91	16.04			
Starch	.487	.135	8.7	50	55.25			
Sucrose	.513	.143	9.9	17.7	18.45			
2-Propanol	.239	.045	30.1	118.1	121.2			
Oleic Acid	.233	.138	18.93	47.17	49.76			
Cheer	.198	.02	1.25	2.34	3.15			
2-Nitrophenol	.213	.146	22	8.33	7.93			
4-Chloro-3-Methyl Phenol	.277	.052	4.37	21.6	22.9			

TABLE XIV (Continued)

	In Terms of BOD							
	Y_t	k_d days^{-1}	k_e' days^{-1}	U_{max} days^{-1}	K_B days^{-1}	k days^{-1}	K_{S1} Judgment mg/L	K_{S2} Assume U_m=k mg/L
Egg Albumen	.88	.125	6.0	4.785	4.717			
Starch	.962	.095	11.8	20	19.6			
Sucrose	.593	.034	6.26	31.06	32.7			
2-Propanol	.623	.091	11.46	5.893	5.890			
Oleic Acid	.399	.123	85	119	119.5			
Cheer	.41	.03	2.17	2.299	2.304			
2-Nitrophenol	.321	.103	38.9	29.77	29.57			
4-Chloro-3-Methyl Phenol	.562	.07	15	20	20.2			

TABLE XV

BIOKINETIC CONSTANTS DETERMINED FOR WASTEWATERS COMPOSED OF COMBINED SUBSTRATES

	In Terms of TOC								
	Y_t	k_d 1/day	k_e' 1/day	U_{max} 1/day	K_B	k 1/day	K_{S1} mg/l	K_{S2} mg/l	N
PRO/CHO	.95	.011	1.75	6.63	7.129	.71	175.7	1,706	23
Phenols	.519	.05	4.83	14.28	14.908	2.77	207.7	1,185	24
Oleic H+/Prop.	.962	.035	1.817	5.509	6.029	2.85	196	666.6	30
PRO/CHO	.795	.033	2.9	24.25	26.38	5.2	400	1,488	38
95 ppm each	.985	.073	2.52	2.301	2.318	6.66	528.8	177	30

	In Terms of COD								
	Y_t	k_d 1/day	k_e' 1/day	U_{max} 1/day	K_B	k 1/day	K_{S1} mg/l	K_{S2} mg/l	N
PRO/CHO	.23	0	6.54	49.44	52.31	--	--	--	8
Phenols	.14	.015	24.9	122.4	127.8	--	--	--	10
Oleic H+/Prop.	.29	.03	5.0	13.3	14.25	--	--	--	15
PRO/CHO	.319	.039	7.24	50	53.5	--	--	--	13
95 ppm each	.333	.065	9.94	36.76	38.78	--	--	--	13

TABLE XV (Continued)

	In Terms of BOD								
	Y_t	k_d 1/day	k_e' 1/day	U_{max} 1/day	K_B	k 1/day	K_{S1} mg/l	K_{S2} mg/l	N
PRO/CHO	.525	0	36.75	75.6	76.02	--	--	--	6
Phenols	.304	0	112.6	436	437.5	--	--	--	9
Oleic H+/Prop.	.775	0	6.89	3.09	2.925	--	--	--	15
PRO/CHO	.47	0	13	25.85	26.26	--	--	--	12
95 ppm each	.906	.09	7.6	5.52	5.45	--	--	--	17

concentration) based upon a knowledge of the compounds comprising the influent (as well as their concentration) and operating conditions as SRT and influent flow rate.

For all of the models considered, it was elected to draw mass balances around the aeration basin and the clarifier as a unit rather than to isolate the aeration basin and include terms for clarifier sludge underflow concentration and flow rate. The equations utilized for the prediction of X and Se by the various models are presented in Table XVI. The Kincannon/Stover and Eckenfelder mass balance, steady state equations for X and Se may be reduced to a set of two equations and two unknowns. The Eckenfelder equation for X takes the form of a quadratic equation. For both the Eckenfelder and Kincannon/Stover models, it can be seen that Se is some direct function of Si. For reasons which will be discussed later, X was determined first and the resultant X was utilized to determine S_e.

All of the models studied incorporate the same mass balance for biomass, and, in terms of S_e, should appear as follows:

$$S_e = S_i - ((\frac{1}{SRT} + k_d) \times t/Y_t)$$

This author was able to solve for X in terms of the biokinetic constants and the controlled parameters F, S_i, and V by:

1. Solving the substrate mass balance for either the Eckenfelder or Kincannon/Stover model in terms of X and,
2. Substituting the above expression for S_e every time S_e appeared in the equation.

The Lawrence and McCarty model allows calculations of X and Se by utilization of two independent equations. Here, Se is a function of SRT and no term for X appears in the equation for Se. Since both the

TABLE XVI

EQUATIONS UTILIZED FOR THE SIMULTANEOUS PREDICTION OF X AND S_e

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Kincannon and Stover Model

$$X = S_iF(Y_tU_{max}-(1/SRT+K_d))/VK_B(1/SRT+K_d)$$

$$S_e = S_i(1-U_{max}/\ (K_B+\frac{FS_i)}{XV}$$

Eckenfelder

$$X = -b/a$$

$$a = -(1/SRT+K_d)V^2k'_e/S_iY_tF^2$$

$$b = V/F(k'_e-(1/SRT+k_d)/Y_t)$$

$$S_e = S_i/\ \frac{(k'_eXV)}{FS_i} + 1$$

Lawrence and McCarty

$$X = \frac{Y_tF}{V} \quad \frac{S_i}{(1/SRT+k_d)} - \frac{K_s}{Y_tk-(1/SRT+k_d)}$$

$$S_e = K_s(1/SRT+k_d)/(Y_tk-(1/SRT+k_d))$$

Modified Lawrence and McCarty

$$X = \frac{Y_tF}{V} \quad \frac{S_i}{(1/SRT+k_d)} - \frac{K_s}{Y_tU_{max}-(1/SRT+k_d)}$$

$$S_e = K_s(1/SRT+k_d)/(Y_tk-(1/SRT+k_d))$$

Lawrence/McCarty and Kincannon/Stover models possess a term for maximum substrate utilization rate (albeit as a function of two separate entities) two versions of the Lawrence/McCarty equation were used. First, k and K_s were determined in the conventional manner for this model. The second method (termed the modified Lawrence and McCarty model) involved replacement of k with the Kincannon/Stover U_{max} and redrawing the slope line with subsequent recalculation of K_s. This author rationalizes this modification by suggesting that a given microbial population possesses but one maximum specific substrate utilization rate. Argument concerning whether this maximum rate is more a function of Se or F/M does not seem to detract from the fact that there should be just one maximum specific substrate utilization rate. If it is assumed that this maximum substrate utilization rate should be the same regardless of which model is employed, the determination of k by the Kincannon/Stover model is obviously more reliable in that there is less data scatter.

4.4 Predictive Techniques

An overall strategy for assimilating the data compiled during these investigations was formulated and consisted of testing the following three working hypotheses:

1. Weighted Constant Assumption
2. Discreet Compound Treatability Assumption
3. Total VSS Treatability Assumption

4.4.1 Weighted Constant Assumption

The reasoning behind this predictive hypothesis is that composite biokinetic constants can be determined for any given combination of influent constituents. These composite or weighted constants can then be used for predicting the activated sludge treatment of that particular combination of influent compounds. The following steps were employed to determine each weighted constant:

1. Each of the eight (8) influent compounds was expressed in terms of the concentration of substrate parameter (either TOC, COD or BOD) that each exerted in the influent mixture using conversion factors determined in the laboratory (Table XVII).
2. The total influent concentration for the substrate parameter being considered was equal to the sum of those exerted by the eight (8) individual compounds.
3. A weighted constant was composed of a summation of the eight (8) individual weighting units. A weighting unit consisted of the biokinetic constant determined for a particular constituent during the single substrate studies multiplied by the fraction of the total influent organic concentration that was exerted by the particular compound.

A simplified example for the calculation of a weighted true yield in terms of TOC for feed constituents A, B and C follows:

Compound	Y_t Determined From Single Substrate Study	Influent Compound Conc. In Combined Unit	TOC Conversion Factor	Influent TOC Conc. In Combined Unit
A	Y_A	C_A	F_A	$C_A \cdot F_A$
B	Y_B	C_B	F_B	$C_B \cdot F_B$
C	Y_C	C_C	F_C	$C_C \cdot F_C$
			Total	$Si(TOC)$

$$\text{Weighted } Y_t = Y_A\left(\frac{C_A \cdot F_A}{Si(TOC)}\right) + Y_B\left(\frac{C_B \cdot F_B}{Si(TOC)}\right) + Y_C\left(\frac{C_C \cdot F_C}{Si(TOC)}\right)$$

TABLE XVII

CONVERSION FACTORS FOR CALCULATING MG/L OF INDICATED ANALYSIS FROM MG/L COMPOUND

Compound	TOC	COD	BOD
Egg Albumen	.423	.963	.270
Starch	.400	.901	.412
Sucrose	.425	.992	.580
2-Propanol	.560	2.085	.590
Oleic Acid	.434	1.855	.961
Cheer	.083	.26	.0947
2-Nitrophenol	.467	1.079	.559
4-Chloro-3-Methyl Phenol	.557	1.468	.830

This predictive technique is similar to that employed by Kincannon et al. (21) but does contain two significant modifications. First, all of the organic constituents of the feed mixture were considered. Second, the compound concentrations were converted to the substrate parameter under consideration.

4.4.2 Discreet Compound Treatability Assumption

The reasoning behind this technique is that each influent constituent is capable of supporting a specified amount of biomass. If it is assumed that the biomass produced is acclimated solely to the metabolism of that specific substrate from which it was generated, then the treatment of the combined substrate wastewaters can be envisioned as a conglomeration of eight individual (discreet) treatment systems. In other words, the treatability of any particular influent constitutent can only be facilitated by the biomass produced from that particular influent constituent. The biomass produced from the metabolism of a certain compound can be described by operational conditions and the biokinetic constants determined from the individual compound studies. A prediction of the total volatile suspended solids (VSS) in any combined substrate treatment system would be a summation of the VSS production predicted for each of the eight discreet treatability systems. Similarly, the summation of the effluent substrate concentrations predicted for each of the eight individual treatment systems would serve as the combined substrate unit prediction for Se. An example follows:

Compound	VSS	Se
	Prediction of indicated parameter based upon the constants derived from individual compound treatability studies.	
A	X_A	$S_A = fn(X_A)$*
B	X_B	$S_B = fn(X_B)$*
C	X_C	$S_C = fn(X_C)$*
Combined Unit Predictions	X_{Tot}	S_{Tot}

*Note: Except Lawrence and McCarty models where S = fn(SRT).

The set of biokinetic constants employed in the prediction of X and Se is dependent upon the particular feed constituent under consideration and the substrate parameter of concern.

4.4.3 Total VSS Treatability Assumption

This predictive technique is similar to the discreet compound treatability technique in that the metabolism of all eight compounds is considered to be a summation of eight different treatability systems. Unlike the discreet compound approach, though, the assumption is made that all volatile suspended solids present are utilized to metabolize all eight substrates sequentially. First, MLVSS predictions were made for the eight influent components at the given operating condition. When determining the amount of residual substrate produced for each influent constituent, the X value utilized is considered to be the total VSS present in the reactor. An example follows:

	Prediction of indicated parameter based upon the constants derived from individual compound treatability studies.	
Compound	VSS	Se
A	X_A	$S_A = fn(X_{Tot})$*
B	X_B	$S_B = fn(X_{Tot})$*
C	X_C	$S_C = fn(X_{Tot})$*
	X_{Tot}	S_{Tot}

*Note: Except for the Lawrence and McCarty models where S = fn(SRT).

As indicated in the notation for the examples illustrating the discreet compound and total VSS techniques, when employing the Lawrence and McCarty model, the predicted value for Se will be the same regardless of which of these two treatability assumptions is used. This is due to the fact that biomass is not considered in the equation utilized to calculate Se in the Lawrence and McCarty model

$$Se = \frac{Ks(1/SRT + kd)}{Y_t k - (1/SRT + kd)}$$

4.5 Results of Predictions

A Texas Instruments 99/4A home computer was programmed to accommodate the models and assumptions used to make the predictions presented in this section. All three predictive hypotheses (assumptions) were employed in terms of the three substrate parameters. For TOC, the Kincannon/Stover, Eckenfelder and Lawrence/McCarty models were utilized. The Lawrence/McCarty model was modified by substituting the more readily determined Kincannon/Stover U_{max} for k. This technique will be referred to as the modified Lawrence and McCarty model.

Relatively poor predictive capability was demonstrated by both the Lawrence/McCarty and the modified Lawrence/McCarty models for the TOC substrate parameter. Therefore, further consideration of these models for the COD and BOD operational data was not thought to be productive. Figure 10 presents a simplified flow chart illustrating the format of the computer program employed.

Before actually presenting the predictive results, a review of the operating data (VSS, Se) for the fifteen combined substrate test conditions (Table XIII) should be made. The ranges in VSS and Se concentrations that must be accounted for by the models and assumptions will now be discussed. For the combined substrate influent mixtures and operating conditions studied, mean volatile suspended solids concentrations ranged from 1,800 to 17,000 mg/L. The effluent substrate data collected for the 10 day SRT unit receiving combined substrate influent No. 1 (carbohydrate and protein) did not appear to be reasonable. Therefore, these results are not considered in subsequent analyses. For the remaining fourteen operating conditions, ranges of the mean effluent substrate concentrations for the three substrate parameters TOC, COD and BOD follow:

TOC	11-30 mg/L
COD	26-80 mg/L
BOD	1.6-10.9 mg/L

Classification of mean values (plus or minus one standard deviation) as being low, intermediate or high (relative to all fourteen or fifteen operational conditions tested) can be made. If this is done, TOC and COD results exhibit close agreement with Condition 2 (phenol), SRT = 4 days and Condition 3 (2-propanol and oleic acid), SRT = 4 days falling in the high range classification while Condition 4 (carbohydrate and protein), SRT = 7 days could be classified as a low range substrate

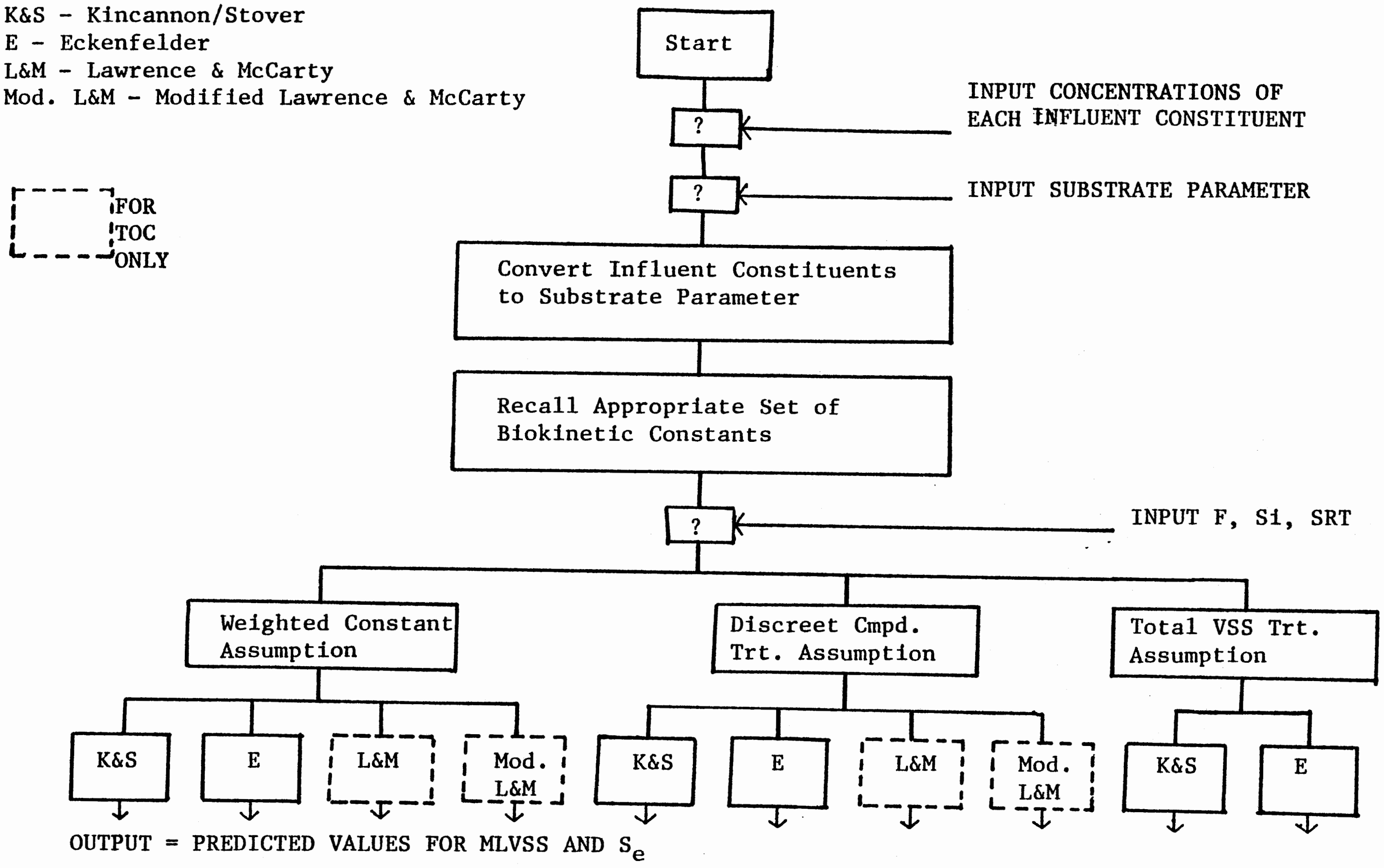

Figure 10. Flow Chart of Computer Program Utilized to Predict X and S_e for Various Predictive Techniques

level. Additionally, Conditions 4 and 5 (equal COD for all compounds), SRT = 12 yielded low range effluent substrate TOC values. All other conditions could be considered as producing intermediate range effluent quality for TOC and COD. As with TOC and COD, effluent BOD values for Condition 4, SRT = 12 can be classified as relative low range. Other lows and highs for effluent BOD concentrations do not correspond as well with TOC and COD data. Condition 2, SRT = 10 and SRT = 7 can be considered as producing low effluent BOD concentrations while Condition 4, SRT = 4 would have to be considered high. This description of the actual operating data for VSS and Se presents a perspective from which the appropriateness of each predictive technique can be evaluated.

4.5.1 Simultaneous Predictions of X and Se

For purposes of design and scale-up of activated sludge treatment facilities, estimates of both X and Se must be extrapolated from pilot data. In this section, predictive results obtained from the simultaneous prediction of X and Se will be examined for the various predictive techniques.

The results of the simultaneous predictions of X and Se obtained from each of the predictive techniques are presented for all fifteen combined unit operating conditions in Tables XVIII, XIX and XX. For comparison, the experimentally observed (observed) mean values for VSS and Se are shown in the right-hand column. Figures 11 through 20 graphically illustrate the same results. The observed mean values of VSS and Se are noted by dark bars. The shaded area represents the mean value plus or minus one standard deviation. The value of the prediction is

TABLE XVIII

SIMULTANEOUS PREDICTIONS OF S_e AND MLVSS BASED UPON TOC FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

		Predictive Technique Employed											
		Weighted Constants				Discreet Compound Treatability Technique				Total VSS Technique			
Wastewater Composition	SRT	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod. Law. & McCarty	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod. Law. & McCarty	Kincannon & Stover	Ecken-felder	Observed	
1. High Protein and Carbohydrate Content: High Organic Concentration	7	6,552	6,900	7,118	7149	5,836	5,784	5,303	5,159	5,837	5,784	4,795	VSS
		42	23	10.8	9.1	71	69	108	114	53	14.1	21.3	TOC
	10	8,493	8,999	9,232	9,259	7,699	8,029	7,750	7,618	7,700	8,029	12,090	VSS
		42	19	8.3	7.1	70	54	78	83	55	11.3	51	TOC
	15	9,759	10,384	10,578	10,604	9,053	9,797	9,366	9,229	9,054	9,797	17,338	VSS
		35	13.3	6.6	5.7	58	36	59	63	48	7.6	23	TOC
2. High Phenol Content: High Organic Concentration	4	3,855	3,964	4,197	4,237	3,339	3,190	2,350	2,407	3,339	3,190	3,039	VSS
		47	38	17.3	13.8	83	91	168	162	47	20	20	TOC
	7	5,313	5,538	5,754	5,784	4,782	4,730	4,100	3,963	4,782	4,731	3,909	VSS
		38.5	24.5	11	9.2	65.4	64.8	105.5	111.5	42.8	12.7	25.6	TOC
	10	7,607	7,970	8,245	8,273	6,996	7,215	6,827	6,691	6,997	7,215	6,698	VSS
		40	22.2	8.8	7.4	67.1	56.9	79.5	84.6	46.8	11.1	22.3	TOC
3. High Fatty Acid & Alcohol Content: Low Organic Concentration	4	1,905	1,985	1,973	1,979	1,759	1,753	896	916	1,759	1,754	2,126	VSS
		22.8	15.9	16.9	16.4	31.4	30.4	108.5	106.5	19.8	5.3	22.1	TOC
	7	2,534	2,674	2,645	2,645	2,391	2,440	1,498	1,467	2,392	2,441	3,514	VSS
		16.9	8.9	10.6	10.6	22.6	18.8	74.5	76.3	16.2	2.9	21.5	TOC
	12	4,168	4,428	4,421	4,419	4,049	4,272	3,064	2,997	4,050	4,273	4,552	VSS
		17.2	7	7.3	7.4	22.6	14.4	60.3	63.2	17.7	2.1	18.3	TOC

TABLE XVIII (continued)

		Predictive Technique Employed											
		Weighted Constants				Discreet Compound Treatability Technique				Total VSS Technique			
Wastewater Composition	SRT	Kincannon & Stover	Eckenfelder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Eckenfelder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Eckenfelder	Observed	
4. High Protein and Carbonate Content: Low Organic Content	4	1,953	2,011	1,983	2,016	1,818	1,825	1,046	1,081	1,818	1,826	1,785	VSS
		18	13.4	15.6	13	25.7	24.2	96.4	93.4	15.7	4	23.1	TOC
	7	3,043	3,174	3,151	3,180	2,875	2,937	1,992	2,023	2,876	2,937	3,227	VSS
		15.6	8.9	10.1	8.5	21.3	17.4	70.6	68.9	14.9	2.6	11.1	TOC
	12	4,128	4,336	4,318	4,343	3,979	4,177	3,072	3,079	3,980	4,178	4,637	VSS
		14.3	6.4	7.1	6.1	19	11.9	54	53.9	14.6	1.8	12.2	TOC
5. All Compounds Added To Give Equal COD Concentrations: Low Organic Concentration	4	2,026	2,085	2,081	2,123	1,758	1,684	687	763	1,739	1,684	2,180	VSS
		21.6	16.8	17.1	13.8	38.2	41.7	128.1	121.6	22.3	8.6	23.8	TOC
	7	3,548	3,703	3,711	3,749	3,192	3,171	1,848	1,879	3,193	3,172	3,940	VSS
		18.3	11	10.6	8.8	31.5	30.7	92.8	91.4	21.4	5.5	21.6	TOC
	12	4,201	4,413	4,426	4,455	3,906	4,111	2,834	2,697	3,906	4,111	4,528	VSS
		16.7	8.1	7.6	6.4	28.3	21.4	68.3	72.8	21	3.9	12.3	TOC

TABLE XIX

SIMULTANEOUS PREDICTIONS OF S_e AND MLVSS BASED UPON COD FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

		Predictive Technique Employed											
		Weighted Constants				Discreet Compound Treatability Technique				Total VSS Technique			
Wastewater Composition	SRT	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Observed	
1. High Protein and Carbohydrate Content: High Organic Concentration	7	5,224	5,316			4,744	4,724			4,744	4,725	5,041	VSS
		75	57			159	166			94	28	70	COD
	10	9,170	9,396			8,473	8,622			8,473	8,622	12,093	VSS
		101	67			201	180			130	31	97	COD
	15	9,087	9,361			8,602	8,917			8,602	8,918	16,616	VSS
		79	45			147	111			104	20	74	COD
2. High Phenol Content: High Organic Concentration	4	3,959	3,924			3,565	3,334			3,566	3,334	2,527	VSS
		95.4	105.2			220.1	284.7			94.1	47.2	80	COD
	7	5,990	6,047			5,591	5,472			5,592	5,472	3,998	VSS
		94.2	82.1			193.7	214.4			99.4	34.8	55	COD
	10	7,236	7,349			6,880	6,861			6,880	6,861	6,604	VSS
		86.8	67.7			169.9	168.9			94.1	27.8	65	COD
3. High Fatty Acid & Alcohol Content: Low Organic Concentration	4	1,882	1,869			1,769	1,726			1,770	1,727	2,082	VSS
		33.1	37.3			68.2	82.1			35.3	11.5	73	COD
	7	2,341	2,357			2,256	2,256			2,257	2,256	3,314	VSS
		24.7	21.3			46.5	46.3			28.4	6.3	61	COD
	12	3,624	3,679			3,604	3,668			3,605	3,668	4,634	VSS
		25.8	17.7			45.4	36			31.1	5	61	COD

TABLE XIX (continued)

Wastewater Composition	SRT	Predictive Technique Employed											
		Weighted Constants				Discreet Compound Treatability Technique				Total VSS Technique			
		Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Observed	
4. High Protein and Carbonate Content: Low Organic Content	4	1,859	1,867			1,732	1,707			1,732	1,708	1,879	VSS
		34	32.3			58.4	66.5			29.9	9.8	57	COD
	7	2,939	2,999			2,772	2,797			2,773	2,797	3,401	VSS
		32.5	23.8			50.1	47.6			30.3	6.9	26	COD
	12	3,573	3,677			3,423	3,509			3,423	3,510	4,695	VSS
		30.6	18			43.6	33.4			29.7	5.1	41	COD
5. All Compounds Added To Give Equal COD Concentrations: Low Organic Concentration	4	1,907	1,892			1,698	1,609			1,698	1,609	2,249	VSS
		40.6	44.6			100.8	126.3			42.9	18.8	47	COD
	7	3,319	3,356			3,066	3,033			3,067	3,034	4,289	VSS
		35.3	29.6			76.6	81.1			40.3	11.8	34	COD
	12	3,824	3,899			3,646	3,705			3,646	3,706	4,684	VSS
		32.9	22.7			65.5	57			39.2	8.7	43	COD

TABLE XX

SIMULTANEOUS PREDICTIONS OF S_e AND MLVSS BASED UPON BOD FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

		Predictive Technique Employed											
		Weighted Constants				Discreet Compound Treatability Technique				Total VSS Technique			
Wastewater Composition	SRT	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Lawrence & McCarty	Mod.Law. & McCarty	Kincannon & Stover	Ecken-felder	Observed	
1. High Protein and Carbohydrate Content: High Organic Concentration	7	5,372	5,388			5,296	5,259			5,296	5,264	5,041	VSS
		9.3	7.8			24	25.4			4.9	4.0	3.3	BOD
	10	8,122	8,155			8,137	8,111			8,138	8,112	11,558	VSS
		10	7.6			23	23.7			5.2	3.8	5.5	BOD
	15	8,091	8,131			8,282	8,278			8,283	8,279	16,525	VSS
		7.1	4.9			14.6	14.5			3.7	2.4	10.7	BOD
2. High Phenol Content: High Organic Concentration	4	3,536	3,537			3,429	3,408			3,429	3,409	2,495	VSS
		13.7	13.5			36.7	38.4			6.3	5	2.6	BOD
	7	4,413	4,422			4,381	4,372			4,381	4,372	3,751	VSS
		8.7	7.7			20.6	20.7			4.1	2.8	2.3	BOD
	10	5,767	5,783			5,805	5,802			5,805	5,803	6,564	VSS
		7.7	6.4			17.1	16.7			3.7	2.3	1.6	BOD
3. High Fatty Acid & Alcohol Content: Low Organic Concentration	4	1,149	1,151			1,117	1,123			1,117	1,123	2,145	VSS
		3.4	3.1			10.5	9.3			2.7	1.4	9.6	BOD
	7	1,074	1,479			1,473	1,483			1,473	1,483	3,640	VSS
		2.3	1.8			6.2	5.1			1.8	0.8	5	BOD
	12	3,723	3,739			3,830	3,859			3,830	3,860	4,634	VSS
		3.7	2.5			8.9	6.8			3	1.1	3.5	BOD

TABLE XX (continued)

Wastewater Composition	SRT	Predictive Technique Employed: Weighted Constants: Kincannon & Stover	Weighted Constants: Ecken-felder	Weighted Constants: Lawrence & McCarty	Weighted Constants: Mod.Law. & McCarty	Discreet Compound Treatability Technique: Kincannon & Stover	Discreet Compound Treatability Technique: Ecken-felder	Discreet Compound Treatability Technique: Lawrence & McCarty	Discreet Compound Treatability Technique: Mod.Law. & McCarty	Total VSS Technique: Kincannon & Stover	Total VSS Technique: Ecken-felder	Observed	
4. High Protein and Carbonate Content: Low Organic Content	4	2,136	2,141			2,094	2,068			2,095	2,068	1,879	VSS
		8.1	7.5			13.6	15.8			3.6	3.1	11	BOD
	7	3,052	3,073			3,037	3,024			3,037	3,024	3,401	VSS
		6.1	4.6			9	9.4			2.9	1.9	6.3	BOD
	12	3,491	3,525			3,541	3,546			3,542	3,546	4,652	VSS
		4.9	3.1			6.3	5.9			2.4	1.2	2.1	BOD
5. All Compounds Added To Give Equal COD Concentrations: Low Organic Concentration	4	1,479	1,482			1,428	1,419			1,428	1,419	2,217	VSS
		5.5	5.2			14.6	15.3			2.7	2	10.3	BOD
	7	2,544	2,555			2,523	2,521			2,523	2,521	3,855	VSS
		4.3	3.4			9.7	9.5			2.2	1.3	9.4	BOD
	12	2,974	2,990			3,025	3,032			3,025	3,033	4,386	VSS
		3.7	2.6			7.4	6.9			1.9	0.9	3.8	BOD

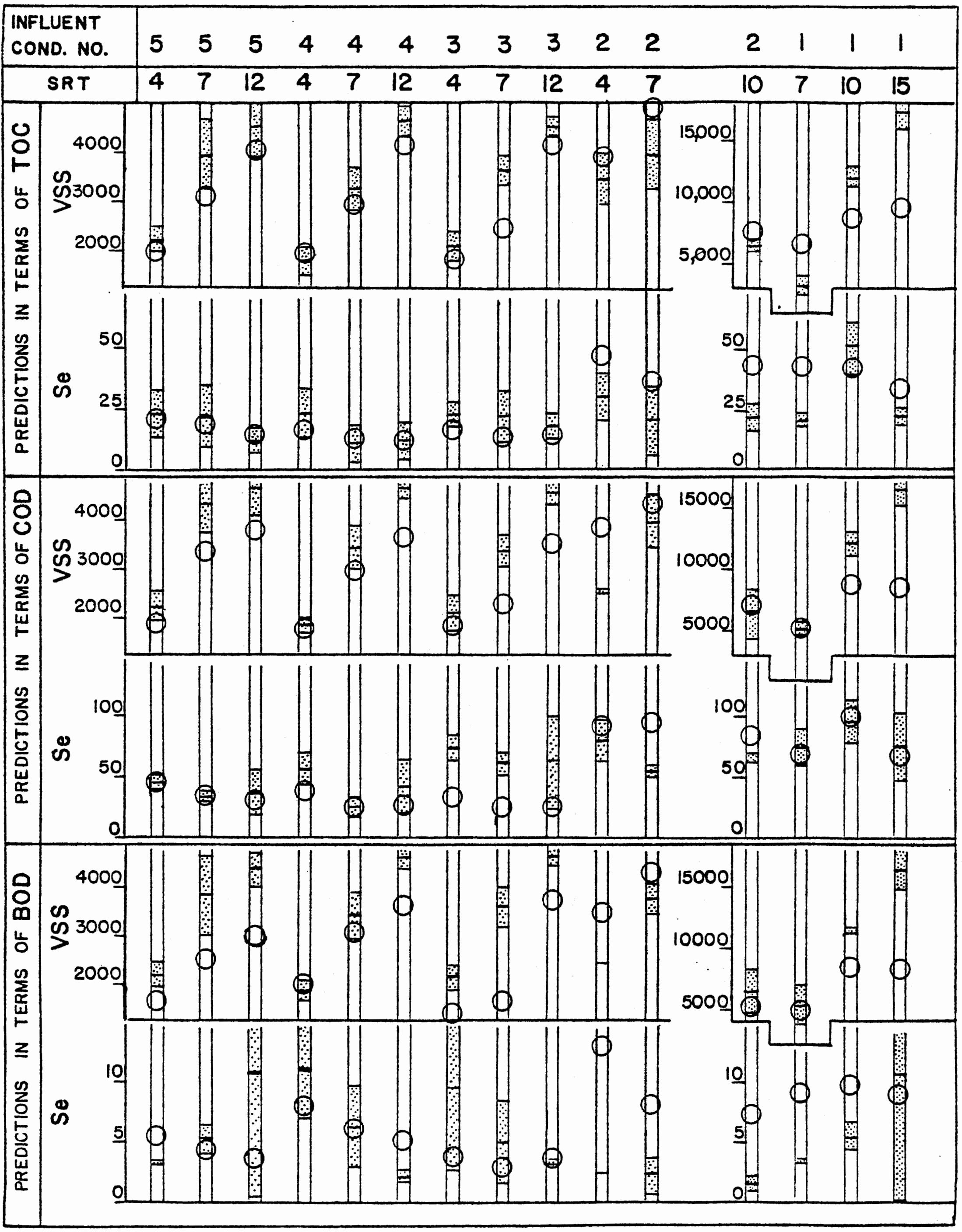

Figure 11. Simultaneous Predictions of X and S_e (in MG/L); Weighted Constant Assumption; Kincannon/Stover Model

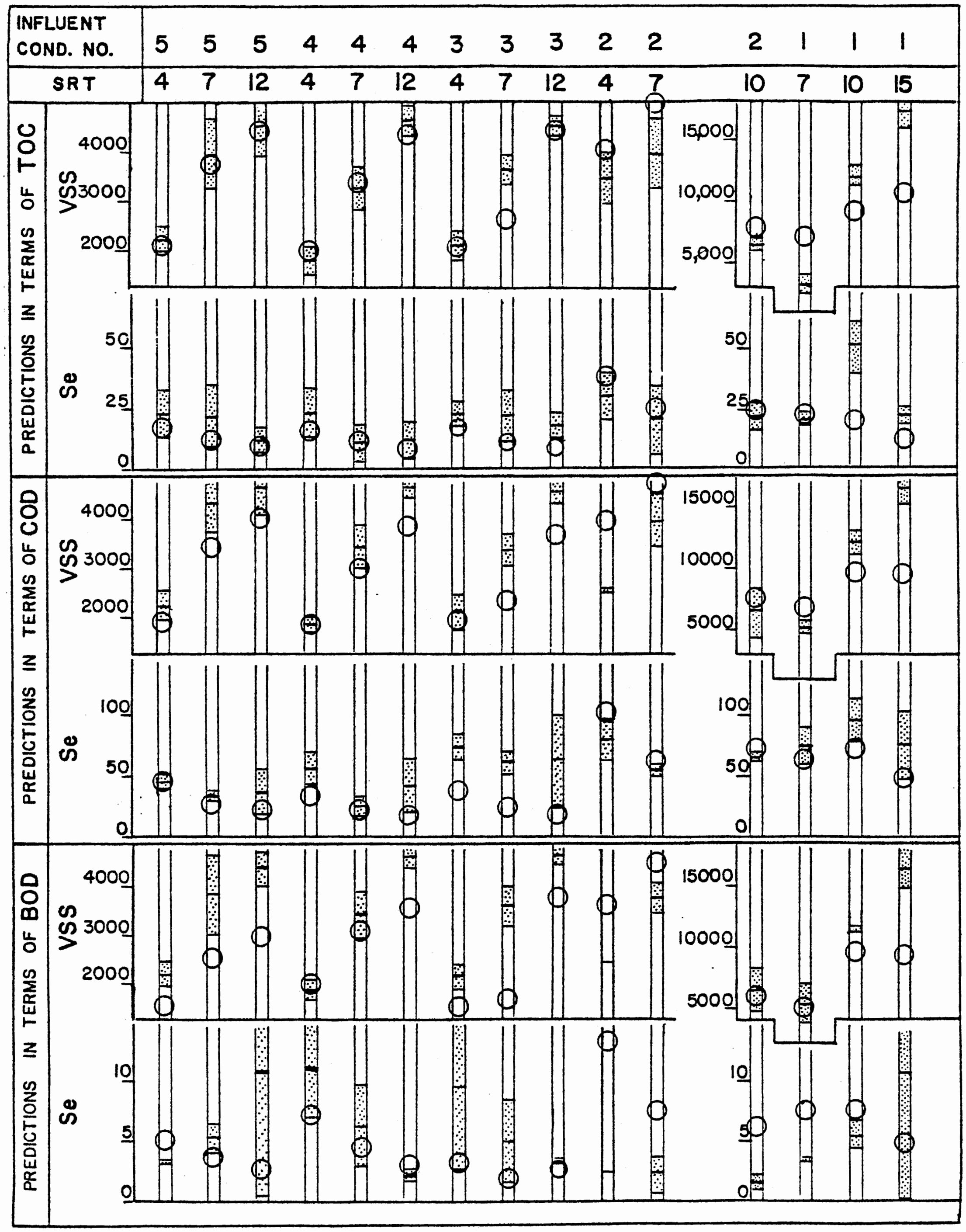

Figure 12. Simultaneous Predictions of X and S_e (in MG/L); Weighted Constant Assumption; Eckenfelder Model

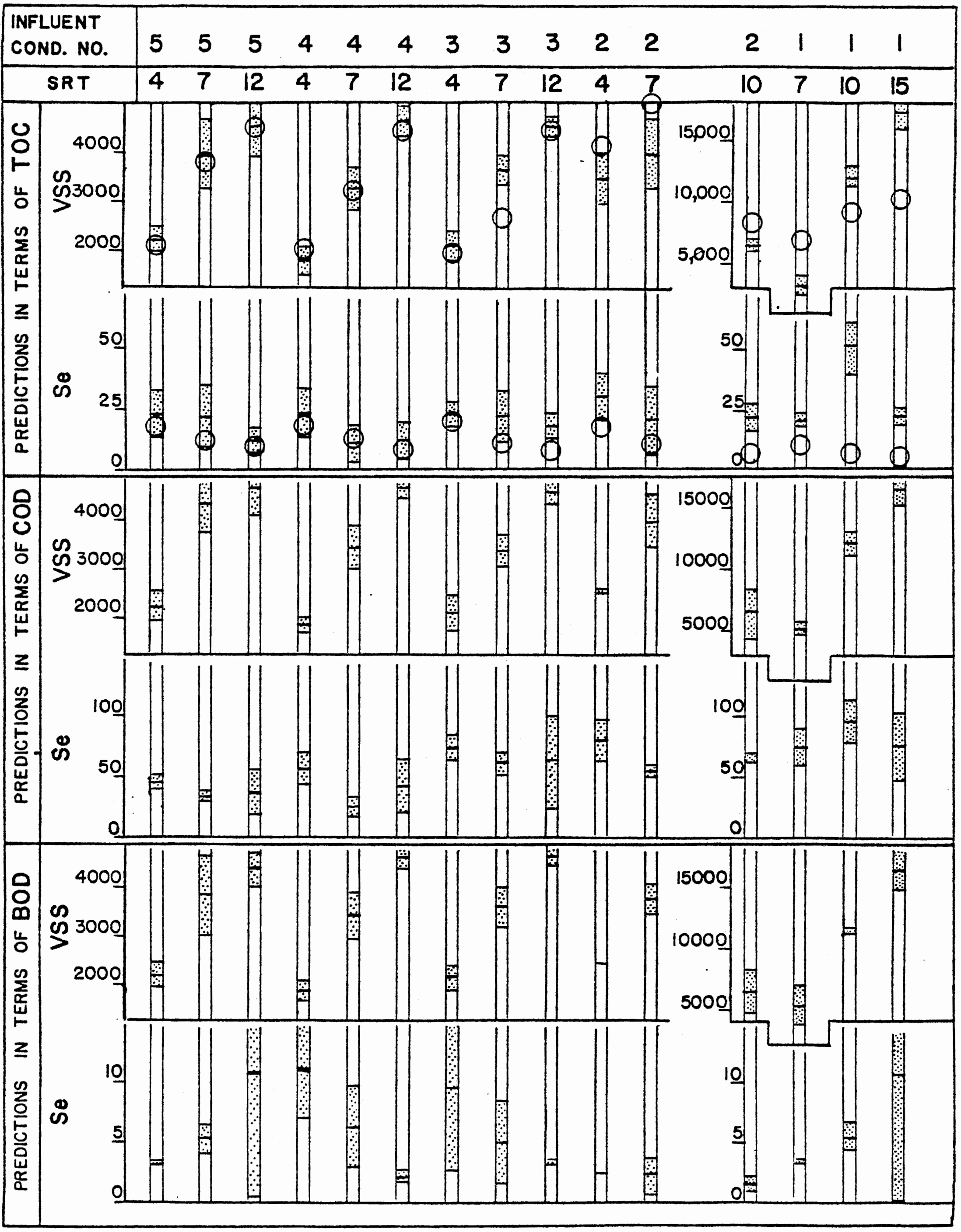

Figure 13. Simultaneous Predictions of X and S_e (MG/L); Weighted Constant Assumption; Lawrence/McCarty Model

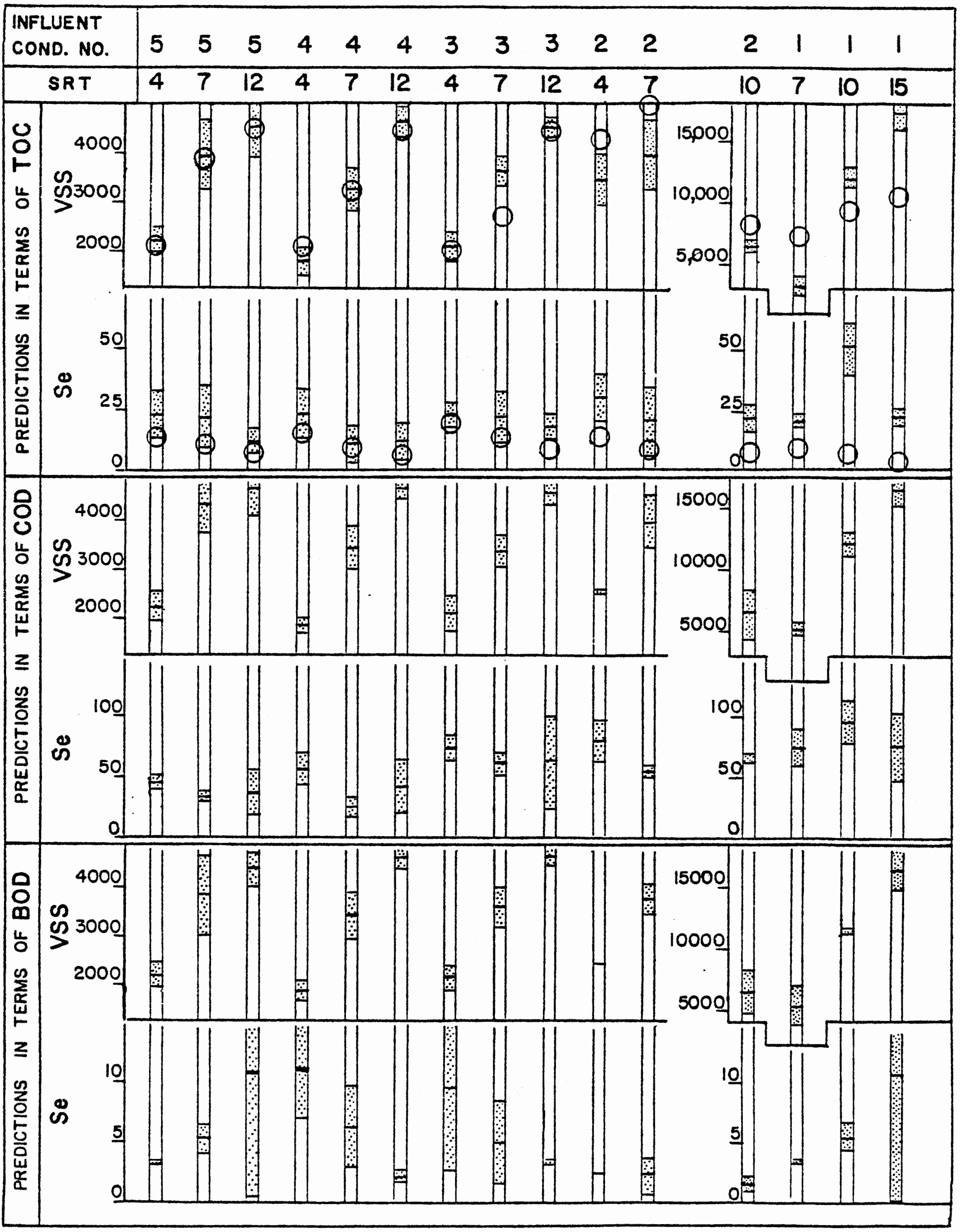

Figure 14. Simultaneous Predictions of X and S_e (MG/L); Weighted Constant Assumption; Modified Lawrence/McCarty Model

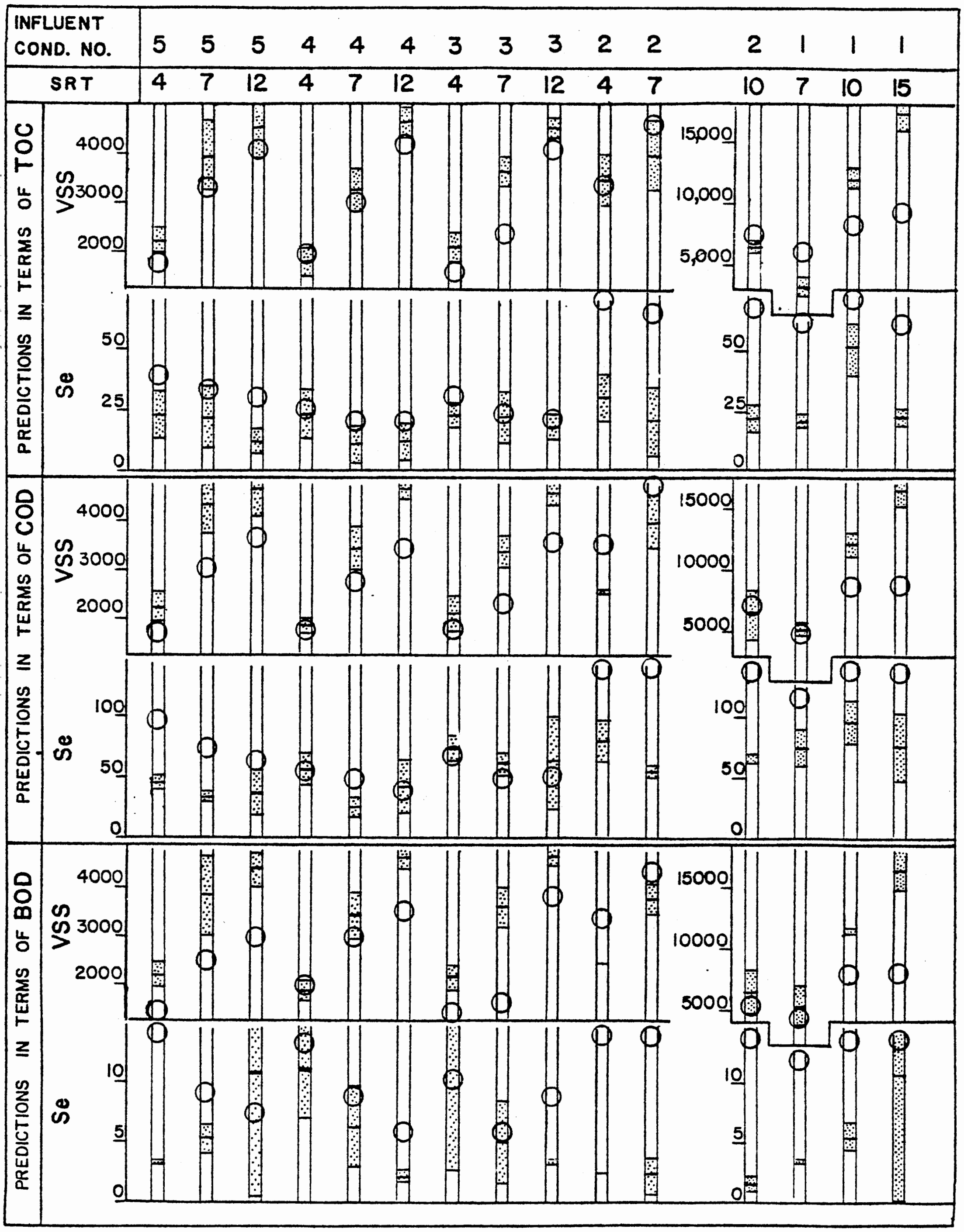

Figure 15. Simultaneous Predictions of X and S_e (MG/L); Discreet Compound Treatability Assumption; Kincannon/Stover Model

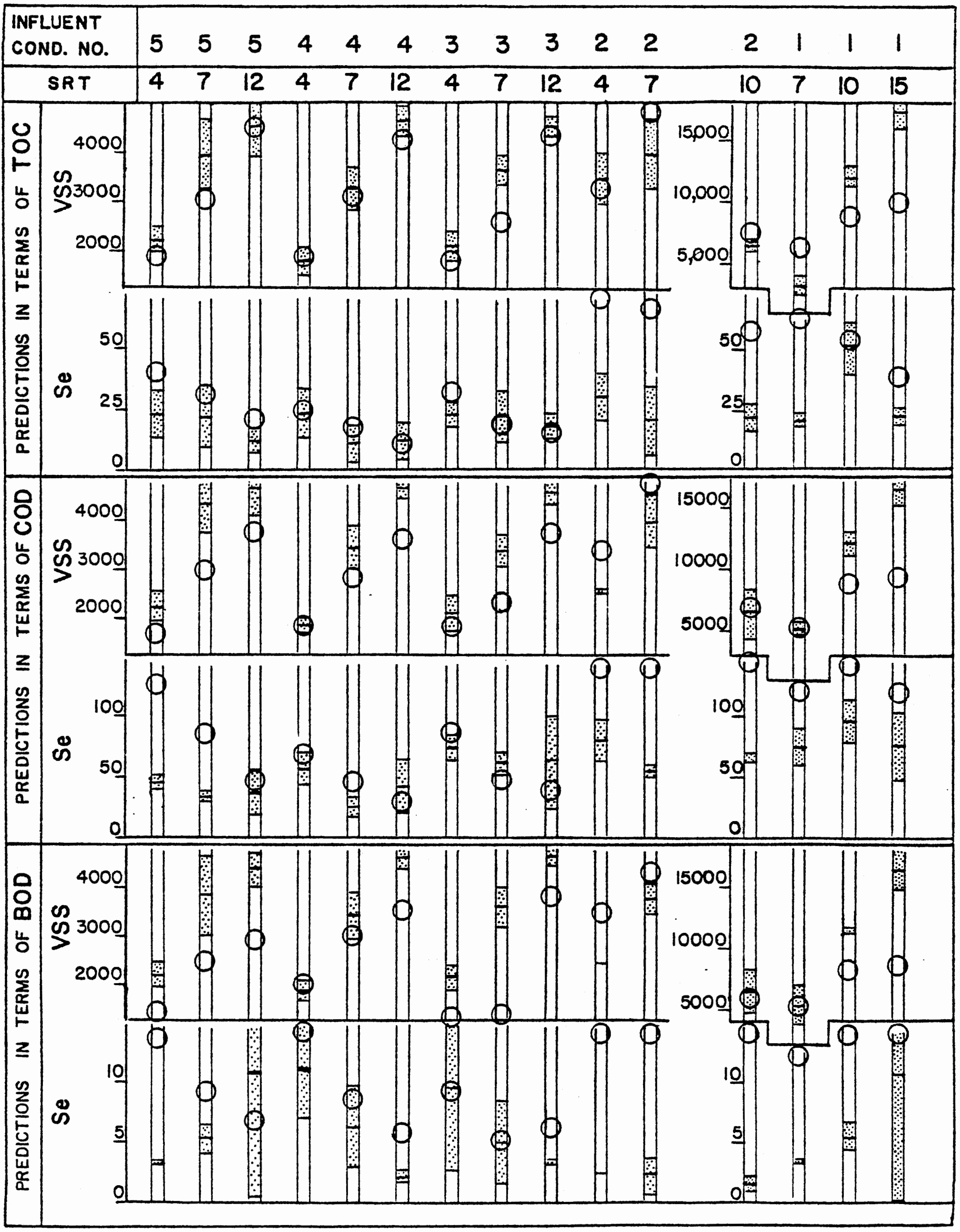

Figure 16. Simultaneous Predictions of X and S_e (MG/L); Discreet Compound Treatability Assumption; Eckenfelder Model

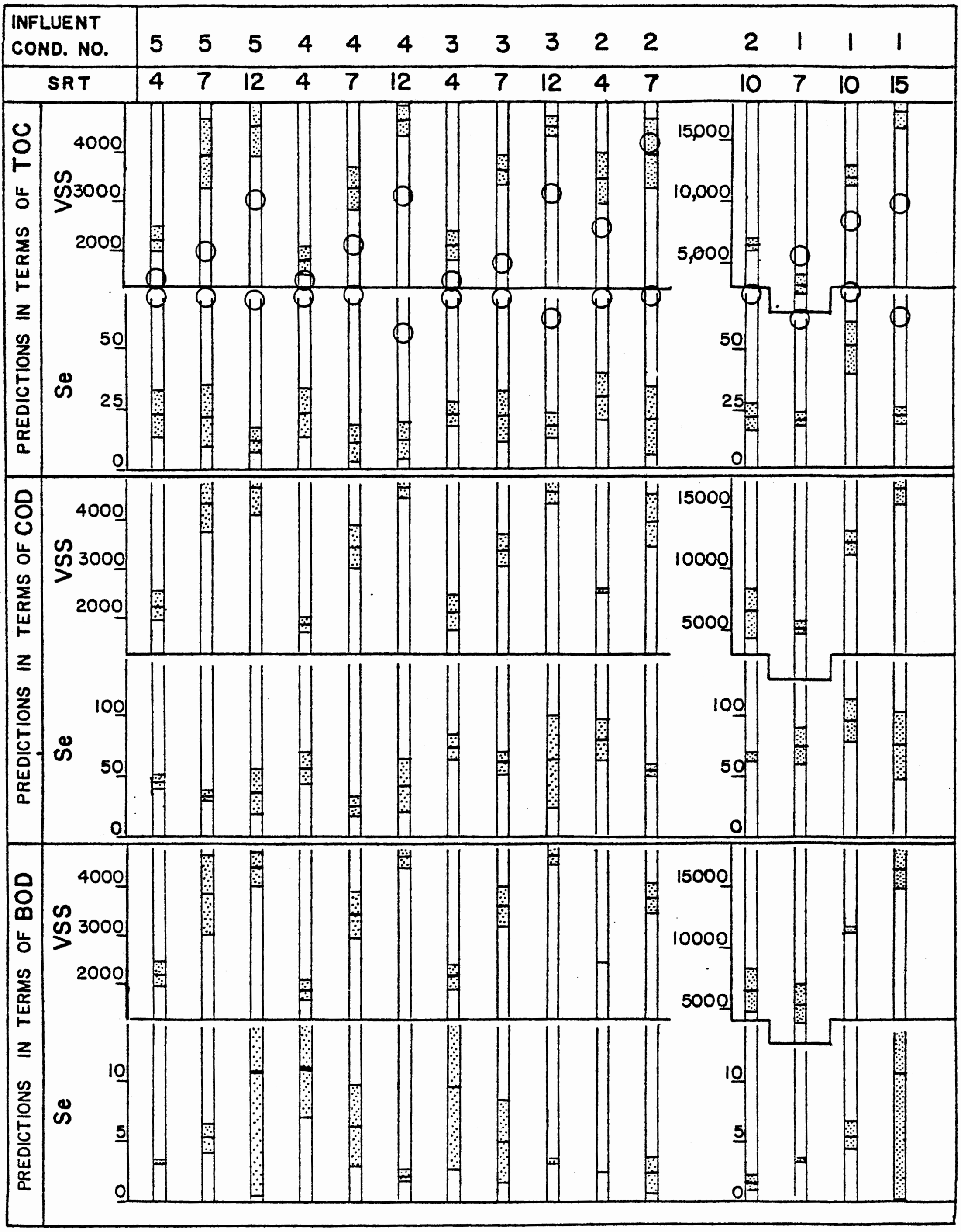

Figure 17. Simultaneous Predictions of X and S_e (MG/L); Discreet Compound Treatability Assumption; Lawrence/McCarty Model

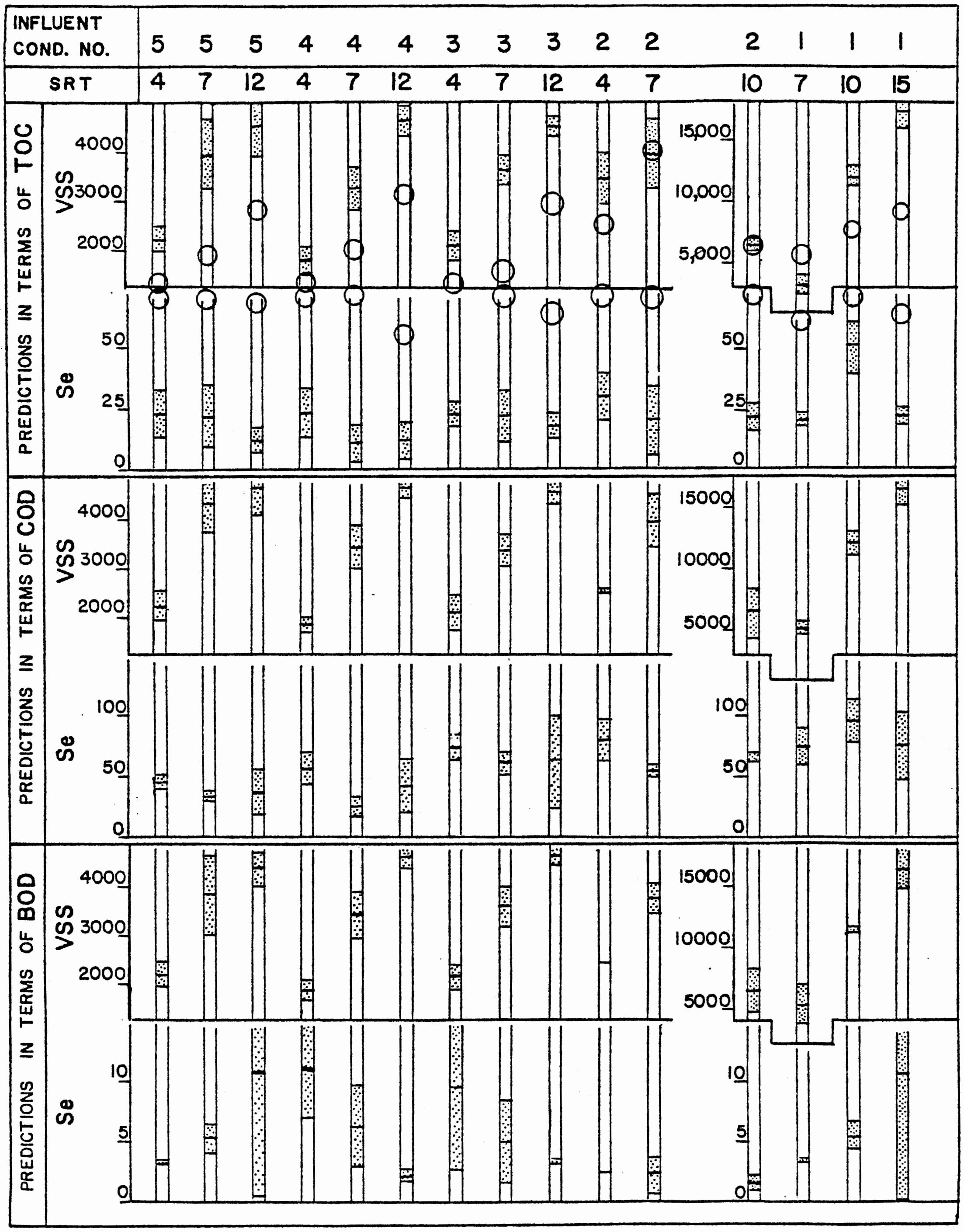

Figure 18. Simultaneous Predictions of X and S_e (MG/L); Discreet Compound Treatability Assumption; Modified Lawrence/ McCarty Model

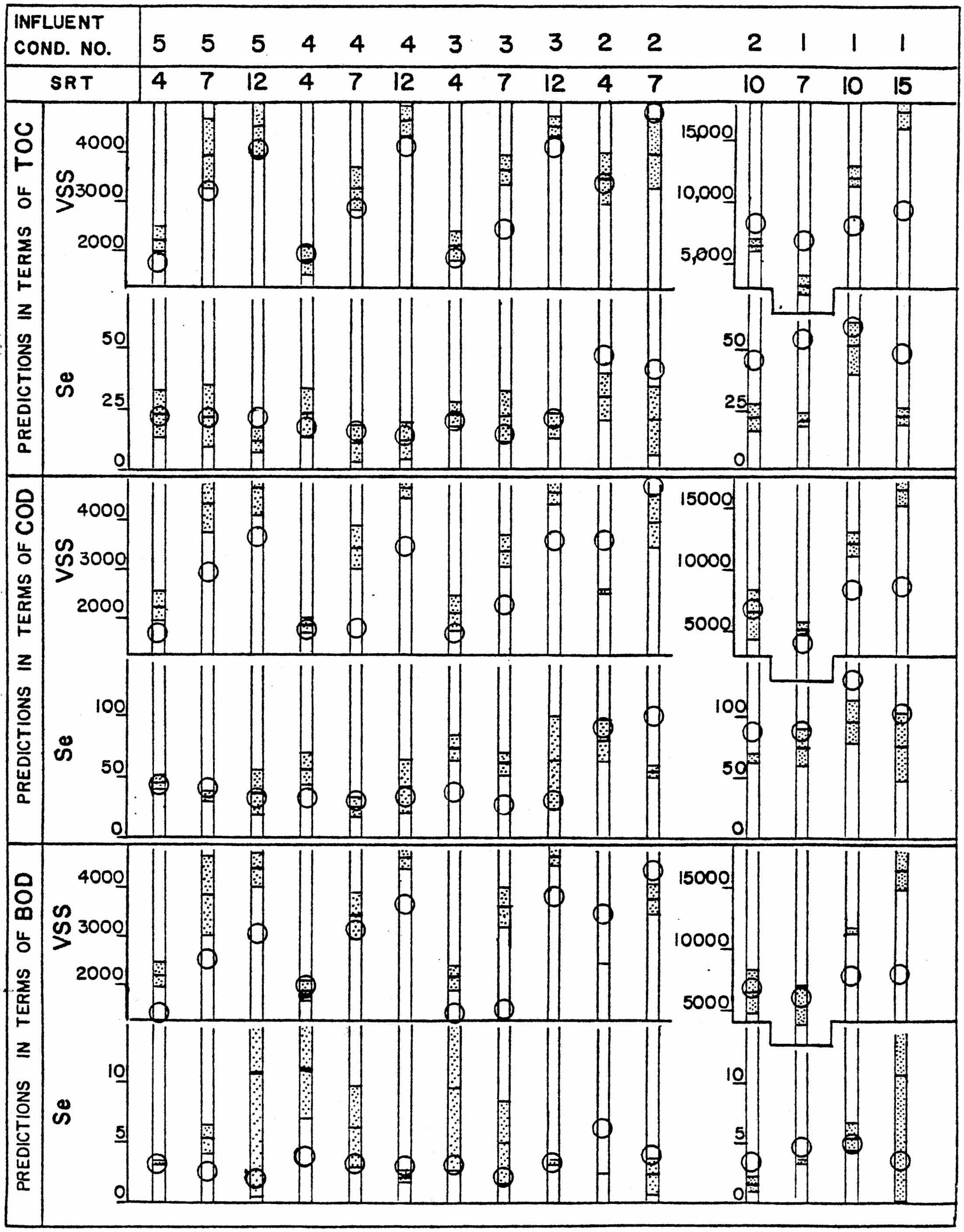

Figure 19. Simultaneous Predictions of X and S_e (MG/L); Total VSS Treatability Assumption; Kincannon/Stover Model

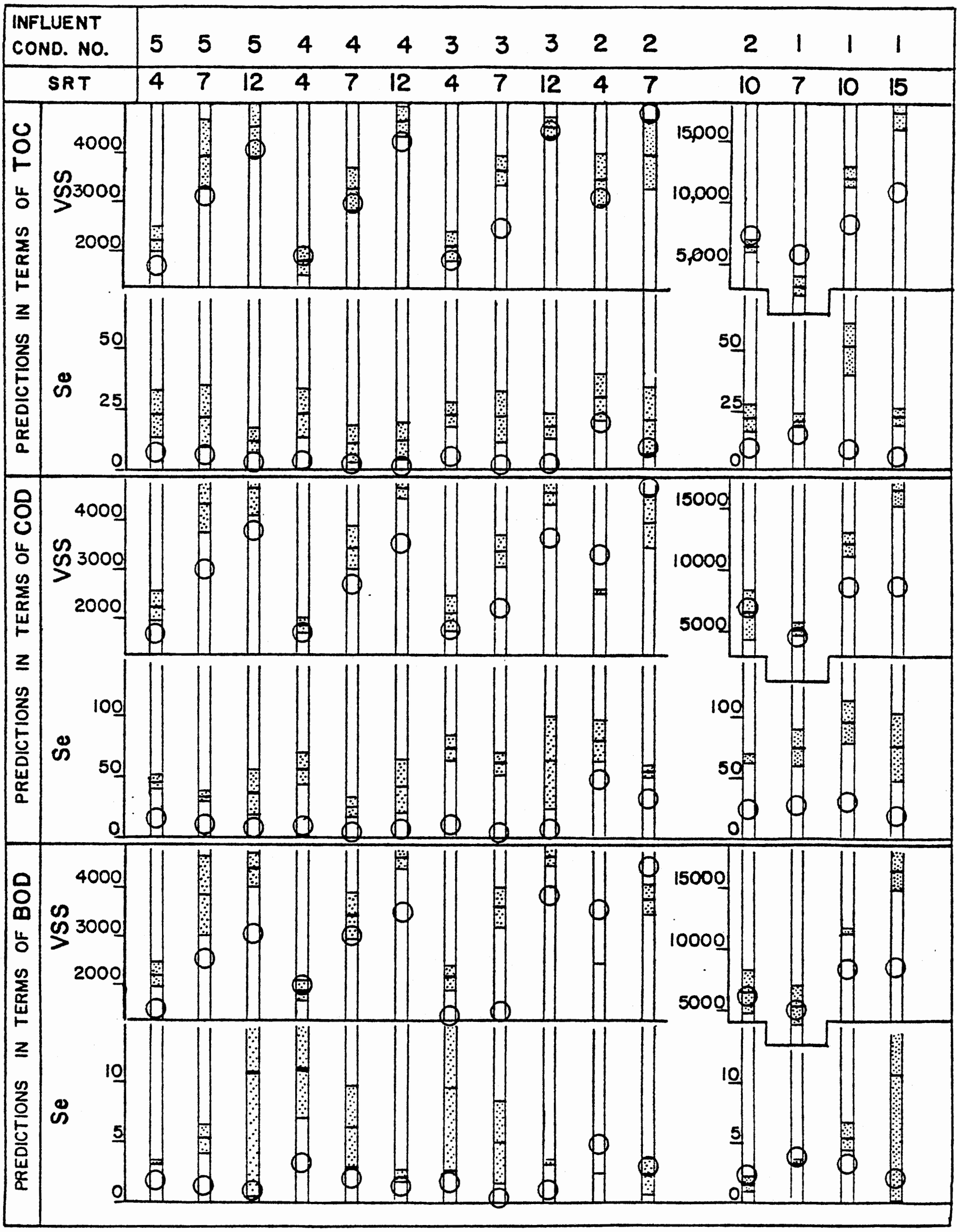

Figure 20. Simultaneous Predictions of X and S_e (MG/L); Total VSS Treatability Assumption; Eckenfelder Model

indicated with a circle. The influent wastewater composition is identified by a condition number (see Tables V to IX) while the operational SRT is also denoted. Each figure depicts the results obtained from just one of the ten predictive techniques employed.

4.5.1.1 Weighted Constant Assumption. Visual examination of the TOC and COD data for the low influent organic concentration conditions (No. 3, 4 and 5) indicated that all of the models utilized gave reasonable predictions when employing the weighted constant assumption (Figures 11 to 14). For the high influent substrate concentrations (No. 1 and 2), both Lawrence/McCarty models resulted in effluent substrate predictions for TOC that were lower than observed TOC values while the Kincannon/Stover model overestimated effluent TOC. Only Eckenfelder's (TOC and COD) and the Kincannon/Stover (COD) models gave reasonable predictions of effluent levels observed during these conditions of high organic substrate concentrations and none of the models accurately predicted the observed MLVSS concentrations (all predictions were generally low). BOD predictions seemed to roughly parallel TOC and COD data but due to variability within the test procedure and limited analyses, the results are difficult to evaluate. For example, such wide variations in effluent BOD analyses were observed during six of the fifteen operating conditions, that almost any predicted value would fall within one standard deviation of the mean.

In addition to predictions of VSS and Se, the weighted constant assumption results in a set of predicted biokinetic constants for each of the five combined influent conditions. A comparison of these predicted constants with those obtained empirically is presented in Table XXI. With the exception of Condition No. 2, true yield values predicted

TABLE XXI

COMPARISON OF PREDICTED VS. EXPERIMENTALLY DETERMINED BIOKINETIC CONSTANTS FOR THE VARIOUS COMBINED WASTEWATERS AND SUBSTRATE ANALYSES

Wastewater Composition	Analysis		Y_t	K_D days^{-1}	U_m days^{-1}	K_B	k_e' days^{-1}	K days^{-1}	K_S mg/l	Modified K_S mg/l
1. CHO/PRO; High S_i	TOC	Predicted	.967	.069	7.216	7.807	3.9	2.892	129	286
		Empirical	.950	.022	6.63	7.13	1.7	.71	176	1,706
	COD	Predicted	.329	.096	40.255	42.541	13.3			
		Empirical	.230	0	49.4	52.3	6.5			
	BOD	Predicted	.631	.080	33.373	33.994	22.6			
		Empirical	.525	0	75.6	76.0	36.7			
2. Phenol; High S_i	TOC	Predicted	.905	.075	5.824	6.232	3.6	2.269	92.8	212.5
		Empirical	.519	.050	14.28	14.91	4.8	2.77	208	1,185
	COD	Predicted	.290	.091	35.177	36.931	13.3			
		Empirical	.140	.015	122.4	127.8	24.9			
	BOD	Predicted	.551	.082	32.905	33.094	25.6			
		Empirical	.304	0	436	437.5	112.6			

TABLE XXI (Continued)

Wastewater Composition	Analysis		Y_t	K_D days^{-1}	U_m days^{-1}	K_B	k_e' days^{-1}	K days^{-1}	K_S mg/l	Modified K_S mg/l
3. Oleic H+/2-Prop.; Low S_i	TOC	Predicted	.887	.061	6.804	7.343	4.2	2.907	122.8	300.9
		Empirical	.962	.035	5.509	6.029	1.8	2.85	196	667
	COD	Predicted	.281	.090	64.341	66.789	19.6			
		Empirical	.290	.030	13.3	14.25	5.0			
	BOD	Predicted	.549	.092	50.277	50.618	36.5			
		Empirical	.775	0	3.09	2.925	6.9			
4. CHO/PRO; Low S_i	TOC	Predicted	.968	.073	7.949	8.494	4.4	3.089	128.3	294.2
		Empirical	.795	.033	24.25	26.38	2.9	5.2	400	1,488
	COD	Predicted	.365	.102	38.559	40.709	13.2			
		Empirical	.319	.039	50	53.5	7.2			
	BOD	Predicted	.685	.076	26.47	26.902	15.1			
		Empirical	.470	0	25.85	26.26	13.0			

TABLE XXI (Continued)

Wastewater Composition	Analysis		Y_t	K_D days^{-1}	U_m days^{-1}	K_B	k_e' days^{-1}	K days^{-1}	K_S mg/l	Modified K_S mg/l
5. 95 ppm COD Each Compound; Low S_i	TOC	Predicted	.918	.072	6.369	6.809	3.9	2.498	104.6	235.5
		Empirical	.985	.073	2.301	2.318	2.5	6.66	529	177
	COD	Predicted	.301	.091	37.635	39.414	14			
		Empirical	.333	.065	36.76	38.78	9.9			
	BOD	Predicted	.571	.080	31.25	31.52	23.1			
		Empirical	.906	.090	5.52	5.45	7.6			

from TOC and COD data generally correlated quite well with observed values. However, all of the other predicted constants (k_d, k'_e, U_{max}, K_B, k, K_{s1} and K_{s2}), as well as true yield for BOD, failed to result in any consistent correlation to the actual constants which were empirically obtained.

4.5.1.2 Discreet Compound Treatability Assumption. Both forms of the Lawrence/McCarty model predicted MLVSS concentrations that were significantly lower and effluent TOC concentrations that were significantly higher than the actual observed values (Figures 17 and 18). The Kincannon/Stover and Eckenfelder models (Figures 15 and 16) resulted in predicted Se concentrations that were generally higher and MLVSS concentrations that were generally lower than actual observed concentrations. For the high influent organic concentration conditions, predicted effluent substrate concentrations were extremely high relative to actual concentrations.

4.5.1.3 Total VSS Treatability Assumption. Predictions of MLVSS for the two models utilized for this assumption (Figures 19 and 20) result in exactly the same values as those calculated for the discreet compound treatability assumption. Effluent substrate predictions for the Kincannon/Stover model resulted in quite good agreement with actual values observed. Eckenfelder's model, on the other hand, generally predicted lower effluent substrate concentrations than were actually observed.

It should be noted that when the discreet compound treatability and total VSS assumptions are employed, a hypothetical mixed liquor VSS and residual effluent substrate concentration for each component can be obtained. An example of these results appears in Table XXII while all of the data, calculated for TOC, is presented in Appendix B.

TABLE XXII

HYPOTHETICAL RESIDUAL EFFLUENT TOC AND MLVSS PRODUCED FROM EACH SUBSTRATE OF COMBINED INFLUENT CONDITION #3 - SRT = 4 DAYS

Influent Components	Discreet Compound				Total Volatile Suspended Solids	
	K+S	Eck	L+M	Mod L+M	K+S	Eck
	Effluent TOC Concentration (mg/l)					
Albumen	1.2	.9	9.4	9.4	.3	0
Starch	2.6	1.6	14.9	12.1	2	.3
Sucrose	1.7	1.3	8.2	9.1	1.2	.2
Propanol	6	4.2	18.6	17.7	3.4	1.4
Oleic Acid	7	5.8	25.2	26.8	5.7	1.4
Cheer	9.2	12.6	12.6	12.6	6.5	1.7
Nitrophenol	9	1	9.1	8.3	.1	0
Chloromethyl Phenol	2.9	3	10.5	10.5	.6	.2
	MLVSS Concentration (mg/l)					
Albumen	76	78	0	0	76	79
Starch	249	261	91	127	249	262
Sucrose	306	311	214	202	306	311
Propanol	553	571	426	435	553	571
Oleic Acid	362	375	152	133	362	376
Cheer	56	0	0	0	56	0
Nitrophenol	72	70	12	18	72	71
Chloromethyl Phenol	85	83	0	0	85	84

4.5.2 Independent Predictions of MLVSS and Effluent Substrate Concentrations

The successful simultaneous prediction of MLVSS(X) and effluent substrate concentration (Se) demands that accurate expressions for X (in terms of Y_t and k_d) and Se (in terms of the substrate removal equations) be available. A shortcoming in either expression will result in poor predictive capability for both Se and X. In the following sections, the predictive capacity of the substrate removal expressions (as a function of observed X) and biomass production expressions (as a function of observed Se) will be examined separately. This technique will facilitate the isolation of any part of the predictive equations which exhibit especially poor predictive performance. Predictive equations utilized in this section were presented previously in Table IV and on page 15.

4.5.2.1 Predictions of X Based Upon Observed Se. These predictions were facilitated by utilizing the biokinetic constants determined during the single substrate treatability studies. A computer program similar to that used for the simulataneous predictions was employed although two (2) modifications were made. First, separate equations for MLVSS and effluent substrate concentration predictions were used (i.e. the MLVSS term did not contain any substrate removal biokinetic constants and vice versa). Second, whenever a term for Se appeared in the equation for X, the observed Se, rather than the predicted Se, was inserted. When employing the discreet compound treatability technique (where eight (8) individual biological solids predictions were made then summed) the effluent substrate predictions for each of the eight influent constituents were, first, adjusted. This adjustment was based upon the ratio of the observed to the predicted effluent substrate concentration. Once this was done, the eight (8) individual predictions of MLVSS were made for each of the influent components and the summation resulted in the prediction of X for the given influent combination and operating condition.

Tables XXIII and XXIV present the predictions of X based upon observed Se for TOC and COD, respectively. The observed value is also presented for purposes of comparison. The weighted constant assumption, which yields the same result for all of the models investigated, as well as the discreet compound treatability assumption (Kincannon/ Stover, Eckenfelder, Lawrence/McCarty and Modified Lawrence/McCarty models) were investigated. Figure 21 to 25 graphically depict these same results superimposed upon the mean observed MLVSS (dark bar) plus and minus one standard deviation from the mean value (shaded area) for each of the influent and operating conditions.

In general, it can be said that, in terms of the TOC substrate parameter, the predictive capability demonstrated for the high influent organic concentration conditions (1 and 2) was poor while that for the low influent organic concentration conditions was good. The same observation could be made when utilizing the COD substrate parameter except that the predictions of MLVSS for the 7 and 12 day SRT for influent condition 3 (oleic acid/propanol) were not very accurate.

4.5.2.2 Predictions of Se Based Upon Observed X. Here again, based upon the biokinetic constants developed during the individual compound studies and utilizing the modified computer program described in Section 4.5.2.1, predictions of Se based upon observed MLVSS were made.

TABLE XXIII

PREDICTED MLVSS BASED UPON OBSERVED EFFLUENT TOC FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

Influent Condition	SRT	Observed MLVSS	Weighted Constant Assumption	Discreet Compound Treatability Assumption			
			All Models	Kincannon & Stover	Eckenfelder	Lawrence & McCarty	Mod. Law. & McCarty
1. High CHO/PRO Content; High Organic Concentration	7	4,795	6,927	6,927	6,897	6,980	6,975
	10	12,090	8,284	8,229	8,119	8,408	8,402
	15	17,338	10,112	10,413	10,347	10,551	10,549
2. High Phenol Content; High Organic Concentration	4	3,039	4,166	4,181	4,119	4,163	4,129
	7	3,909	5,520	5,582	5,557	5,613	5,607
	10	6,698	7,969	8,195	8,174	8,241	8,238
3. High Oleic Acid and Propanol Content; Low Organic Concentration	4	2,126	1,913	1,877	1,814	1,845	1,852
	7	3,514	2,453	2,413	2,382	2,242	2,215
	12	4,552	4,140	4,180	4,146	4,128	4,115
4. High CHO/PRO Content; Low Organic Concentration	4	1,785	1,890	1,852	1,833	1,846	1,857
	7	3,227	3,131	3,097	3,082	2,983	2,949
	12	4,637	4,184	4,189	4,167	4,105	4,071
5. Equal COD Concentrations; Low Organic Concentration	4	2,180	1,999	1,966	1,875	1,830	1,763
	7	3,940	3,479	3,454	3,424	3,443	3,394
	12	4,528	4,310	4,438	4,424	4,484	4,483

TABLE XXIV

PREDICTED MLVSS BASED UPON OBSERVED EFFLUENT COD FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

			Weighted Constant Assumption	Discreet Compound Treatability Assumption	
Influent Condition	SRT	Observed MLVSS	All Models	Kincannon & Stover	Eckenfelder
	7	5,041	5,258	5,190	5,197
	10	12,093	9,216	9,158	9,164
	15	16,616	9,148	9,238	9,239
	4	2,527	4,011	4,022	4,006
	7	3,998	6,169	6,240	6,235
	10	6,604	7,355	7,519	7,509
	4	2,082	1,751	1,754	1,745
	7	3,314	2,163	2,185	2,184
	12	4,634	2,384	2,459	2,455
	4	1,879	1,754	1,737	1,737
	7	3,401	2,983	2,926	2,931
	12	4,695	3,488	3,444	3,448
	4	2,249	1,883	1,879	1,869
	7	4,289	3,327	3,335	3,333
	12	4,684	3,749	3,822	3,817

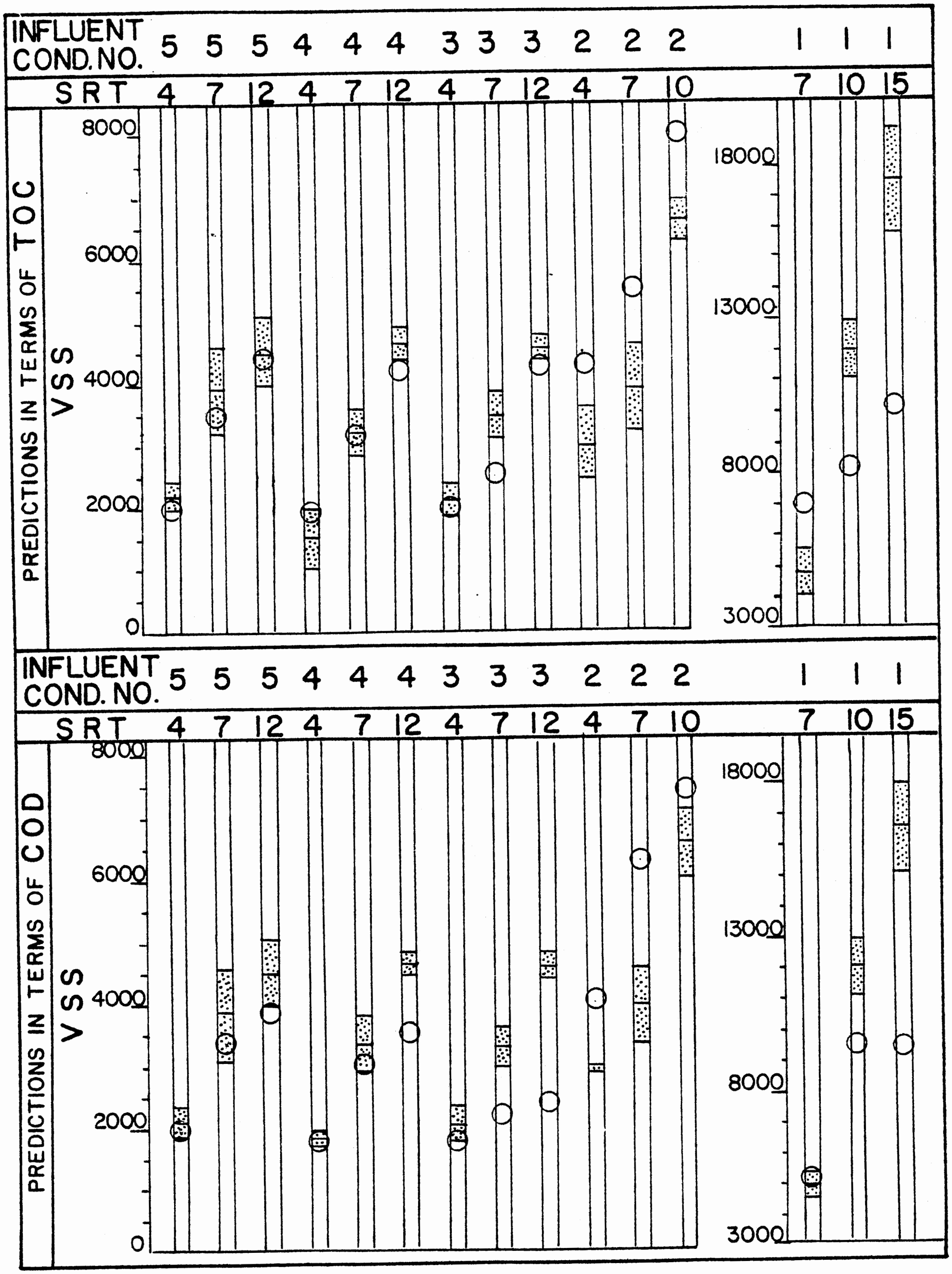

Figure 21. Prediction of MLVSS Based Upon Observed S_e; Weighted Constant Assumption; All Models

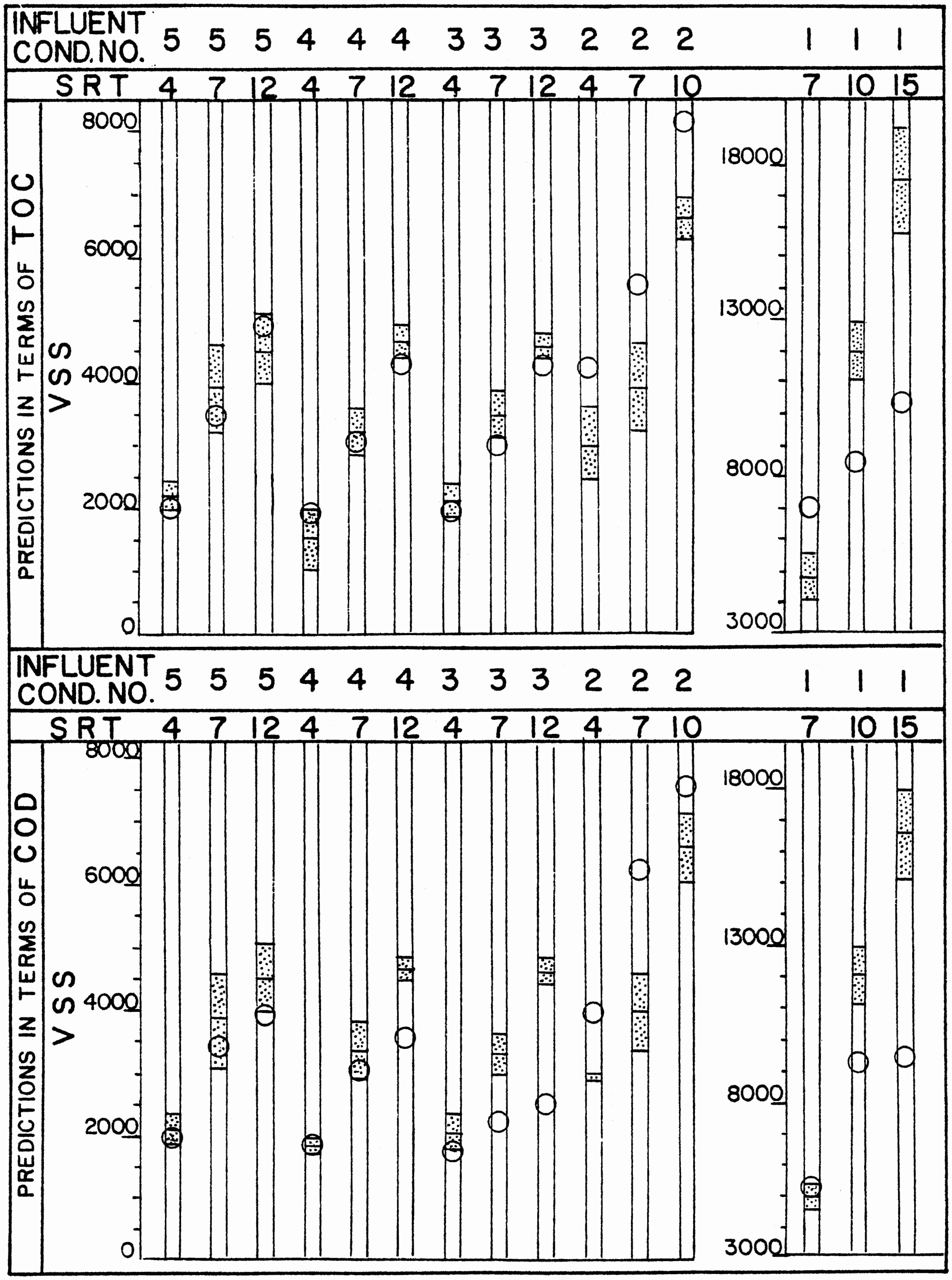

Figure 22. Prediction of MLVSS Based Upon Observed S_e; Discreet Compound Treatability Assumption; Kincannon/Stover Model

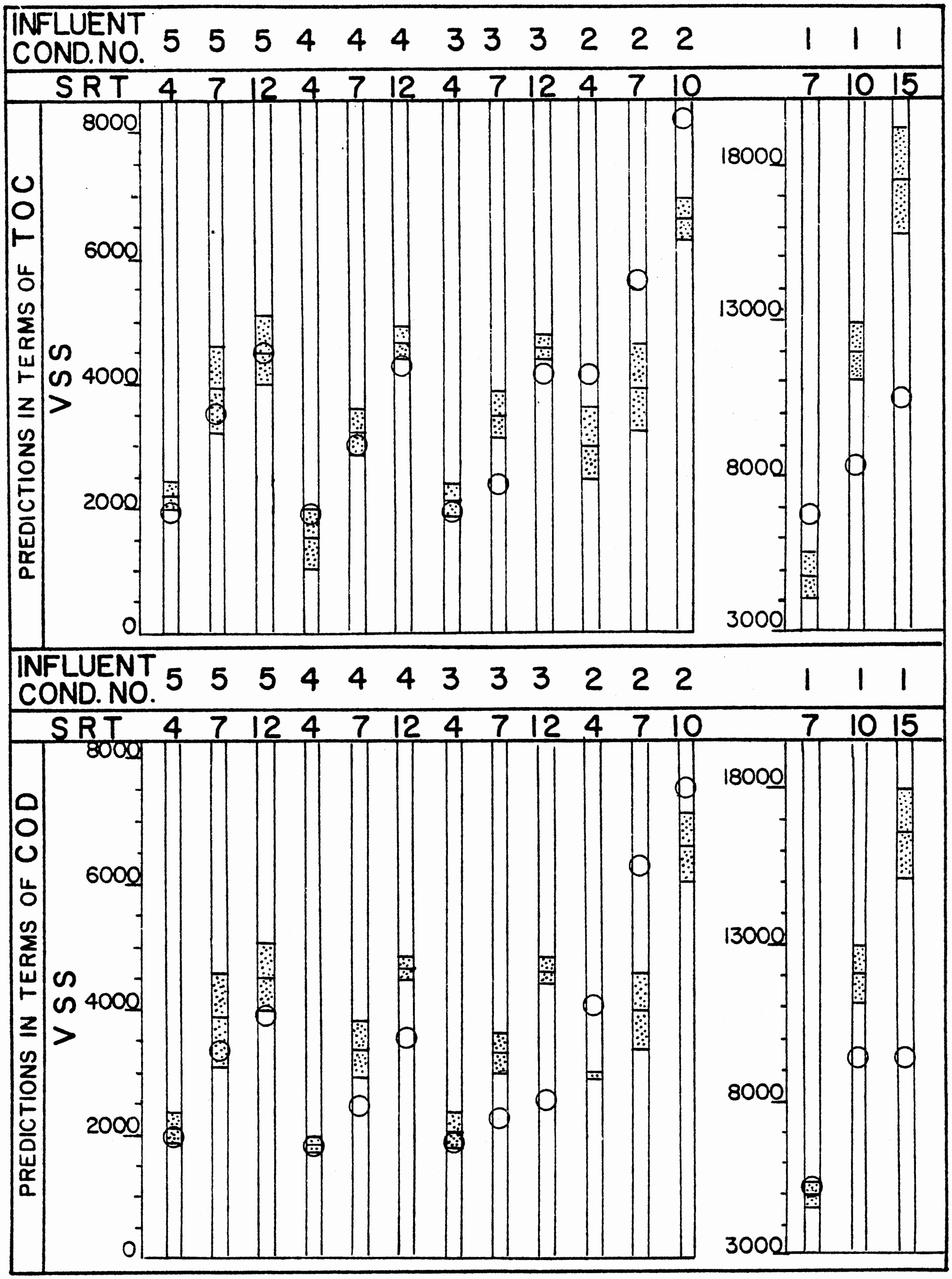

Figure 23. Prediction of MLVSS Based Upon Observed S_e; Discreet Compound Treatability Assumption; Eckenfelder Model

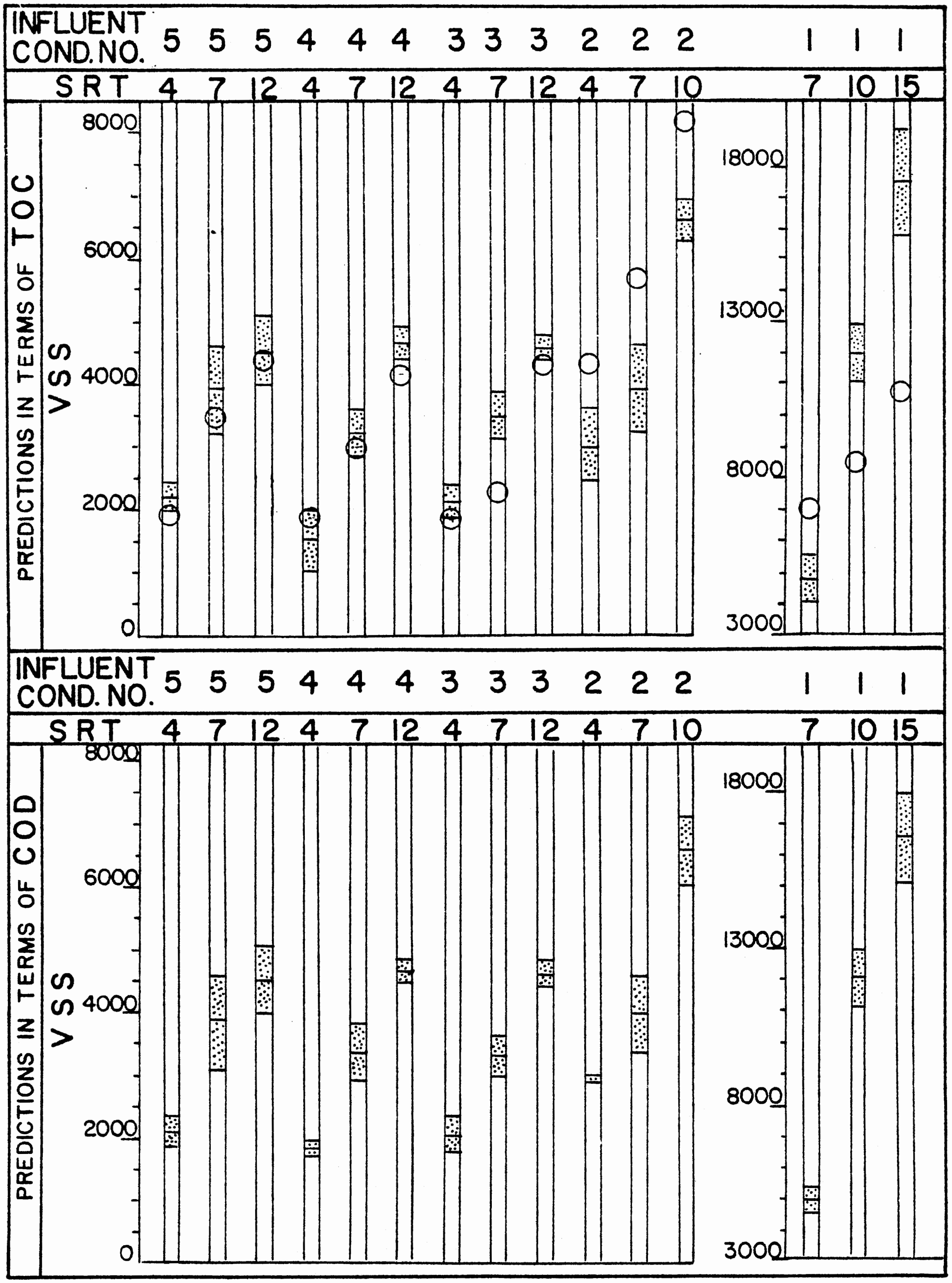

Figure 24. Prediction of MLVSS Based Upon Observed S_e; Discreet Compound Treatability Assumption; Lawrence/McCarty Model

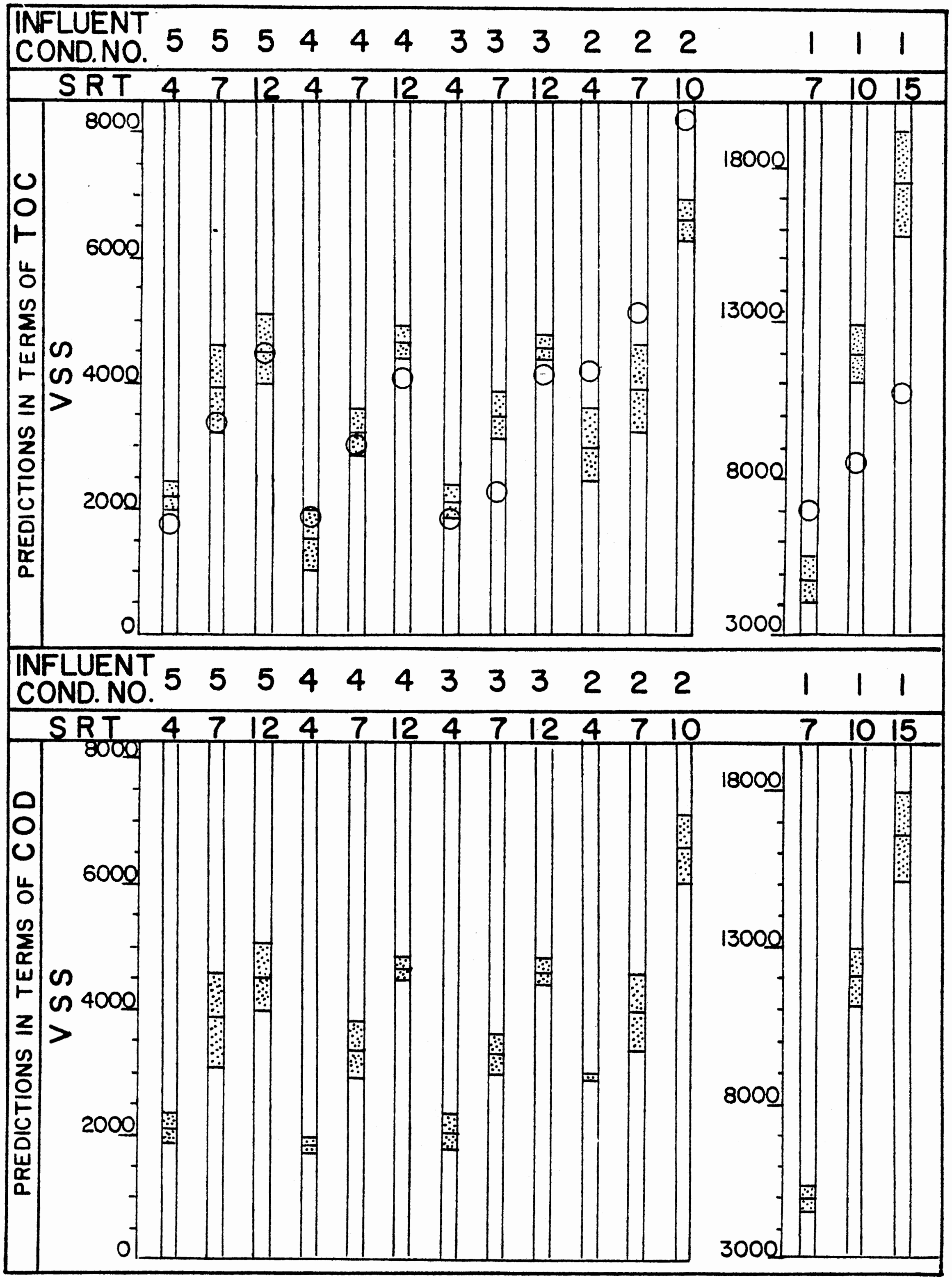

Figure 25. Prediction of MLVSS Based Upon Observed S_e; Discreet Compound Treatability Assumption; Modified Lawrence/McCarty Model

Results of these predictions are presented in Tables XXV and XXVI for TOC and COD, respectively, while graphic illustrations are shown in Figures 26 through 29. Both the Eckenfelder and, especially, the Kincannon/Stover models utilizing the weighted constant assumption demonstrated good predictive capability using both the TOC and COD substrate parameters. Generally, more accurate predictions were obtained for the low influent organic concentration conditions (3, 4 and 5) with the exception of the Kincannon/Stover Se predictions for condition 1 (using the COD substrate parameter) which were also very accurate. Predictions of Se (both TOC and COD) utilizing the discreet compound treatability assumption (both the Kincannon/Stover and Eckenfelder models) were, generally, a bit high for the low Si conditions (3, 4 and 5) and extremely high for the high Si conditions (1 and 2). The Lawrence and McCarty substrate predictions were unaffected by the fact that observed MLVSS values were being employed since, for those calculations, Se would be a function of SRT rather than MLVSS.

4.6 Settleability and Dewatering

4.6.1 Effluent Quality With Respect to Suspended Solids

One critical aspect of biological wastewater treatment which is sometimes overlooked is the ability to achieve adequate solids/liquid separation in the final clarifier. Effluent suspended solids concentrations can often be used to indicate solids/liquid separation efficiency. Operational data pertaining to the effluent suspended solids concentrations observed for each of the 27 individual compound test reactors and the 15 combined substrate test reactors are presented in Tables XXVII and XXVIII, respectively.

TABLE XXV

PREDICTED EFFLUENT TOC BASED UPON OBSERVED MLVSS FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

Influent Condition	SRT Days	Observed Effl. TOC	Weighted Constant Assumption: Kincannon & Stover	Weighted Constant Assumption: Eckenfelder	Discreet Compound Treatability Assumption: Kincannon & Stover	Discreet Compound Treatability Assumption: Eckenfelder
1. High CHO/PRO Content; High Organic Concentration	7	21	46	32	75	74
	10	51	39	14	64	43
	15	23	32	81	53	24
2. High Phenol Content; High Organic Concentration	4	20	53	48	86	92
	7	26	43	34	70	71
	10	22	42	26	68	60
3. High Oleic Acid and Propanol Content; Low Organic Concentration	4	22	22	15	29	28
	7	21	15	7	20	15
	12	18	17	7	22	14
4. High CHO/PRO Content; Low Organic Concentration	4	23	19	15	26	24
	7	11	15	9	21	16
	12	12	14	6	18	11
5. Equal COD Concentrations; Low Organic Concentration	4	24	21	16	35	38
	7	22	18	10	30	28
	12	12	16	8	27	20

TABLE XXVI

PREDICTED EFFLUENT COD BASED UPON OBSERVED MLVSS FOR THE COMBINED SUBSTRATE TEST UNITS (ALL VALUES REPORTED AS mg/L)

			Weighted Constant Assumption		Discreet Compound Treatability Assumption	
Influent Condition	SRT Days	Observed Effl. COD	Kincannon & Stover	Eckenfelder	Kincannon & Stover	Eckenfelder
1. High CHO/PRO Content; High Organic Concentration	7	70	75	60	155	160
	10	97	96	52	180	143
	15	74	73	26	125	67
2. High Phenol Content; High Organic Concentration	4	80	116	156	254	315
	7	55	108	120	225	256
	10	65	89	75	173	173
3. High Oleic Acid and Propanol Content; Low Organic Concentration	4	73	32	34	64	75
	7	61	23	15	41	36
	12	61	23	10	42	30
4. High CHO/PRO Content; Low Organic Concentration	4	57	34	32	57	63
	7	26	31	21	47	42
	12	41	29	14	40	26
5. Equal COD Concentrations; Low Organic Concentration	4	47	38	38	90	114
	7	34	33	23	67	66
	12	43	31	19	60	48

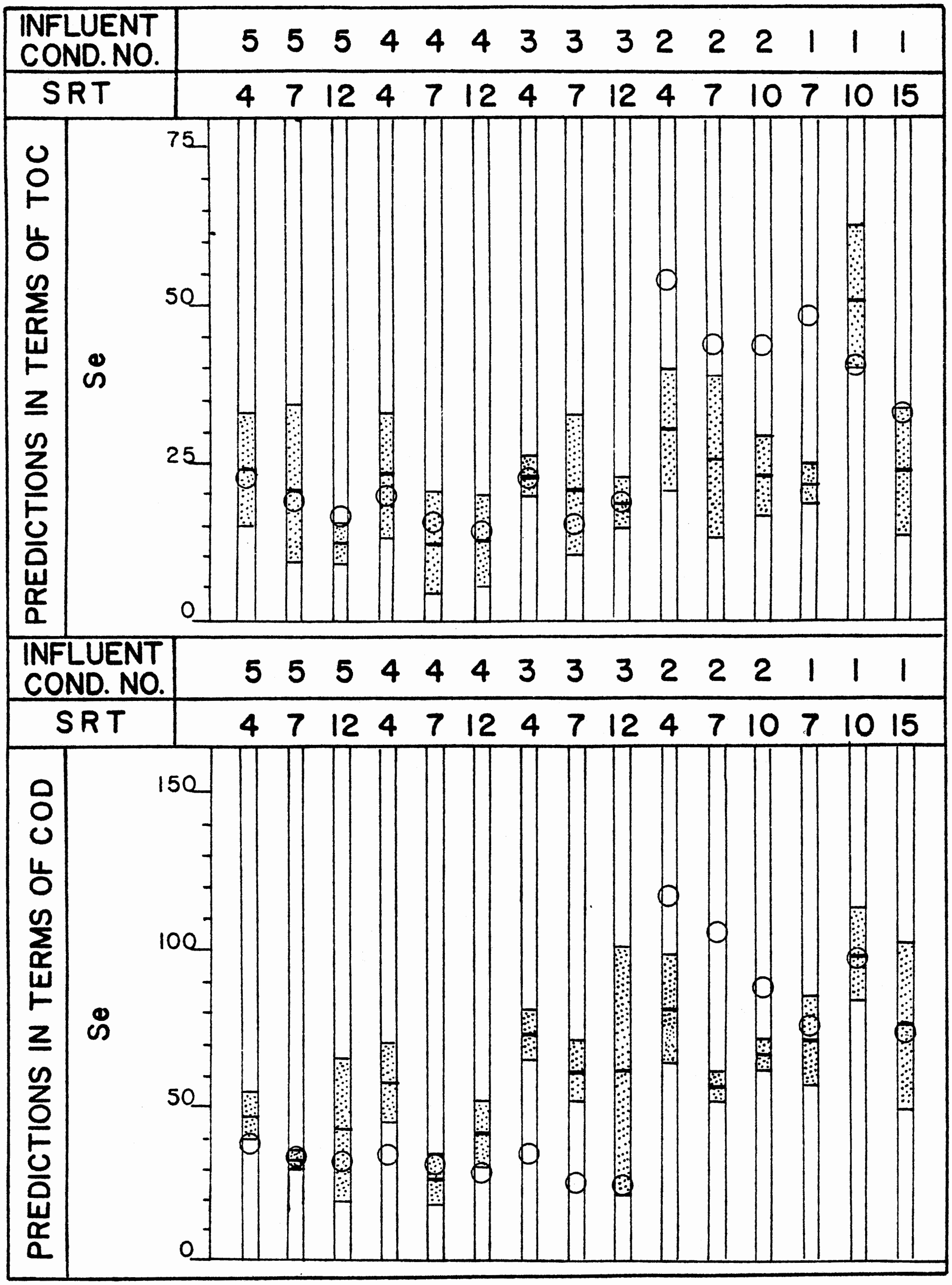

Figure 26. Prediction of S_e Based Upon Observed MLVSS; Weighted Constant Assumption; Kincannon/Stover Model

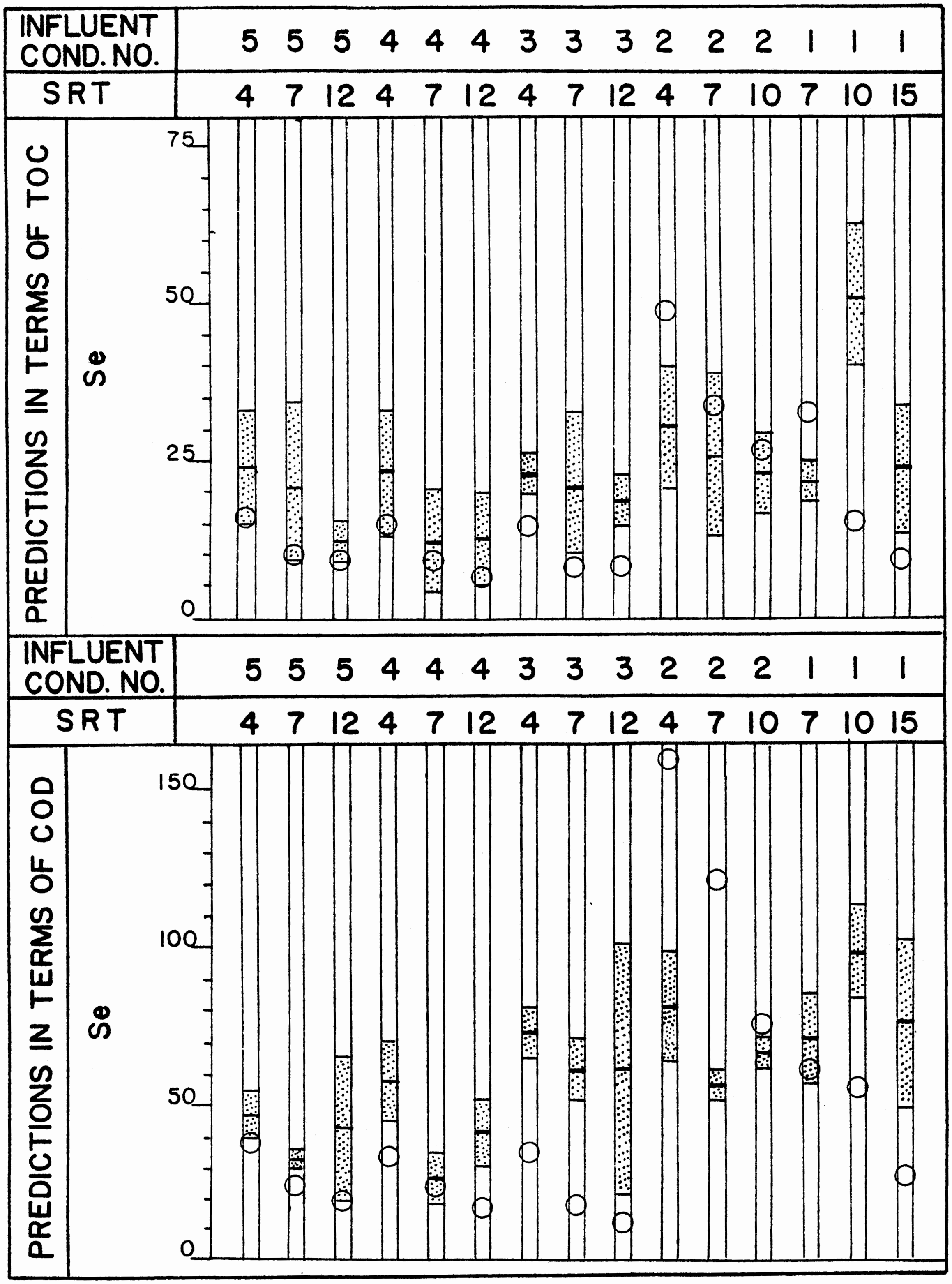

Figure 27. Prediction of S_e Based Upon Observed MLVSS; Weighted Constant Assumption; Eckenfelder Model

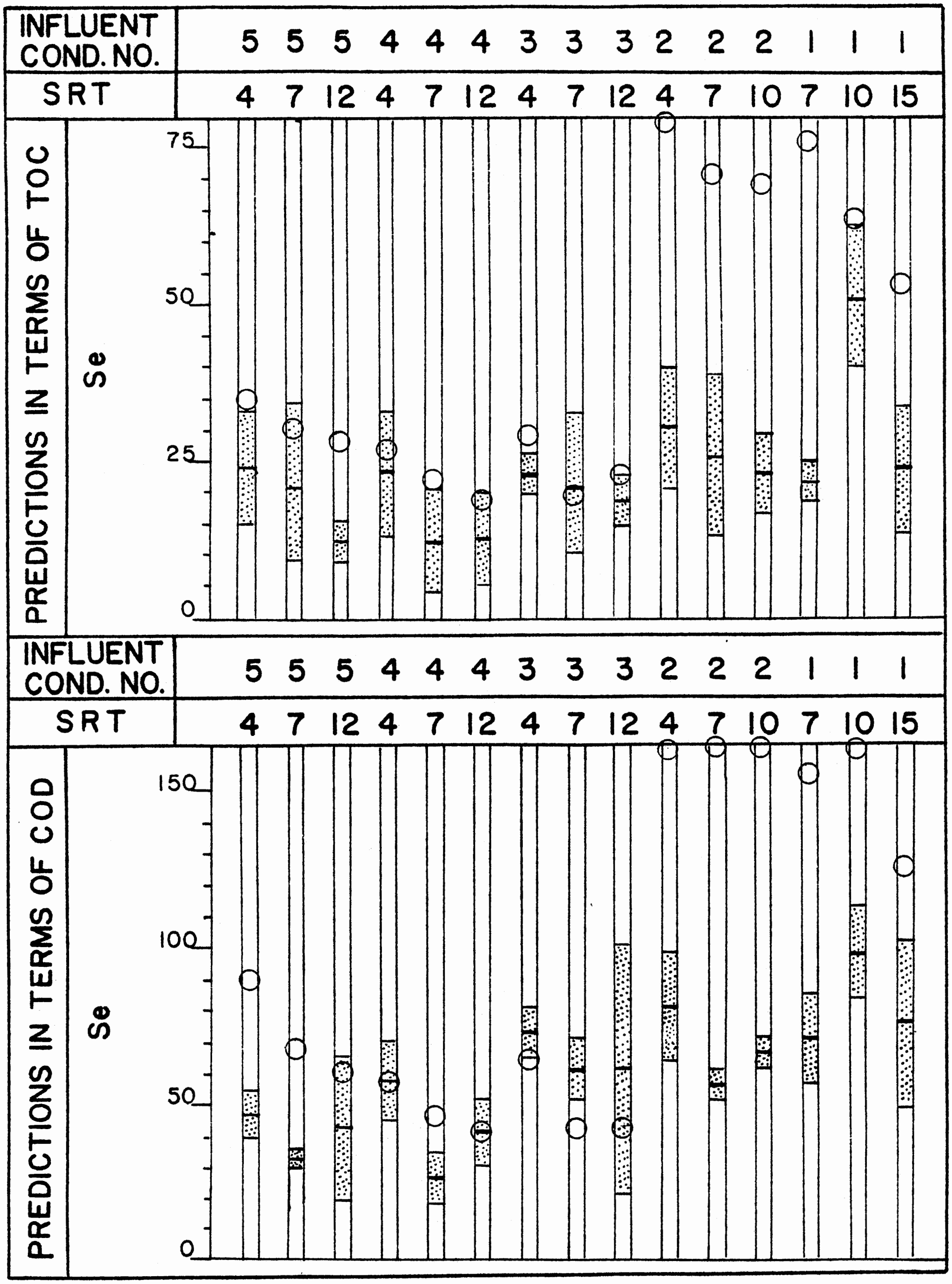

Figure 28. Prediction of S_e Based Upon Observed MLVSS; Discreet Compound Treatability Assumption; Kincannon/Stover Model

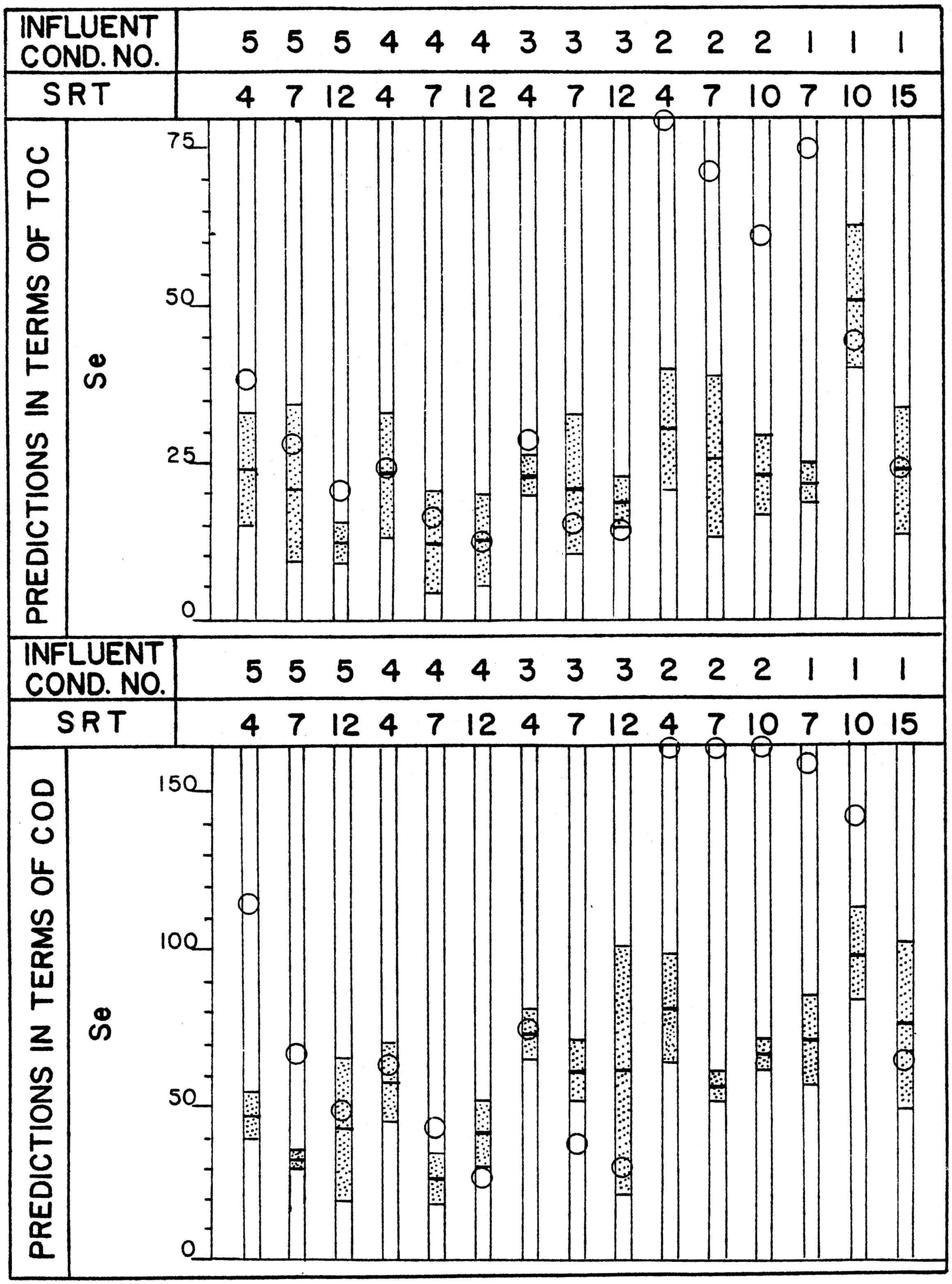

Figure 29. Prediction of S_e Based Upon Observed MLVSS; Discreet Compound Treatability Assumption; Eckenfelder Model

TABLE XXVII

EFFLUENT SUSPENDED SOLIDS ANALYSES FOR THE SINGLE SUBSTRATE TEST UNITS

Influent	Statistical Parameter	X_e	X_e	X_e	X_e	X_e
Egg Albumen	SRT	2	6	10		
	N	33	34	26		
	Mean	55.9	56	51		
	SD	28.9	45	45		
Starch	SRT	2	5	12		
	N	20	8	17		
	Mean	25	89	11		
	SD	31	88	6		
Sucrose	SRT	1	2	4	~ 4	12
	N	16	27	13	10	20
	Mean	115	50	32.3	308.6	50
	SD	100	36.4	20.2	211	23
2-Propanol	SRT	2	2	3	5	10
	N	10	10	9	28	12
	Mean	8	7	7	31	9.8
	SD	7	9	7	29	8.7
Oleic Acid	SRT	3	5	10		
	N	47	32	34		
	Mean	57	59	64		
	SD	27	46	23		
Cheer	SRT	6	12	18		
	N	28	10	24		
	Mean	30	15	21		
	SD	10	5	7		
2-Nitrophenol	SRT	5	5	10		
	N	17	13	15		
	Mean	24	13.1	10.5		
	SD	10	8.7			
4-Chloro-3-Methyl Phenol	SRT	8	15			
	N	34	34			
	Mean	15	15			
	SD	9	9			

Note: Units are days for SRT and mg/L for X_e.

TABLE XXVIII

EFFLUENT SUSPENDED SOLIDS ANALYSES FOR COMBINED SUBSTRATE TEST UNITS

Influent	Statistical Parameter	X_e	X_e	X_e
Combined Substrate Condition #1	SRT	7	10	15
	N	11	25	29
	Mean	50	76	72
	SD	17	32	27
Combined Substrate Condition #2	SRT	4	7	10
	N	12	25	24
	Mean	56.5	26	22.6
	SD	45.8	21	15
Combined Substrate Condition #3	SRT	4	7	12
	N	24	32	19
	Mean	32	17	15
	SD	15	12	9
Combined Substrate Condition #4	SRT	4	7	12
	N	18	24	24
	Mean	17	7	7
	SD	8	4	4
Combined Substrate Condition #5	SRT	4	7	12
	N	27	27	36
	Mean	7	14	19
	SD	4.4	5.7	13

Note: Units are days for SRT and mg/L for X_e.

Certain individual compounds, notably egg albumen, sucrose and oleic acid, seemed prone to produce effluents with high suspended solids concentrations. The biological test units which were administered influents possessing low organic concentrations generally experienced effluent suspended solids concentrations of less than 30 mg/L with most of the units producing effluent suspended solids concentration of less than 15 mg/L. The high organic concentrations administered during the combined substrate influent conditions number 1 (CHO and protein) study caused high levels of effluent suspended solids to be emitted from those units. However, with the exception of the unit operated at SRT = 4, the high organic concentration influent studied during the combined substrate influent condition number 2 (phenols) did not generate unusually high effluent suspended solids concentrations.

4.6.2 Sludge Volume Index and Capillary Suction Time (CST) Results

In addition to effluent suspended solids concentrations, the sludge volume index test, with all of its shortcomings (10), was employed to gauge the sludge settleability (solids/liquid separation tendency) for the test units studied. A standard sludge concentration of 2000 mg/L was selected as a basis for comparison. A capillary suction time apparatus was utilized to indicate the dewatering properties of the test sludges. A standard sludge concentration of 8000 mg/L was used for these tests. Tables XXIX and XXX summarize the test results for the individual compound and combined substrate tests, respectively.

The methods investigated for predicting settling and dewatering characteristics were simplistic. First, a descriptive settling or

TABLE XXIX

SETTLING AND DEWATERING CHARACTERISTICS OF THE SINGLE SUBSTRATE ACTIVATED SLUDGE SYSTEMS

Influent Description	SRT days	$\frac{F}{M}$[1]	Sludge Volume Index[2] - ml/g	CST[4] sec.
Egg Albumen	2	1.074	67	8.95
	6	.286	194	8.95
	10	.244	157	10.2
Starch	2	.582	441	14.5
	12	.160	243	26.5
Sucrose	1	.903	630	
	4	.294	33	7.9
	12	.176	41	7.45
2-Propanol	2	.844	605	3.7
	5	.437	62.5	5.2
	10	.197	167	9.6
Oleic Acid	3	.524	226[3]	
	5	.443	220[3]	
	10	.273	60	
Cheer	6	.552	25.3	16.9
	12	.303	27.6	15.8
	18	.17	50	8
2-Nitrophenol	5	.547	30	7
	10	.366	129	7.2
4-Chloro-3-Methyl Phenol	8	.275	19.25	6.1
	15	.187	14	5.8

[1] Based upon TOC and VSS.
[2] Test sludge concentration approximately 2000 mg/L TSS.
[3] Showed increased deterioration with time.
[4] Test sludge concentration approximately 8000 mg/L TSS.

TABLE XXX

SETTLING AND DEWATERING CHARACTERISTICS OF THE COMBINED SUBSTRATE ACTIVATED SLUDGE SYSTEMS

Influent Description	SRT days	$\frac{F}{M}$[1]	Sludge Volume Index[2] - ml/g	CST[3] sec.
Combined Condition No. 1; PRO/CHO; High S_i	7	.348	103	5.96
	10	.137	65	5.2
	15	.087	44.6	5.0
Combined Condition No. 2; Phenols; High S_i	4	.531	380	8.5
	7	.378	112	10.3
	10	.252	141	7.6
Combined Condition No. 3; Oleic H^+/2-Prop; Low S_i	4	.37	153	11.5
	7	.19	93.5	6.27
	12	.18	67	6.5
Combined Condition No. 4; PRO/CHO #2; Low S_i	4	.414	78	14.6
	7	.235	110	8.9
	12	.156	127	7.5
Combined Condition No. 5; 93 mg/L COD for Each Component; Low S_i	4	.375	117	8.4
	7	.24	107	7.54
	12	.175	143	6.2

[1] Based upon TOC and VSS.

[2] Test sludge concentration approximately 2000 mg/L TSS.

[3] Test sludge concentration approximately 8000 mg/L TSS.

dewatering characteristic was assigned to each operating condition. No consideration was given to SRT relative to its effect upon settleability. Rather, composite SVI and CST results were obtained for each of the influent conditions (individual or combined substrate) by averaging all of the SRT conditions studied within that particular influent condition. For the individual substrate tests, the results from two conditions (Sucrose, SRT = 1 day and 2-Propanol, SRT = 2 days) were disregarded as these were thought to be unreasonable.

The assumption was made that any sludge produced in the combined unit from the degradation of a particular substrate will have the same settling properties (as described by SVI) as the sludge cultured in the single substrate study of that compound. To approximate the quantity of sludge produced by the degradation of each of the eight organic constituents, results obtained from the Eckenfelder predictive model utilizing the discreet compound treatability assumption were used (Appendix B). This model was selected in that it was capable of computing solids production for each influent constituent and the predicted total VSS correlated fairly well with the observed values. The Kincannon/Stover model could have been utilized, also. The combined substrate constituents were characterized in terms of the percent of volatile suspended solids (VSS) each produced relative to the total VSS (Table XXXI). Table XXXII presents similar relationships for total suspended solids (TSS) productions based upon VSS/TSS ratios observed during the individual compound studies. These values were obtained from the intermediate SRT unit operated for each influent condition. Although it has been reported that SRT will impact the ratio of volatile to total mixed liquor suspended solids, only minor variations in this ratio were

TABLE XXXI

HYPOTHETICAL FRACTION OF VOLATILE SUSPENDED SOLIDS PRODUCED FROM EACH OF THE SUBSTRATE COMPONENTS FOR THE FIVE COMBINED SUBSTRATE INFLUENTS; DISCREET COMPOUND TREATABILITY ASSUMPTION; ECKENFELDER'S MODEL

Influent Constituent	Influent Condition Number				
	1. CHO/PRO; High S_i	2. Phenol; High S_i	3. Oleic H^+/Prop; Low S_i	4. CHO/PRO; Low S_i	5. Equal COD Low S_i
Albumen	.119	.071	.047	.168	.111
Starch	.192	.130	.344	.306	.192
Sucrose	.326	.213	.139	.324	.208
2-Propanol	.116	.112	.343	.086	.133
Oleic Acid	.082	.090	.205	.031	.075
Cheer	.101	.045	.021	.016	.049
Nitrophenol	.039	.132	.036	.028	.104
Chloromethyl Phenol	.024	.207	.050	.039	.120

TABLE XXXII

HYPOTHETICAL FRACTION OF TOTAL SUSPENDED SOLIDS PRODUCED FROM EACH OF THE SUBSTRATE COMPONENTS FOR THE FIVE COMBINED SUBSTRATE INFLUENTS; DISCREET COMPOUND ASSUMPTION; ECKENFELDER'S MODEL

Influent Constituent	Influent Condition Number				
	1. CHO/PRO; High S_i	2. Phenol; High S_i	3. Oleic H^+/Prop; Low S_i	4. CHO/PRO; Low S_i	5. Equal COD Low S_i
Albumen	.115	.065	.047	.168	.110
Starch	.270	.165	.119	.278	.179
Sucrose	.203	.129	.171	.334	.216
2-Propanol	.096	.086	.291	.074	.114
Oleic Acid	.089	.091	.230	.034	.084
Cheer	.159	.066	.034	.027	.080
2-Nitrophenol	.032	.102	.030	.024	.028
4-Chloro-3-Methyl Phenol	.036	.296	.078	.062	.189

observed for the test units subjected to any given wastewater the intermediate SRT operation condition and was found to be fairly representative. Influent wastewater composition was found to influence the ratio of volatile to suspended mixed liquor suspended solids to a much greater degree than did SRT. Weighted SVI predictions were developed from predictions of total or volatile suspended solids produced by each influent constituent, and representative SVI data for each of the eight influent compounds determined during single substrate treatability studies. The following equation was utilized to determine the composite SVI for each of the five combined substrate influent conditions based upon volatile suspended solids (VSS):

For compounds 1 through 8,

$$SVI_{PREDICTED} = SVI_1 \frac{VSS_1}{VSS_{TOT}} + \frac{VSS_2}{VSS_{TOT}} + \cdots\cdots SVI_8 \frac{VSS_8}{VSS_{TOT}}$$

A similar equation was employed utilizing total instead of volatile mixed liquor suspended solids.

The results of the predictions of combined substrate unit settleability (as indicated by the SVI test) based upon both volatile suspended solids and total suspended solids are presented in Table XXXIII and XXXIV, respectively. As can be seen from these tables, neither predictions based upon VSS nor TSS yielded acceptable results.

The same rationale was utilized to develop predictions of dewaterability of the combined substrate sludges (as indicated by the CST test). Based upon CST data collected during the single substrate treatability studies and estimates of the TSS produced by the degradation of

TABLE XXXIII

PREDICTED VS. OBSERVED SLUDGE VOLUME INDEX FOR THE FIVE COMBINED SUBSTRATE INFLUENT CONDITIONS BASED UPON VOLATILE SUSPENDED SOLIDS

Combined Substrate Condition No.	Observed SVI Based Upon VSS	Predicted SVI Based Upon VSS
1. CHO/PRO (High S_i)	50.9	109.6
2. Phenols	152.5	89.7
3. Oleic H^+/Prop.	71.1	183.0
4. CHO/PRO (Low S_i)	72.6	140.1
5. 93 mg/L COD Each Component	96.0	113.3

TABLE XXXIV

PREDICTED VS. OBSERVED SLUDGE VOLUME INDEX FOR THE FIVE COMBINED SUBSTRATE INFLUENT CONDITIONS BASED UPON TOTAL SUSPENDED SOLIDS

Influent Condition	Observed SVI Based Upon TSS	Predicted SVI Based Upon TSS
1. CHO/PRO (High S_i)	71	128
2. Phenols	211	98
3. Oleic H^+/Prop.	104	206
4. CHO/PRO (Low S_i)	105	158
5. Equal COD	122	130

each influent constituent (Table XXXII), predictions of combined substrate unit CST values are presented in Table XXXV. If volatile suspended solids concentrations were utilized instead of total suspended solids, the predictive utility of the technique was diminished.

With the exception of the combined substrate condition No. 1, this predictive technique appeared to give reasonable results when comparison to the observed results was made.

4.7 Analysis of Individual Substrates

Table XXXVI presents all of the specific substrate analyses performed upon the single substrate test unit effluents. These residual effluent specific substrate concentrations were converted to corresponding TOC concentrations via previously described conversion factors. For comparison, the observed effluent TOC concentrations are presented in the last column. Examining the six compounds for which data was available, it can be seen that virtually all of the residual effluent TOC was due to metabolites resulting from microbial utilization of the influent constituents.

During the individual compound treatability studies, analyses of effluents for specific feed constituents generally indicated that very low residuals remained in the effluent (<0.2 mg/L). There were, however, two notable exceptions. Oleic acid was present in effluent samples (especially low SRT) analyzed from between 0.7 to 2.5 mg/L. Units subjected to a Cheer influent were found to have effluent residuals of up to 7 mg/L surfactants (90% removal when compared to influents). Again, the low SRT units showed greater surfactant leakage.

TABLE XXXV

PREDICTED *VS.* OBSERVED CAPILLARY SUCTION TIME ANALYSES FOR THE FIVE INFLUENT SUBSTRATE CONDITIONS

Influent Condition	Observed Composite CST (SEC)	Predicted CST (SEC) Based Upon TSS
1. CHO/PRO (High S_i)	5.38	11.4
2. Phenols	8.8	9.0
3. Oleic H^+/Prop.	8.1	7.53
4. CHO/PRO (Low S_i)	10.3	11.27
5. Equal COD	7.38	9.6

TABLE XXXVI

SPECIFIC COMPOUND ANALYSES PERFORMED UPON THE SINGLE SUBSTRATE TEST UNIT EFFLUENTS

Influent Substrate	SRT (days)	Specific Compound Analyses (mg/L)	Calculated Effluent TOC Attributable To Residual Influent Constituents (mg/L)	Observed Effluent TOC (mg/L)
Egg Albumen	2	0.12	0.05	15.3
	6	0.02	0.01	17.0
	10	ND	<0.01	15.3
Starch	2	0.07	0.03	15.7
Oleic Acid	3	1.23	0.53	26.4
	5	1.57	0.68	23.5
	10	0.82	0.36	27.0
Cheer*	6	4.5	0.37	30.0
	12	4.2	0.35	29.0
	18	0.2	0.02	27.0
2-Nitrophenol	5	<0.1†	<0.05	3.9
	10	<0.3	<0.14	6.4
4-Chloro-3-Methyl Phenol	8	<0.1	<0.06	12.4
	15	<0.1	<0.06	9.8

*Reported as mg/L LAS (multiply by 9.8 to obtain mg/L Cheer).
†Unidentified compound noted on GC chromatogram (shorter RT than 2-Nitrophenol).

Table XXXVII summarizes the results obtained from analyses for the specific substrates remaining in the effluents from the combined substrate test units. Where possible, the individual compound concentrations were converted to TOC concentrations and the sum of all eight individual compound TOC values appears in the second column from the right (Table XXXII). Generally, the observed TOC values are seven times greater than the TOC concentration determined by summing the individual residual influent components. This indicates that the great majority of effluent TOC consists of microbial intermediates rather than from unmetabolized influent constituents.

It should be mentioned that since one of the effluent constituents was strippable (2-propanol), analyses of the exhaust gas emitted from the aeration basis were performed upon the combined substrate unit subjected to high propanol concentrations (Condition No. 3). Significant air stripping of 2-propanol would have necessitated incorporation of a stripping term into the substrate removal expression. However, since less than 0.2% of the propanol administered was detected in the off-gas, further testing or the incorporation of a stripping term were not deemed necessary.

In the previous sections, methods that might predict effluent substrate concentrations in terms of TOC, COD and BOD were investigated. A technique which could predict the residual effluent concentration of each of the eight individual influent constituents would also be useful. Two compounds, oleic acid and cheer, were selected for study because:

1. A greater amount of analytical data were available for these two compounds.

TABLE XXXVII

SPECIFIC COMPOUND ANALYSIS PERFORMED UPON THE COMBINED UNIT EFFLUENTS (ALL ANALYSES REPORTED AS mg/L)

Influent Condition	SRT days	Egg Albumen	CHO	Prop.	Oleic H^+	Detergents†	2-Nitro Phenol	Chloro Methyl Phenol	Calculated Effluent TOC Attributable To Residual Influent Constituents	Observed Effluent TOC
1. CHO/PRO; High S_i	7					0.84	<0.3	<0.3		21.3
	10	<4				0.74				50.7
	15					1.46	<0.3	<0.3		23.0
2. Phenols; High S_i	4				<0.2	0.94	<0.3	<0.3		22.0
	7				<0.2		<0.3	<0.3		25.5
	10				<0.2	0.48	<0.3	<0.3		30.0
3. Oleic H^+/Prop.; Low S_i	4	1.4	0.3		0.2	0.69	0.6	1.2	3.3*	22.0
	7		0.4		<0.2	0.22	9.3	4.5		21.4
	12	1.3	0.3	0.45	0.4	0.16	2.3	0.6	2.7	18.3
4. CHO/PRO; Low S_i	4	1.4	0.3	0.44	<0.2	0.08	4.5	0.5	3.5	23.1
	7	0.6	<0.2	0.16	<0.2	0.14	<0.1	<0.1	<0.8	8.1
	12	<0.2	0.16		<0.2	0.08	<0.1	<0.1	<1.0*	7.0
5. 93 mg/L COD Each Compound; Low S_i	4	0.9	0.4		0.4	0.41	5.0	0.2	4.2*	23.8
	7	1.1	0.3		0.2		<0.1	<0.1		21.6
	12	0.2	<0.2		<0.2	0.45	<0.1	<0.1	1.5*	12.3

*Assume 1 mg/L propanol in effluent.

†Reported as mg/L LAS (multiply by 9.8 to obtain mg/L detergent).

2. Measurable effluent residuals were noted for these two compounds during the single substrate treatability studies.

Again, the Kincannon/Stover, Eckenfelder and Lawrence/McCarty models were utilized. The predictive assumptions used were identical to the discreet compound and total VSS assumptions described previously. However, observed VSS concentrations were used in the total VSS assumption (Kincannon/Stover and Eckenfelder models). An estimate of volatile suspended solids which would be employed for the discreet compound treatability assumption was obtained by reviewing the TOC predictions of VSS determined by utilizing this same predictive assumption (Appendix B). The fraction of the total biomass which was attributable (by prediction) to the substrate under investigation was used to correct the observed VSS for subsequent substitution into the Kincannon/Stover and Eckenfelder expressions for S_e. As mentioned before, the Lawrence/McCarty expression for S_e is not a function of VSS. Table XXXVIII presents the biokinetic constants utilized to determine predicted effluent concentrations of oleic acid and cheer. The biokinetic plots from which these constants were determined are presented in Appendix C.

Table XXXIX and XL show the results of the various predictive methods for oleic acid and cheer, respectively. The Kincannon/Stover model was prone to give predictions of S_e which were negative, especially when utilizing the total VSS assumption. Negative values for S_e occur when U_{max} is greater the quantity $K_B + (FS_i/XV)$. It was attempted to adjust the biokinetic plot (within reasonable limits) to determine whether the number of negative values could be reduced. If the slope was increased and the intercept decreased to give $U_{max} = 100$ and $K_B = 103$, more reasonable predictions resulted when the total VSS assumption

TABLE XXXVIII

BIOKINETIC CONSTANTS IN TERMS OF SPECIFIC COMPOUND ANALYSES DETERMINED FOR THE SINGLE SUBSTRATE TEST UNITS

Compound	Oleic Acid	Cheer
U_{max} $\frac{1}{\text{days}}$	66.67	18.6
K_B $\frac{1}{\text{days}}$	65.67	16.77
k_e' $\frac{1}{\text{days}}$	420.0	47.0
k $\frac{1}{\text{days}}$	10.0	3.39
K_S (mg/L)	13.8	1.36
Y_t	0.249	0.054
K_d $\frac{1}{\text{days}}$	0.062	0.062

TABLE XXXIX

PREDICTIONS OF EFFLUENT OLEIC ACID CONCENTRATIONS FOR THE COMBINED SUBSTRATE TEST UNITS

				Predicted Effluent Oleic Acid Concentration (mg/L)				
				VSS Produced By Oleic Acid (Estimate) Discreet Compound Treatability Assumption			Total VSS Treatability Assumption	
Combined Substrate Influent Condition Number	SRT days	Influent Oleic Acid Concentration (mg/L)	Observed Effluent Oleic Acid Concentration (mg/L)	Kincannon/ Stover	Eckenfelder	Lawrence/ McCarty	Kincannon/ Stover	Eckenfelder
2	4	82	<0.2	50	9.9	1.95	0*	0.02
	7	82	<0.2	39	7.8	1.23	0*	0.01
	10	82	<0.2	23	5.1	0.97	0*	0.01
3	4	80	0.2	0.4	0.4	1.98	0*	0.03
	7	80	<0.2	0*	0.2	1.23	0*	0.02
	12	80	0.4	0*	0.2	0.85	0*	0.01
4	4	15	<0.2	18	3.5	1.99	0*	0
	7	15	<0.2	9.6	1.9	1.24	0*	0
	12	15	<0.2	6.3	1.4	0.86	0*	0
5	4	30	0.4	25	5.0	1.98	0*	0
	7	30	0.2	16	3.4	1.21	0*	0
	12	30	<0.2	12	2.7	0.85	0*	0

*Note: Actual prediction was negative.

TABLE XL

PREDICTIONS OF EFFLUENT CHEER CONCENTRATIONS FOR THE COMBINED SUBSTRATE TEST UNITS

				Predicted Effluent Cheer Concentration (mg/L)				
				VSS Produced By Cheer (Estimate) Discreet Compound Treatability Assumption			Total VSS Treatability Assumption	
Combined Substrate Influent Condition Number	SRT days	Influent Cheer Concentration (mg/L)	Observed Effluent Cheer Concentration (mg/L)	Kincannon/ Stover	Eckenfelder	Modified Lawrence/ McCarty	Kincannon/ Stover	Eckenfelder
1	7	731	8.2	285 (27)	165	5.1	0* (22)	9.2
	10	731	7.3	19.5 (22)	35	3.7	0* (21)	3.6
	15	731	14.3	0* (22)	17.7	2.8	0* (21)	2.6
2	4	549	9.2	549 (549)	549	8.6	0* (16)	8.3
	10	549	4.7	50 (17.2)	40	3.8	0* (16)	3.8
3	4	137	6.7	137 (137)	137	8.7	0* (4.0)	0.7
	7	137	2.2	31 (4.6)	18	5.0	0* (4.0)	0.4
	12	137	1.6	3.0 (4.2)	6.3	3.3	0* (4.0)	0.4
4	4	137	0.8	137 (137)	17.7	8.8	0* (4.0)	0.9
	7	137	1.4	46 (4.8)	26	5.0	0* (4.0)	0.5
	12	137	0.8	6.1 (4.2)	7.4	3.3	0* (4.0)	0.4
5	4	290	4.0	290 (290)	290	8.7	0* (8.5)	3.5
	12	290	4.4	7.7 (8.8)	13.7	3.3	0* (8.5)	1.6

*Note: Actual prediction was negative.
Brackets surround Kincannon/Stover predictions after redrawing kinetic plot.

was utilized (see results in brackets in Table XL). If the slope was decreased while the intercept was increased, the predictions became even more negative. Difficulty was also encountered while using the Lawrence/McCarty predictive model in predicting effluent cheer concentrations. From the kinetic plot of the pilot data, it was noted the maximum growth rate for cheer utilizing organisms would be:

$$Y_t \,.\, k = (.054).(3.39) = 0.183$$

This corresponds to an SRT of:

$$\frac{1}{(\mu - k_d)} = \frac{1}{(.183 - .062)} = 8.3 \text{ days}$$

Since pilot units were operated at an SRT of six (6) days, there appeared to be some deficiency with the Lawrence/McCarty plot. Therefore, it was decided to use the modified Lawrence/McCarty technique where k would be equivalent to the Kincannon/Stover U_{max} and the kinetic slope was redrawn ($U_{max} = 18.6$; $K_B = 16.8$). These are the results presented in Table XL. For oleic acid, some negative estimates of S_e were noted (Kincannon/Stover model) but these were usually only slightly negative (greater than -1).

Generally speaking, those models employing the total VSS treatability assumption more accurately predicted effluent cheer and oleic acid concentrations. Although the Lawrence/McCarty model predictions (after modifying the cheer plot) were reasonable, they were insensitive to influent substrate concentrations. At least for the cheer component, influent concentration as well as SRT seemed to impact effluent concentrations.

CHAPTER V

DISCUSSION

5.1 Contrast of Biokinetic Constants Determined For Each Of The Eight Substrates

Figures 30 through 34 present the results of the biokinetic plots in terms of TOC and VSS utilized to determine each of the constants employed in these investigations. For any given plot, the results obtained for each individual compound are shown superimposed upon the same graph. By analyzing these plots and by possessing a knowledge of the confidence that can be placed in determining the exact location of each curve (Appendix A), the observer can judge just how significant any differences in biokinetic constants between the eight compounds are. The yield and decay coefficient plots generally carry a high degree of reliability in that SRT can be accurately maintained while substrate utilization rates for any influent and SRT condition will usually fluctuate within a fairly specific range. During this study, the higher yielding compounds (with respect to TOC) were found to be Cheer and Sucrose while Egg Albumen, 2-Propanol and 2-Nitrophenol were found to result in rather low cell yields. Oleic Acid and 2-Nitrophenol were found to be associated with rather high cell maintenance coefficients. Perhaps due to the fact that 2-Nitrophenol has been demonstrated to induce a degree of uncoupling of oxidative phosphorylation (although not

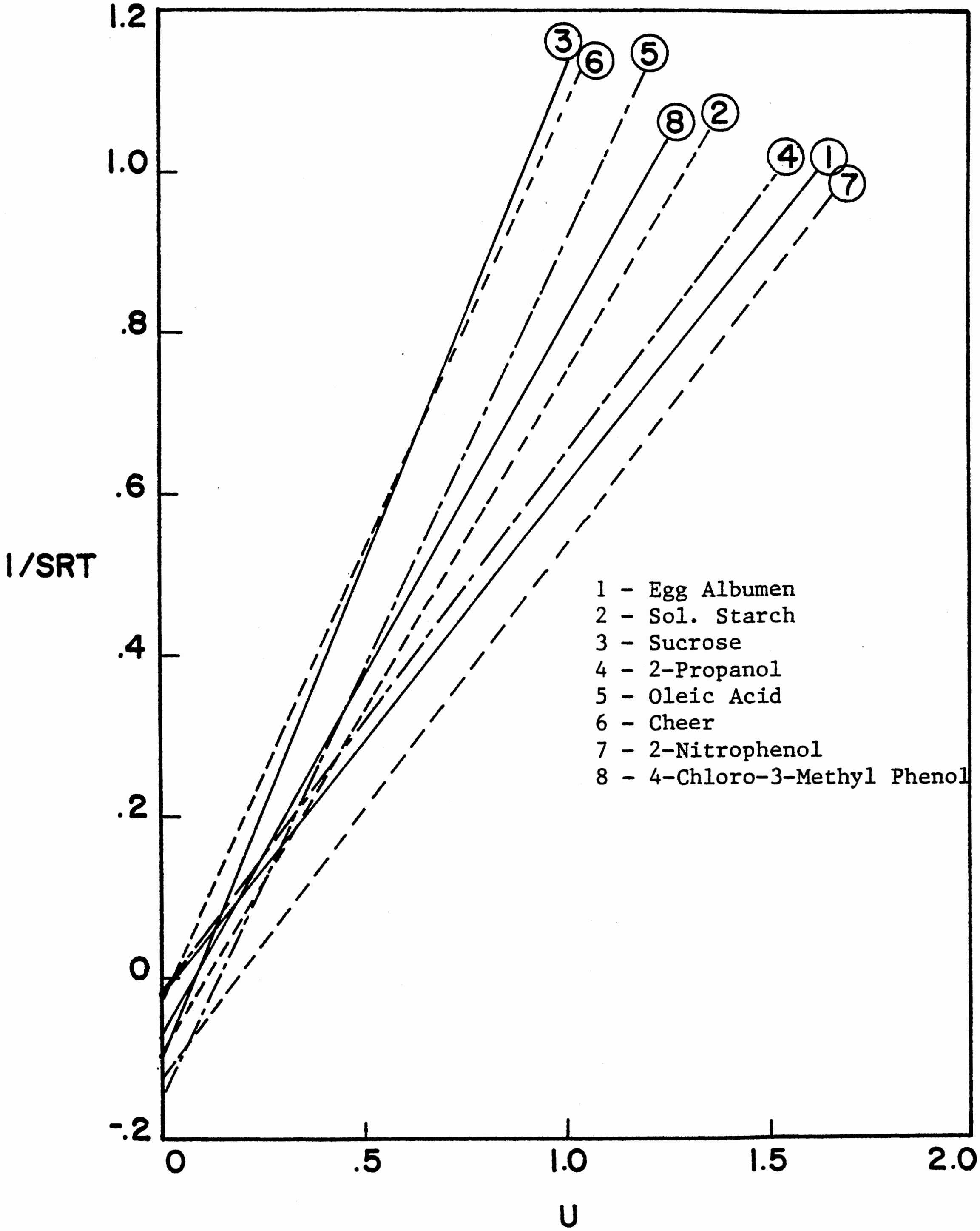

Figure 30. Biokinetic Plots for the Determination of Y_t and k_d for Each of the Organic Constituents of the Combined Unit Influents in Terms of TOC and VSS

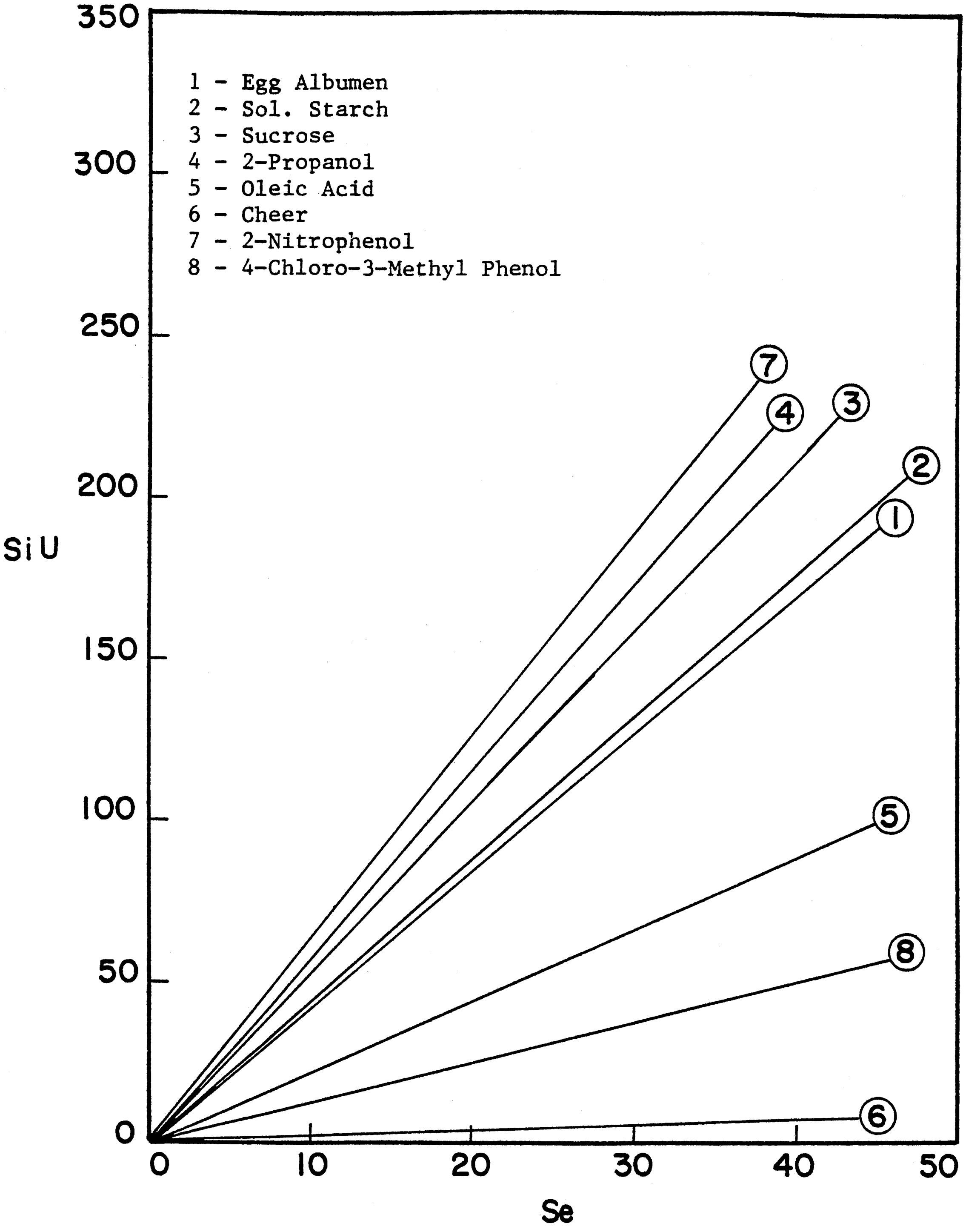

Figure 31. Biokinetic Plots for the Determination of Eckenfelder's k_e' for Each of the Organic Constituents of the Combined Unit Influents in Terms of TOC and VSS

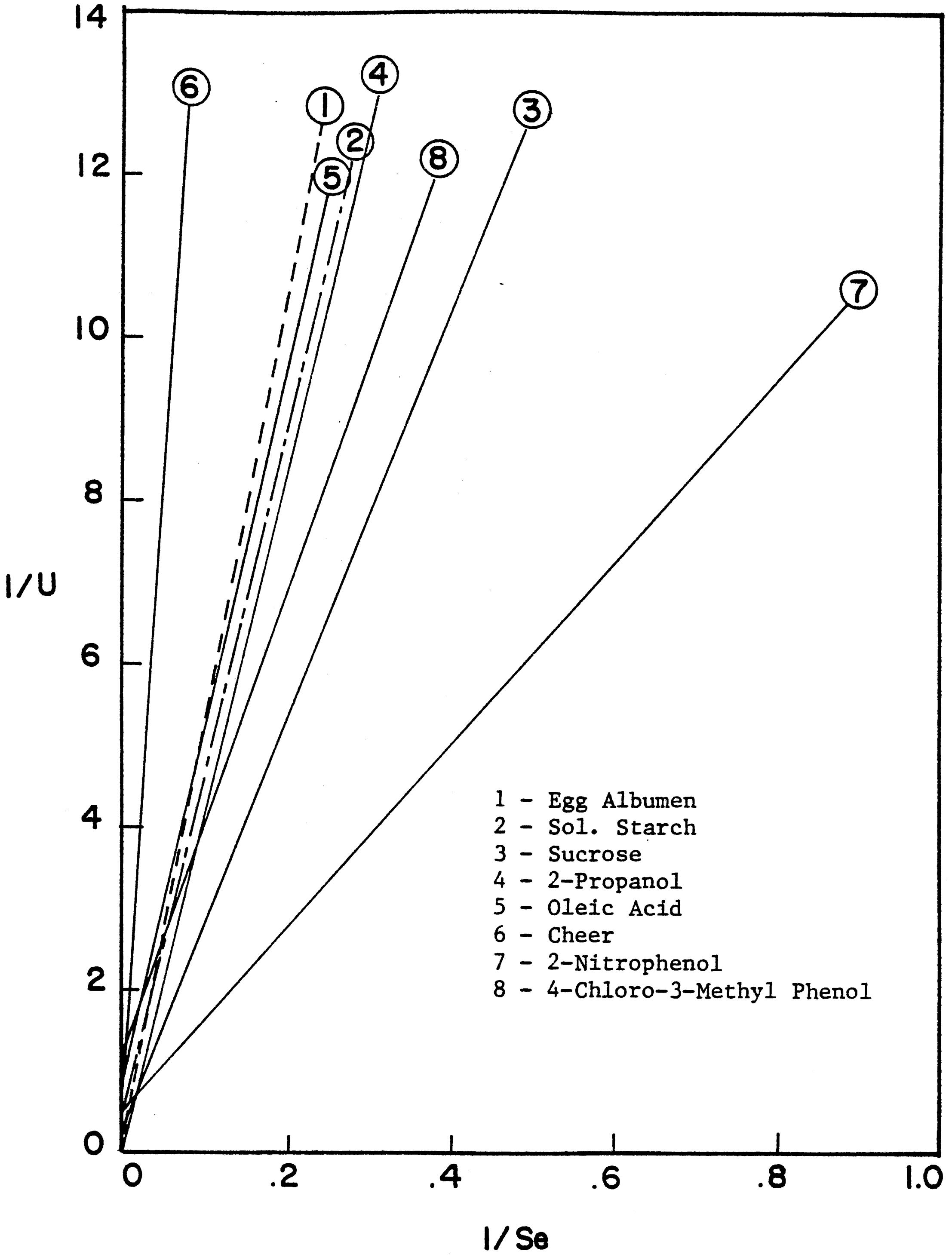

Figure 32. Biokinetic Plots for the Determination of Lawrence and McCarty's k and K_s for Each of the Organic Constituents of the Combined Unit Influents in Terms of TOC and VSS

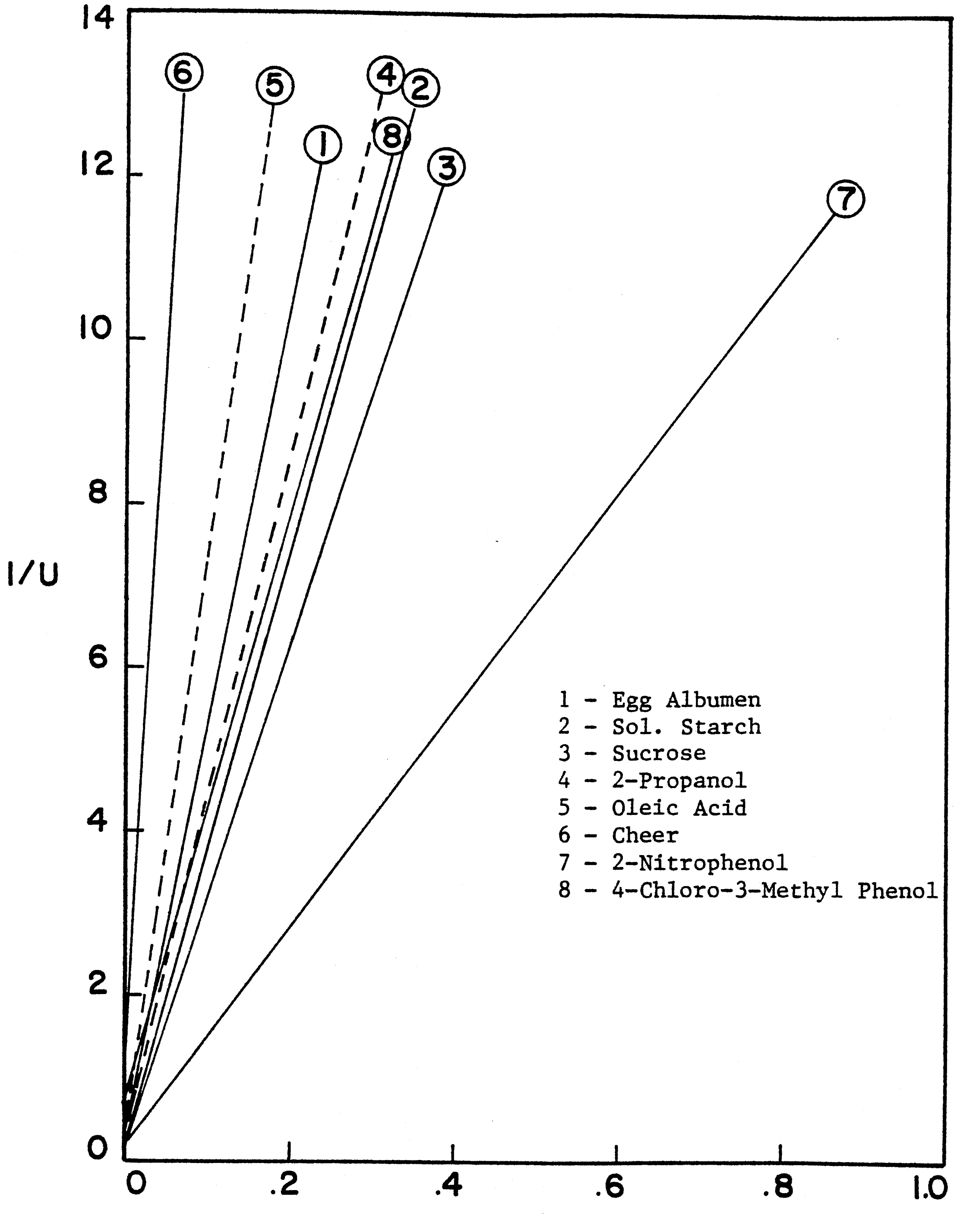

Figure 33. Biokinetic Plots for the Determination of Modified Lawrence and McCarty's k and K_s for Each of the Organic Constituents of the Combined Unit Influents in Terms of TOC and VSS

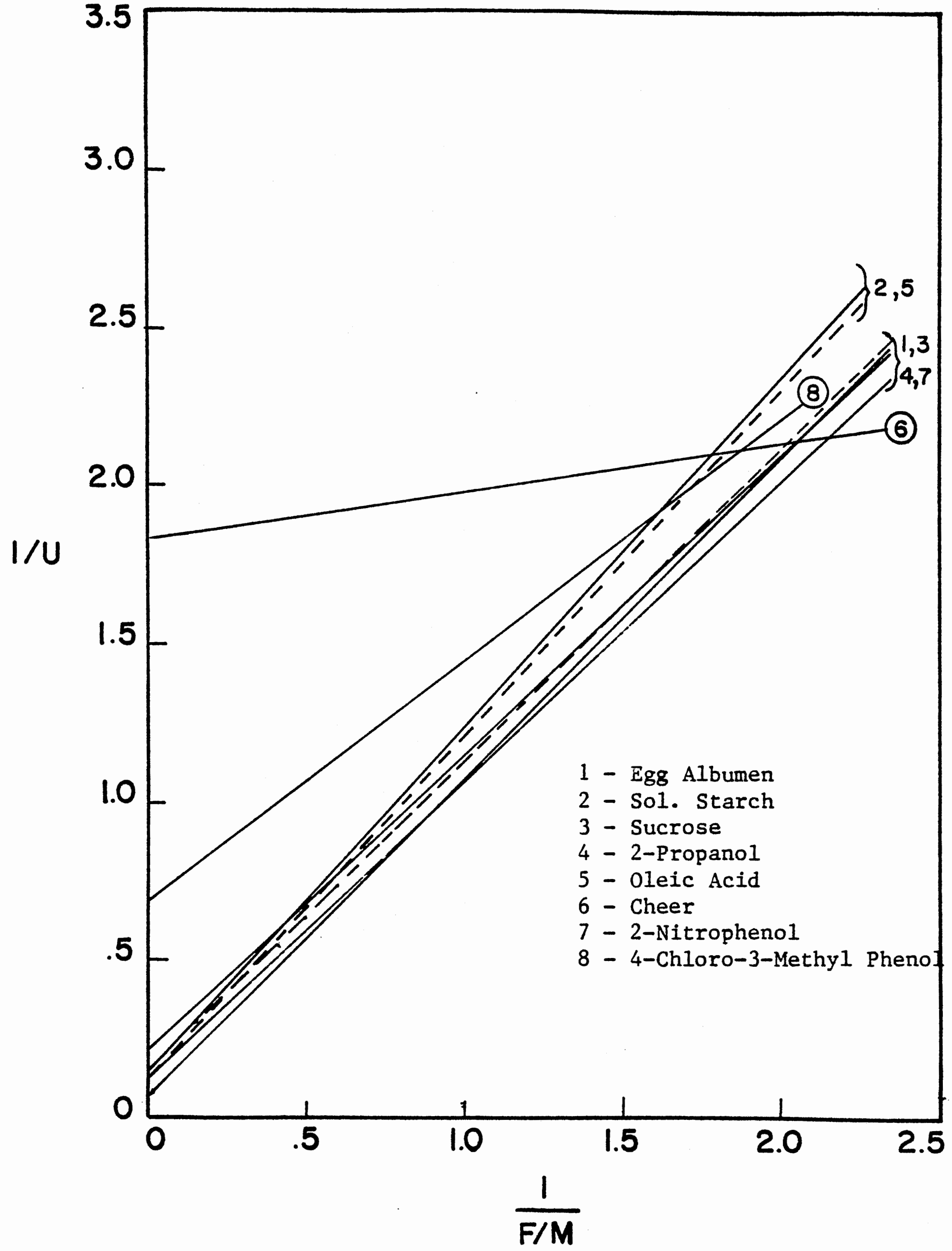

Figure 34. Biokinetic Plots for the Determination of Kincannon and Stover's U_{max} and K_B for Each of the Organic Constituents of the Combined Unit Influents in Terms of TOC and VSS

as potent as 2, 4-Dinitrophenol), cell yield is kept low while the maintenance coefficient is high. Cell yield was also found to be low in the combined substrate studies where 2-Nitrophenol was added at a high concentration.

Eckenfelder's plot using the TOC substrate parameter was subject to much data scatter. For the compounds studied, there was no reason to suspect that inclusion of a non-biodegradability term was necessary. Therefore, the intercept for all of the plots was assumed to be zero. As can be seen from Appendix A, some doubt exists concerning how to draw the slope line which would describe the substrate removal expression (ke') for each compound studied. Nevertheless, from Figure 22, it could be generalized that Cheer and possibly 4-Chloro-3-Methyl Phenol were shown to be removed at relatively slow rates while 2-Nitrophenol, 2-Propanol and, perhaps, Sucrose were shown to be rapidly removed.

The plots of Lawrence and McCarty (Figure 23) were also found to be replete with data scatter. For these plots, however, both the intercept and the slope are given significance and, generally, numerous lines of various slopes and intercepts could be employed to describe the data. A modification of the Lawrence and McCarty plot (Figure 24) was employed whereby the intercept (1/k) was assumed to be the same as that determined from the Kincannon and Stover model ($1/U_{max}$). This technique allowed fixing of the intercept and a more convenient procedure for determining the slope. From either version of the Lawrence and McCarty plots, it can be seen that the Cheer maximum substrate utilization rate was relatively low while the 2-Nitrophenol maximum substrate utilization rate was among the higher of those compounds investigated.

It has been mentioned before that the Kincannon and Stover plot has less inherent variability and that a high degree of confidence can be given a curve fit through the data collected during pilot studies. From Figure 25, it may be observed that six of the eight compounds studied exhibited reciprocal maximum specific substrate utilization rates that were quite similar (0.1-0.25 days) with slopes (from which K_B would be determined) showing only slight differences. Cheer bench scale studies indicated a rather low maximum specific substrate utilization rate while 4-Chloro-3-Methyl Phenol studies showed a maximum specific substrate utilization rate somewhere between those determined for Cheer and the other six compounds.

An attempt was made to correlate COD biokinetic constants to those determined using the TOC substrate parameter. Again, conversion factors determined in the laboratory were utilized to accomplish this objective. For Yt and ke', the results obtained by direct usage of COD data correlated fairly well with the results obtained by converting TOC data to COD data. U_{max} results obtained by conversion to COD values did not correlate quite as well with results obtained by direct analysis of COD data. Even for ke' and Yt, however, caution should be exercised before undertaking the calculation of a particular biokinetic constant in terms of one substrate parameter from a constant obtained by analyses incorporating a different substrate parameter.

5.2 Evaluation of Methods Pertaining To The Simultaneous Prediction of Mixed Liquor Volatile Suspended Solids (X) and Soluble Effluent Substrate Concentration (S_e)

In order to incorporate these pilot study data for scale-up and design over a wide range of operating conditions (influent composition, influent organic concentration, wastewater flow and SRT) simultaneous predictions of X and S_e were made. Two (2) kinetic expressions possessing two unknowns (X and S_e) were solved simultaneously and predictions of these two parameters for the various operating conditions determined. A means by which to compare and evaluate the utility of each of the ten predictive techniques was needed in order to select the technique(s) which would offer the greatest value. A statistical technique (collection of percent errors) was employed in order to apply a mathematical unbiased evaluation. However, an empirical approach was also used (see Section 5.2.4). For the statistical evaluation system, the predictive results were divided into the following three categories:

1. High S_i Conditions (Condition Numbers 1 and 2).
2. Low S_i Conditions (Condition Numbers 3 through 5).
3. Overall (All Conditions).

The grading scale was based upon the mean percent error of measurement relative to the mean observed value. Results of the percent error calculations appear in Appendix D. The percent error was computed for each combined substrate unit operating condition by the following formula:

$$\frac{Z_p - Z_o}{Z_o} \times 100$$

where Z_p was the predicted value and Z_o the mean observed value for the particular operating condition. A positive percent error indicated that the predicted value was greater than the observed value while a negative percent error indicated that the reverse was true. The collection of percent errors within a category (High S_i, Low S_i or Overall) was statistically evaluated and mean and standard deviations (of percent errors) calculated. The arbitrary grading system was as follows:

A = mean percent error was less than 10% and did not have a standard deviation greater than 10%.

B = mean percent error was less than 20% with one standard deviation from the mean being within 30% of the actual value.

C = mean percent error was less than 30% with one standard deviation being within 40% of the actual value.

D = mean percent error was less than 40% with one standard deviation being within 60% of the actual value.

E = greater percent error than D.

Due to the magnitude of the values required for predictions of volatile suspended solids, it was less difficult to achieve a high grade for these estimates. However, for the predictions of soluble effluent substrate concentrations, it was much more difficult for a predictive technique to achieve a high grade due to the fact that an error of just a few milligrams per liter could translate to a high percent error. For instance, if a mixed liquor volatile suspended solids predictive technique is to be of much usefulness, it should almost assuredly obtain at least a high B grade. On the other hand, a soluble effluent substrate predictive technique could have utility if it is awarded only a C grade. Although a D grade for a solids predictive method has little meaning, the D and E grade was used for substrate technique evaluation to remove from consideration any totally unacceptable methods (E) but hold for future modification any marginal techniques (D). If a predictive technique was either high or low relative to the observed values, an L (low) or H (high) follows the assigned grade.

5.2.1 Simultaneous Predictions of X and S_e Using the TOC Substrate Parameter

The resultant evaluations of the predictive techniques employed for the simultaneous determination of S_e and X in terms of TOC are presented in Tables XLI and XLII, respectively. The most reasonable predictions of S_e were made employing the weighted constant assumption. The Kincannon/Stover model was found to be more appropriate for the low S_i influent conditions while the Eckenfelder model was found to be more appropriate for the high S_i conditions. However, the Lawrence/McCarty model only gave marginal predictions and the modification only rendered them slightly less accurate. The poor predictive capability of the discreet compound treatability technique proves invalid the assumption that only biomass produced from the degradation of a specific compound can be employed to degrade that compound. This finding has also been brought to light in the work of Lackman et al. (25) The total VSS predictive technique did reduce the percent error of the models employed but results were still unsatisfactory. In addition, an underlying flaw in the model is its inability to translate this additional substrate removal into biomass production.

TABLE XLI

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; S_e IN TERMS OF TOC

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	E(H)	$\underline{\text{B}}$	$\underline{\underline{\text{D(H)}}}$
	Eckenfelder	$\underline{\text{B}}$	$\underline{\text{D(L)}}$	$\underline{\underline{\text{D(L)}}}$
	Lawrence/McCarty	E(L)	$\underline{\text{D(L)}}$	$\underline{\underline{\text{D(L)}}}$
	Mod. Lawrence/McCarty	E(L)	$\underline{\text{D(L)}}$	E(L)
Discreet Cmp. Trt.	Kincannon/Stover	E(H)*	E(H)	E(H)
	Eckenfelder	E(H)*	$\underline{\text{D(H)}}$	E(H)
	Lawrence/McCarty	E(H)*	E(H)*	E(H)*
	Mod. Lawrence/McCarty	E(H)*	E(H)*	E(H)*
Total VSS Trt.	Kincannon/Stover	E(H)	$\underline{\text{C(H)}}$	E(H)
	Eckenfelder	$\underline{\text{D(L)}}$	E(L)	E(L)

*Demonstrated very poor predictive capability.

TABLE XLII

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; X IN TERMS OF TOC

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	C(H)	A(L)	B
	Eckenfelder	D(H)	A	B
	Lawrence/McCarty	D(H)	A	B
	Mod. Lawrence/McCarty	D(H)	B	B
Discreet Cmp. Trt.	Kincannon/Stover	B(L)	B(L)	B(L)
	Eckenfelder	B(L)	B(L)	B(L)
	Lawrence/McCarty	C(L)	D(L)	C(L)
	Mod. Lawrence/McCarty	C(L)	D(L)	D(L)
Total VSS Trt.	Kincannon/Stover	B(L)	B(L)	B(L)
	Eckenfelder	B(L)	B(L)	B(L)

Probably the most useful volatile suspended solids predictions were obtained from the Kincannon/Stover model employing the weighted constant assumption while Eckenfelder's model also gave reasonable results (same assumption). Both tended to overestimate solids production for the high S_i influent condition, however. In general, the weighted constant assumption yielded much better estimates of X than either the discreet compound or total VSS treatability assumption.

5.2.2 Simultaneous Predictions of X and S_e Using the COD Substrate Parameter

The results of the evaluations of the various predictive techniques employed for the simultaneous prediction of X and S_e using the COD substrate parameter are shown in Tables XLIII and XLIV for S_e and X, respectively. Due to the poor performance of the Lawrence/McCarty models when utilizing the TOC substrate parameter, further evaluation of these models was discontinued.

None of the predictive techniques tested correlated very well to the observed S_e values. The Kincannon/Stover (weighted constant assumption) model probably gave the best overall performance but even this was marginal.

Suspended solids concentrations for both the high and low S_i influent conditions were best predicted, here, utilizing the discreet compound treatability assumption (both models) but, again, the correlation was not very good.

Unfortunately, much more TOC data was gathered than was COD data. It is quite conceivable that the amount of COD data collected was not

TABLE XLIII

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; S_e IN TERMS OF COD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	D(H)	D(L)	D(L)
	Eckenfelder	C(H)	E(L)	D(L)
Discreet Cmp. Trt.	Kincannon/Stover	E(H)*	E(H)	E(H)
	Eckenfelder	E(H)*	E(H)	E(H)
Total VSS Trt.	Kincannon/Stover	E(H)	D(L)	D
	Eckenfelder	E(L)	E(L)	E(L)

*Demonstrated very poor predictive capability.

TABLE XLIV

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; X IN TERMS OF COD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	E(H)	B(L)	C(L)
	Eckenfelder	D(L)	B(L)	C
Discreet Cmp. Trt.	Kincannon/Stover	C	B(L)	C(L)
	Eckenfelder	C	B(L)	C(L)
Total VSS Trt.	Kincannon/Stover	C	B(L)	C(L)
	Eckenfelder	C	B(L)	C(L)

statistically sufficient to account for the biosystem fluctuations or the analytical variability inherent in the test procedures.

5.2.3 Simultaneous Predictions of X and S_e Using the BOD Substrate Parameter

Simultaneous predictions of S_e and X utilizing the BOD substrate parameter are presented in Tables XLV and XLVI, respectively. None of the techniques tested generated predictions of S_e that correlated very well with the mean values of the observed data. However, as pointed out before, the variability noted for BOD test results for each operating condition was quite high. In addition, the number of BOD samples analyzed during each test condition was quite small compared to the number of TOC samples analyzed raising the question of whether or not the sample was statistically significant.

Predictions of suspended solids concentrations were, overall, rather poor. The predictions made during the high influent substrate concentration conditions (1 and 2) were generally better than those determined for the low S_i predictions.

5.2.4 Empirical Evaluation of Predictive Methods

The statistical evaluation and grading system used in the preceding sections has the advantage of being rigidly structured and unbiased but tends to be somewhat abstract. Therefore, a second, empirical, more simplistic evaluation system was utilized to gauge the usefulness of each predictive technique. Referring to Figures 11 through 21, one can find the mean observed operating parameter (X or S_e) plus and minus one

TABLE XLV

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; S_e IN TERMS OF BOD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	E(H)*	E(L)	E(H)
	Eckenfelder	E(H)*	E(L)	E(H)
Discreet Cmp. Trt.	Kincannon/Stover	E(H)*	E(H)	E(H)*
	Eckenfelder	E(H)*	E(H)	E(H)*
Total VSS Trt.	Kincannon/Stover	E(H)	E(L)	E(L)
	Eckenfelder	E(H)	E(L)	E(L)

*Demonstrated very poor predictive capability.

TABLE XLVI

EVALUATION OF PREDICTIVE TECHNIQUES FOR THE SIMULTANEOUS PREDICTION OF X AND S_e; X IN TERMS OF BOD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	B	D(L)	D(L)
	Eckenfelder	B	D(L)	D(L)
Discreet Cmp. Trt.	Kincannon/Stover	B(L)	D(L)	D(L)
	Eckenfelder	B(L)	D(L)	D(L)
Total VSS Trt.	Kincannon/Stover	B(L)	D(L)	D(L)
	Eckenfelder	B(L)	D(L)	D(L)

standard deviation for the various predictive techniques, substrate parameters (TOC, COD or BOD), and combined substrate unit operating conditions. If it is assumed that a prediction falling within one standard deviation is a "reasonable value", then each technique can be rated relative to the percentage of "reasonable predictions" obtained. This evaluation is presented in Table XLVII.

Analysis of Table XLVII in terms of the TOC substrate parameter indicates that the highest prediction success rate was associated with combined substrate test units subjected to low S_i. All models utilizing the weighted constant assumption at these combined unit influent conditions produced very reasonable predictions for both X and S_e. Besides these low influent organic concentration combined unit operating conditions where the substrate parameter TOC was utilized, very few successes were realized. Notable exceptions follow:

1. S_e in terms of TOC - High S_i - Weighted Constant Assumption - Eckenfelder model.
2. S_e in terms of TOC - Low S_i - Total VSS Treatability Assumption - Kincannon/Stover model.
3. S_e in terms of BOD - High S_i - Total VSS Treatability Assumption - Eckenfelder model.
4. S_e in terms of BOD - Low S_i - Weighted Constant Assumption - Kincannon/Stover model.
5. S_e in terms of BOD - Low S_i - Total VSS Treatability Assumption - Kincannon/Stover model.

The lack of success achieved by the discreet compound treatability assumption casts doubt upon the utility of that method. The inability of any of the assumptions and models to produce reasonable predictions

TABLE XLVII

SUCCESS RATE (PERCENT) OF PREDICTIVE TECHNIQUE UTILIZED FOR THE SIMULTANEOUS PREDICTION OF X AND S_e RELATIVE TO THE OBSERVED PERFORMANCE OF THE COMBINED SUBSTRATE TEST UNITS

		Predictive Technique Employed									
		Weighted Constant				Discreet Compound Treatment				Total VSS	
		K + S	Eck.	L + M	Mod. L + M	K + S	Eck.	L + M	Mod. L + M	K + S	Eck.
High S_i											
TOC	X	20	0	0	0	40	20	20	40	40	20
	S_e	0	80	20	20	0	0	0	0	0	10
COD	X	60	20	--	--	40	40	--	--	40	40
	S_e	60	80	--	--	0	0	--	--	60	0
BOD	X	40	40	--	--	40	40	--	--	40	40
	S_e	20	20	--	--	0	0	--	--	20	80
Low S_i											
TOC	X	56	89	89	89	44	55	0	0	44	55
	S_e	89	89	89	89	56	67	0	0	89	9
COD	X	33	44	--	--	22	22	--	--	22	22
	S_e	67	44	--	--	44	44	--	--	67	0
BOD	X	22	22	--	--	33	22	--	--	33	22
	S_e	78	56	--	--	56	56	--	--	78	9

at both the high and low influent organic concentration conditions may indicate some underlying flaw in the models concerning the effect of S_i upon S_e.

5.2.5 Discreet Compound and Total VSS Assumptions

As can be seen in Appendix B, the discreet compound and total VSS assumptions result in a set of predictions of residual substrate and biomass production due to the degradation of each of the components comprising the influent. As per these projections, the Cheer component of the effluent is almost always the major contributor of residual substrate. This may be due to the very slow uptake of this detergent shown by all biokinetic models. These values are only hypothetical, however, and further studies (perhaps radioisotope tracer studies) are needed to gauge the appropriateness of these predictions. The marginal utility of these assumptions in predicting accurate total S_e and X values has been previously discussed.

5.3 Evaluation of Methods Pertaining to the Independent Prediction of Mixed Liquor Volatile Suspended Solids (X) and Soluble Effluent Substrate Concentration (S_e)

In Section 5.2, techniques which could predict, simultaneously, X and S_e were evaluated. Since these predictions were based upon the solution of two independent equations, a deficiency in one expression could adversely affect the prediction of the other. Independent prediction of X and S_e requires that each equation be solved utilizing the actual observed value for the unknown variable. In so doing, any weaknesses inherent in either the substrate or biomass expressions can be elucidated. Application of these depended expressions may also be useful in the operational control of full scale facilities.

An evaluation of the techniques investigated for the independent prediction of X and S_e follows. A grading/evaluation system identical to that used for the simultaneous prediction of X and S_e was employed. Due to problems involving data variability and limited sample population, the BOD substrate parameter was not considered here. Since the prediction of X utilizing the total VSS treatability assumption would not be different from the discreet compound treatability assumption and since S_e predictions would not change significantly, this assumption was not evaluated in this section.

5.3.1 Predictions Using the TOC Substrate Parameter

Tables XLVII and XLVIII present the evaluation of independent predictive techniques for S_e and X, respectively for the TOC substrate parameter. The empirical evaluation system for both TOC and COD results is summarized in Table XLIX.

The statistical evaluation of S_e predictions calculated based upon observed X indicated little improvement in predictive capability (compare with Table XLI). The empirical evaluation technique also showed that little improvement in the prediction of S_e was attained by utilizing observed rather than predicted X in the predictive equations (compare with Table XLVII).

TABLE XLVIII

EVALUATION OF PREDICTIVE TECHNIQUES FOR S_e BASED UPON OBSERVED X IN TERMS OF TOC

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	E(H)	B	D(H)
	Eckenfelder	E(H)	E(L)	D(L)
Discreet Cmp. Trt.	Kincannon/Stover	E(H)	E(H)	E(H)
	Eckenfelder	E(H)	E(H)	E(H)

TABLE XLIX

EVALUATION OF PREDICTIVE TECHNIQUES FOR X BASED UPON OBSERVED S_e IN TERMS OF TOC

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	All	C(H)	A	B
Discreet Cmp. Trt.	Kincannon/Stover	C(H)	A	B
	Eckenfelder	C(H)	B^+	B
	Lawrence/McCarty	C(H)	B^+	B
	Mod. Lawrence/McCarty	C(H)	B^+	B

TABLE L

SUCCESS RATE (PERCENT) OF PREDICTIVE TECHNIQUES UTILIZED FOR THE INDEPENDENT PREDICTIONS OF X AND S_e RELATIVE TO THE OBSERVED PERFORMANCE OF THE COMBINED SUBSTRATE TEST UNITS

		Predictive Technique Employed							
		Weighted Constant				Discreet Compound Treatment			
		K + S	Eck.	L + M	Mod. L + M	K + S	Eck.	L + M	Mod. L + M
TOC	X	0	0	0	0	0	0	0	0
	S_e	40	40	--	--	0	20	--	--
COD	X	20	20	20	20	20	20	--	--
	S_e	40	20	--	--	0	20	--	--
TOC	X	78	78	78	78	67	67	67	56
	S_e	89	67	--	--	56	67	--	--
COD	X	56	56	56	56	56	56	--	--
	S_e	67	22	--	--	56	44	--	--

5.3.2 Predictions Using the COD Substrate Parameter

Tables LI and LII present the evaluation of the independent predictive techniques for S_e and X, respectively using the COD substrate parameter. Utilization of the observed value of X in the substrate expression and observed S_e in the biomass expression had the general effect of improving the predictions although for certain comparisons (with simultaneous predictions), predictive accuracy actually diminished. However, the improvement was barely perceptible and major problems appear to lie with these techniques, especially with regard to effluent substrate predictions. The empirical data evaluation (Table L), also, supports these findings.

It should be mentioned that there could be a myriad of interactions and intricacies existing as a heterogeneous population of microorganisms is subjected to a multicomponent organic wastewater. At the biochemical level, there could exist cases of one compound inhibiting the metabolism of another or influencing a particular shunt to operate causing production of metabolic intermediates that would not otherwise be produced. At the microbiological level, a multicomponent substrate could conceivably encourage the development of species which may have symbiotic or, perhaps, synergistic tendencies thus affecting effluent substrate concentrations. It has been the point of view of this researcher to first investigate simplistic and relatively manageable predictive techniques. If deficiencies appear, these may be highlighted and further work performed in order to correct the weaknesses. At the kinetic modeling level, none of the commonly used wastewater treatment models appears to be able to describe effluent substrate concentrations when influent

TABLE LI

EVALUATION OF PREDICTIVE TECHNIQUES FOR S_e BASED UPON OBSERVED X IN TERMS OF COD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	Kincannon/Stover	D(H)	C(L)	D
	Eckenfelder	E(H)	E(L)	D(L)
Discreet Cmp. Trt.	Kincannon/Stover	E(H)	D(H)	E(H)
	Eckenfelder	E(H)	E(H)	E(H)

TABLE LII

EVALUATION OF PREDICTIVE TECHNIQUES FOR X BASED UPON OBSERVED S_e IN TERMS OF COD

Predictive Assumption	Predictive Model	Predictive Utility		
		High S_i	Low S_i	Overall
Weighted Constant	All	C(H)	C(L)	B
Discreet Cmp. Trt.	Kincannon/Stover	C(H)	C(L)	B
	Eckenfelder	C(H)	B(L)	B

organic strength differs significantly from that of the treatability studies. Many researchers have reported that influent organic strength will be attenuated (i.e., a doubling of S_i will cause something less than a doubling of S_e). Yet, the Lawrence/McCarty and Gaudy models predict that S_i has no impact upon S_e while the Eckenfelder (second order), Kincannon/Stover and Weston model show that a doubling of S_i will double S_e. Modification of these models to reflect the actual field and laboratory observations may improve their versatility relative to prediction over a wide range of influent organic strengths.

5.4 Settling and Dewatering Predictive Techniques

No reasonable technique to predict settleability, as measured by the sludge volume index test (SVI), was found. It is conceivable that the organisms cultured upon single substrates could be limited as to species diversity while the diverse nature of the combined substrate influent could have impact upon the variety of microbial species present. This species diversity could, in turn, impact settleability. Although there are more sophisticated settleability available, it was beyond the scope of this work to become too deeply involved in settling model development.

Dewatering, as measured by the CST test, was found to be predicted quite well by possessing a knowledge of the influent substrate constituents. A weighted constant technique was employed whereby the concentration of total suspended solids (TSS) predicted to be produced from the degradation of a given compound (in relation to the total TSS of the mixed liquor) was used as a weighting factor for the CST determined during the individual compound studies of that compound. A weaker predictive relationship was developed utilizing volatile suspended solids concentrations. It should be noted that the CST test only measured the drainability of water from a column of sludge and that cake moisture content was not considered here.

5.5 Individual Compound Analyses

The residual combined unit effluent TOC which was demonstrated to be caused by influent constituents was generally found to be less than 15% of the total residual TOC. However, very few tests were conducted to establish undisputable evidence pertaining to this matter. In addition, periodic 2-Nitrophenol leakage was suspected in that its characteristic color would develop in the effluent for a few days and then subside. This phenomenon was observed frequently for the 4- and 7-day SRT units regardless of which influent combination was being administered. The 12-day SRT unit almost never experienced that problem. It could be speculated that if 2-Nitrophenol leakage was observed to have occurred, then the other components, which are not identifiable by color, may have exhibited the same cyclical leakages.

When several predictive techniques were utilized to estimate the effluent concentrations of two of the feed constituents (oleic acid and cheer), the Eckenfelder model utilizing the total VSS treatability assumption was found to give the most consistent performance. The Kincannon/Stover (total VSS treatability assumption) and Lawrence/McCarty models yielded reasonable predictions. The discreet compound treatability assumption, again, predicted effluent concentrations for both cheer and oleic acid which were greatly in excess of the observed values. This may indicate that biomass produced from the degradation of one substrate to be utilized to metabolize other substrates. It should be stressed that these observations were based upon limited data (most often only one analysis per operating condition).

CHAPTER VI

CONCLUSIONS

The following conclusions can be drawn from this research effort:

1. In terms of TOC data, reasonable predictions of effluent substrate concentration could be made based upon knowledge of the influent constituents and operating conditions of the activated sludge system. A weighted constant technique was found to be most appropriate but several models could be employed (within this assumption) dependent upon whether high or low influent organic concentrations were administered. The Kincannon/Stover and Eckenfelder models were found to be most appropriate.

2. Again, in terms of TOC data, reasonable predictions of mixed liquor suspended solids concentrations could be made based upon the same prerequisite information. Again, the weighted constant assumption employing the Kincannon/Stover or Eckenfelder model was most appropriate.

3. The assumption that any given compound in a multisubstrate influent can only be degraded by the portion of the total biomass produced from the metabolism of that compound was shown to be invalid.

4. The Kincannon/Stover and Eckenfelder techniques generally demonstrated better predictive capability than did the Lawrence/McCarty models when considering the TOC, COD or BOD substrate parameters. However, none of the models appeared to be flexible enough to describe

influent organic concentrations significantly different than those utilized in the single substrate treatability studies.

5. Influent constituents were reduced to very low or even undetectable concentrations in the effluent.

6. Residual effluent substrate was found to be composed mainly of metabolic intermediates with less than 15% of the residual attributable to influent constituents.

7. Substrate removal was quite good for all wastewaters tested with the exception of the detergent study.

8. Two substrates (oleic acid and Cheer) were selected for specific compound modeling. A modeling system utilizing total mixed liquor volatile suspended solids in the combined units and either the Kincannon/Stover, Eckenfelder, or Lawrence/McCarty biokinetic models was appropriate.

9. Settleability, as measured by the sludge volume index, could not be accurately predicted for the combined substrate units based upon a knowledge of the influent constituents.

10. A simplistic method to predict dewaterability of a combined substrate wastewater based upon a knowledge of the influent constituents (as measured by capillary suction time) was found to be quite successful.

6.1 Suggestions for Future Work

1. The effect of influent substrate concentration upon effluent substrate concentration should be more adequately described by biokinetic models.

2. Identification of the fate of the influent compounds could be determined by radioactive labeling and analyses of sludge, residual effluent organics and off-gas.

3. More intensive analyses of all influent constituents remaining in the effluent could be useful in determining with what consistency each is removed.

4. More study is required pertaining to the effect of wastewater composition of SRT upon sludge settleability. It may very well be that sludge settleability concerns, rather than soluble effluent substrate concentration, will govern in most designs.

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APPENDIX A

BIOKINETIC PLOTS UTILIZING THE TOC, COD AND BOD SUBSTRATE PARAMETER

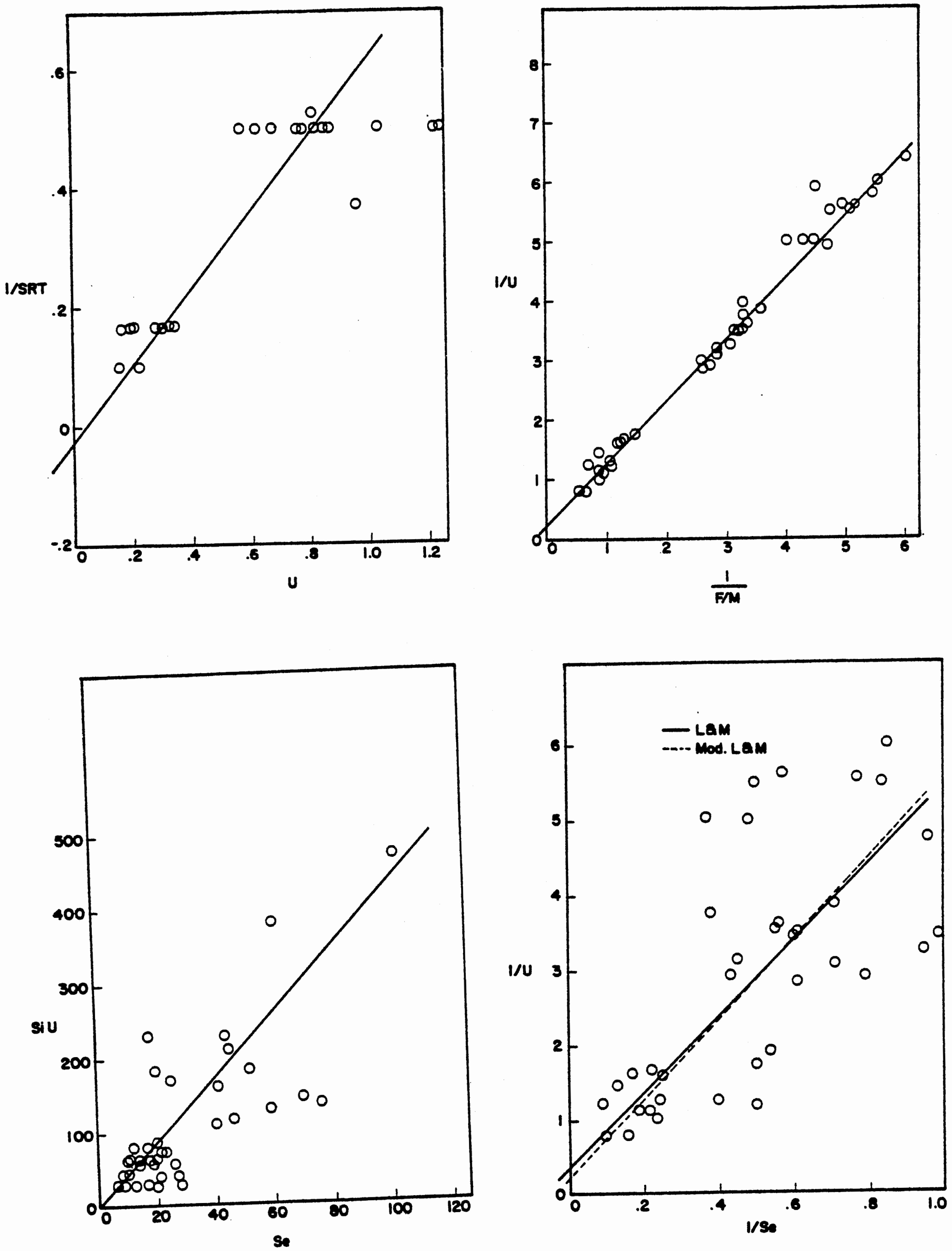

Figure 35. Biokinetic Plot; Albumen, TOC

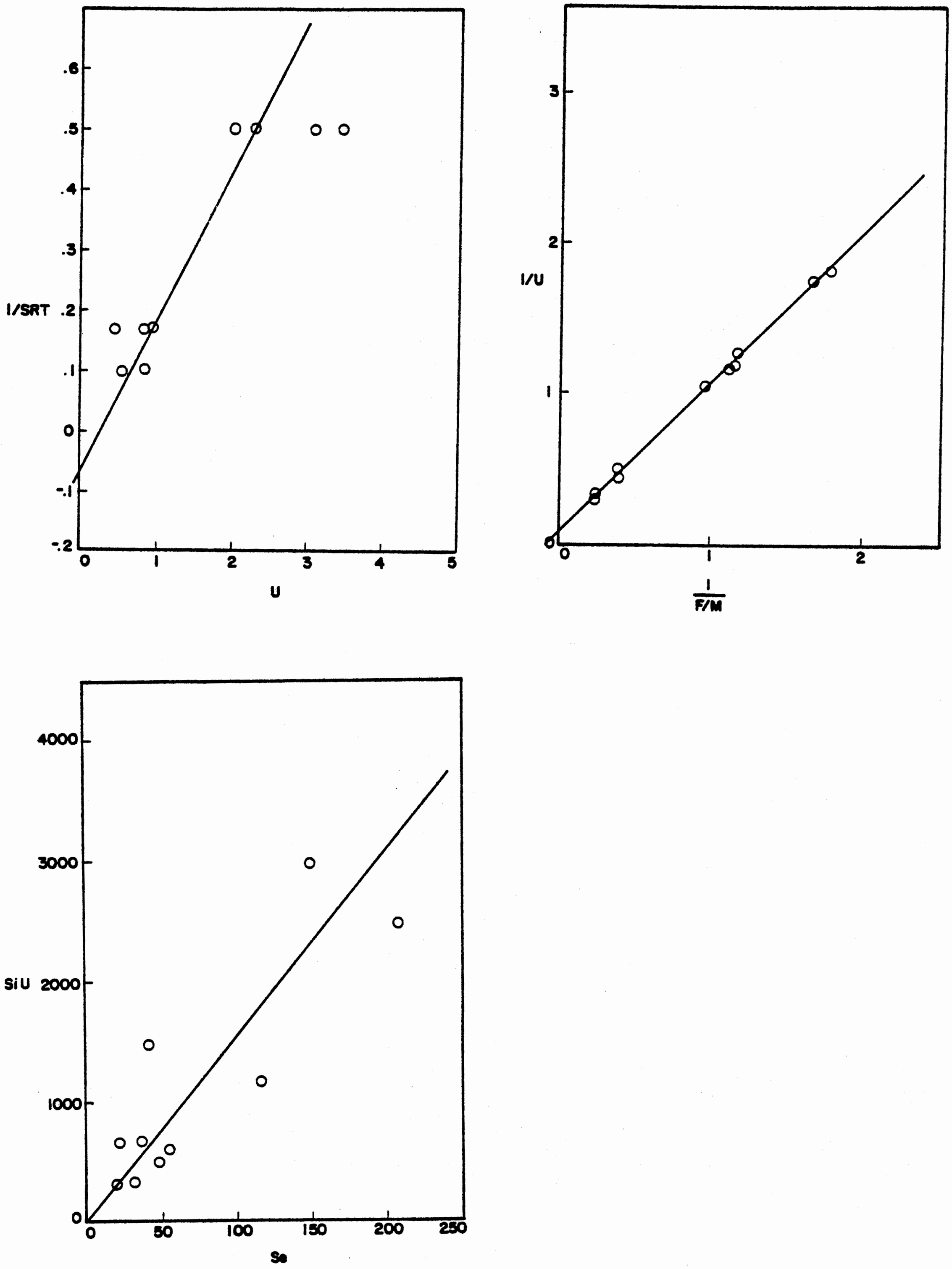

Figure 36. Biokinetic Plot; Albumen, COD

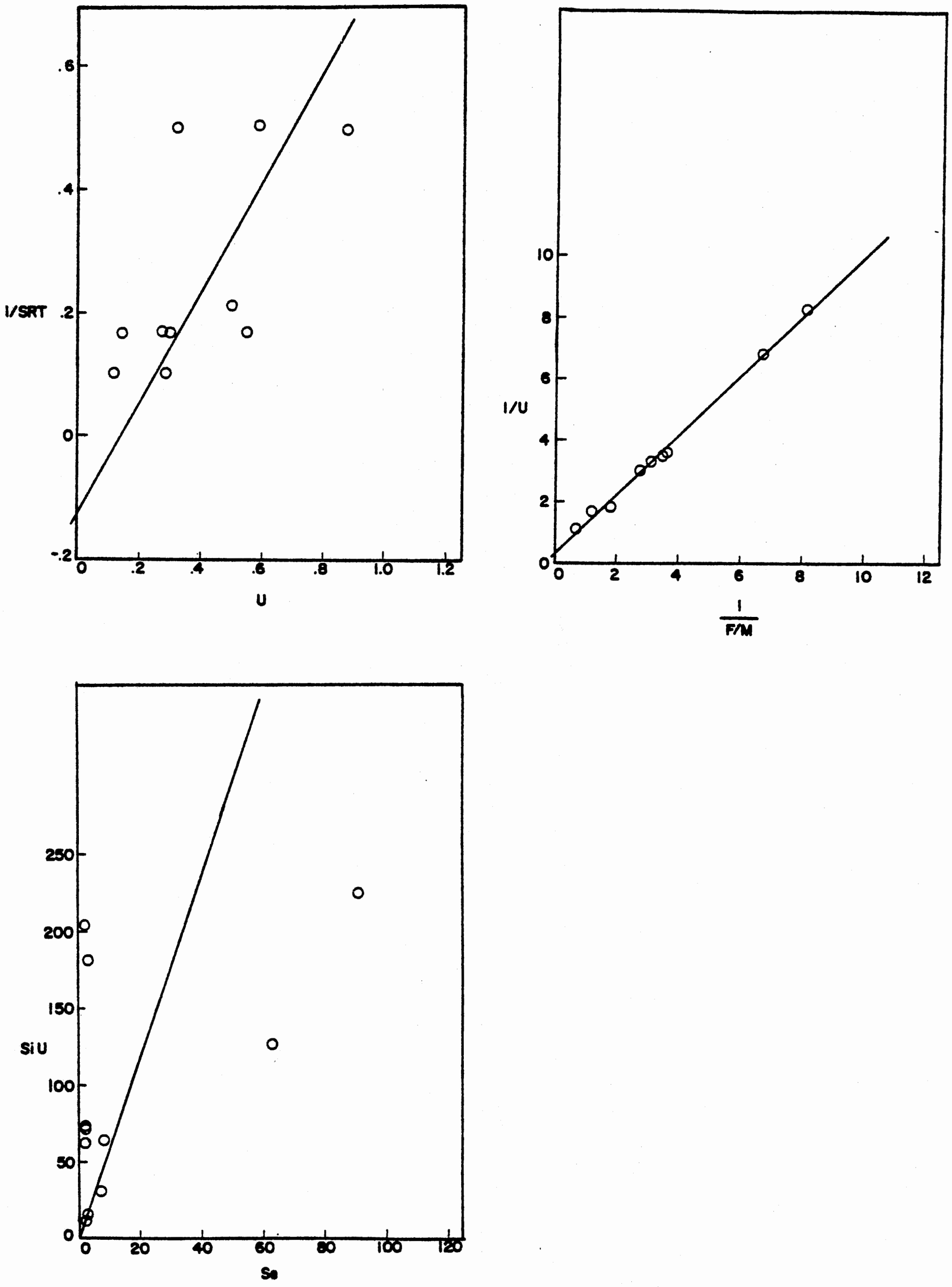

Figure 37. Biokinetic Plot; Albumen, BOD

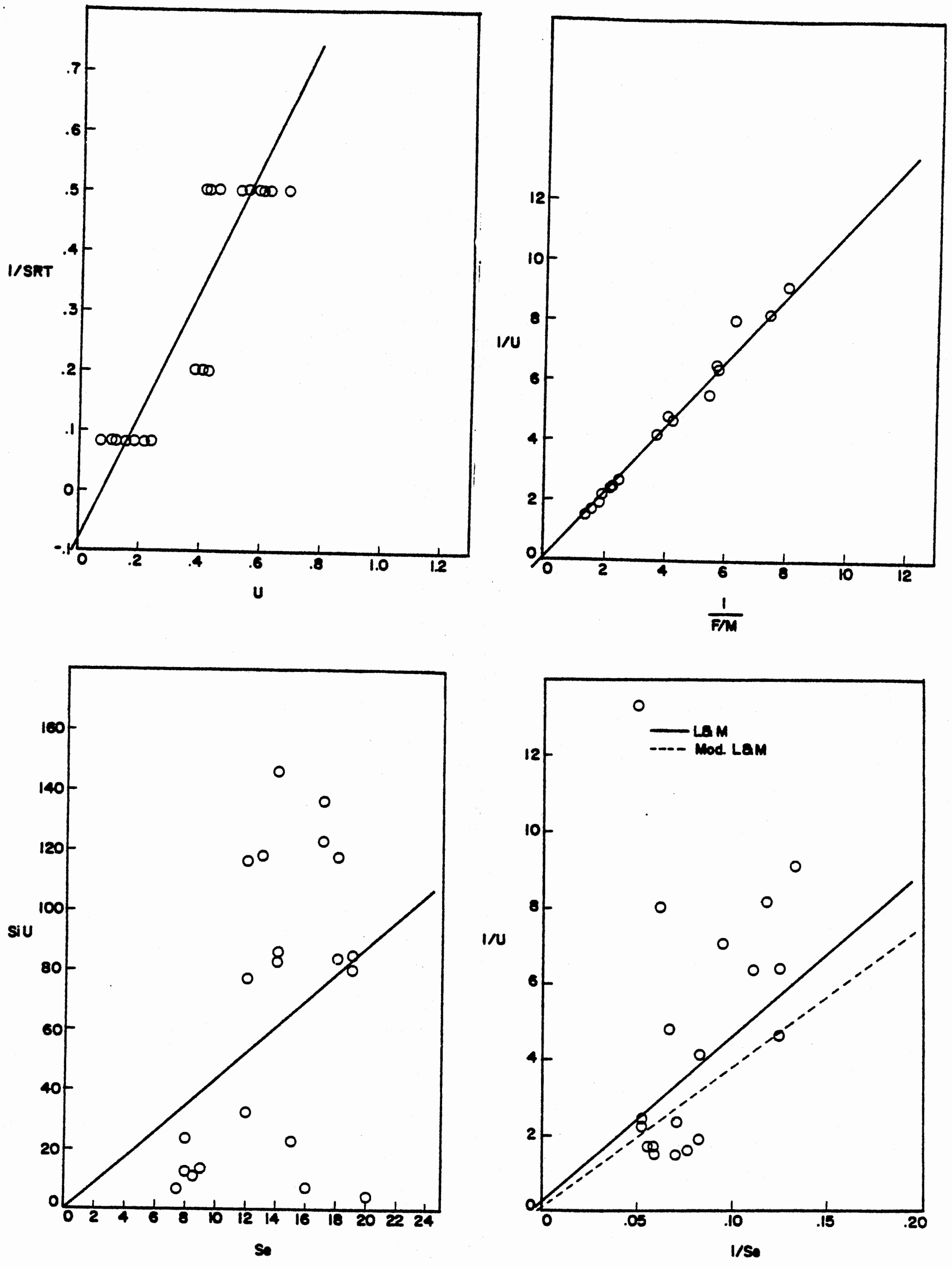

Figure 38. Biokinetic Plot; Starch, TOC

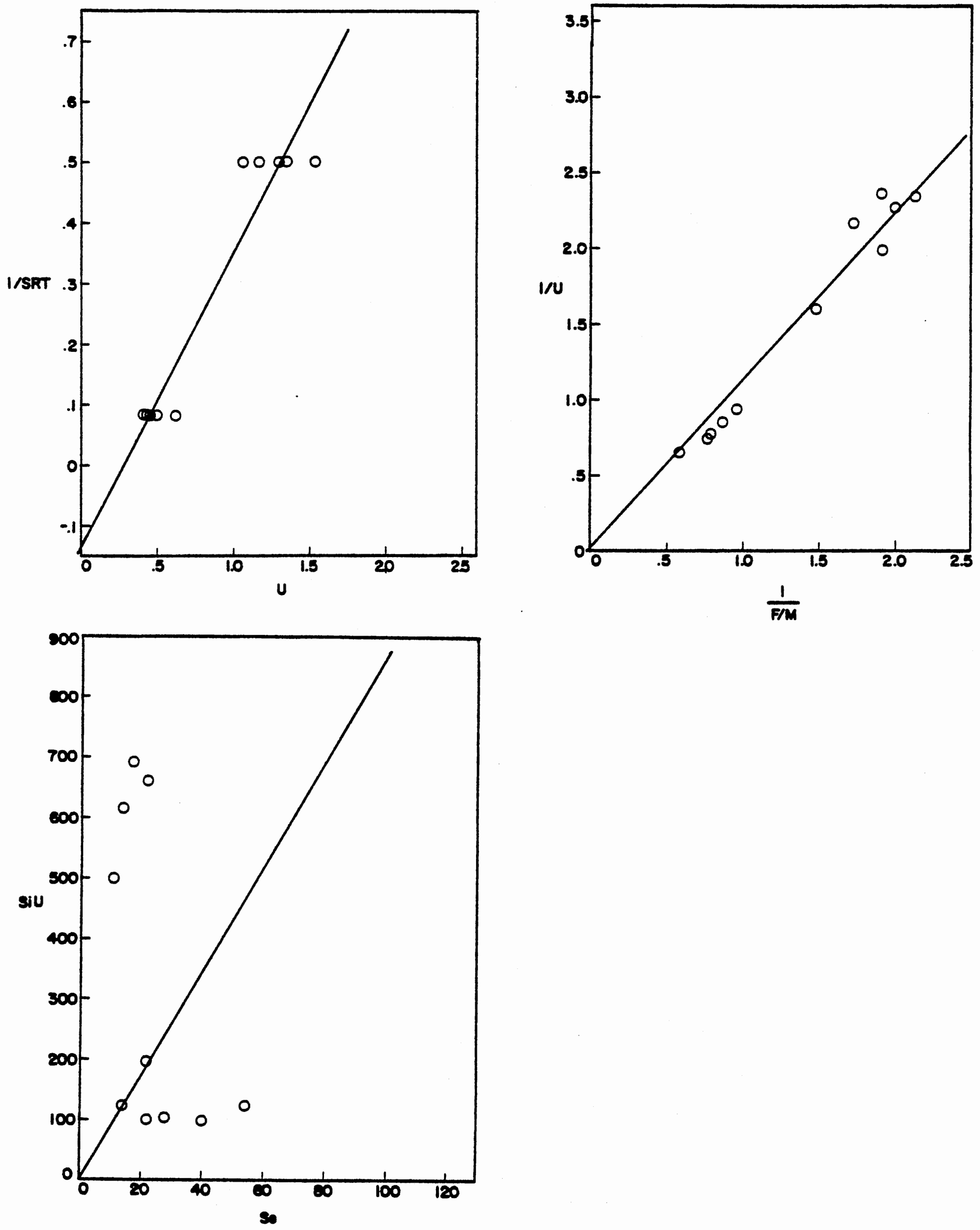

Figure 39. Biokinetic Plot; Starch, TOC

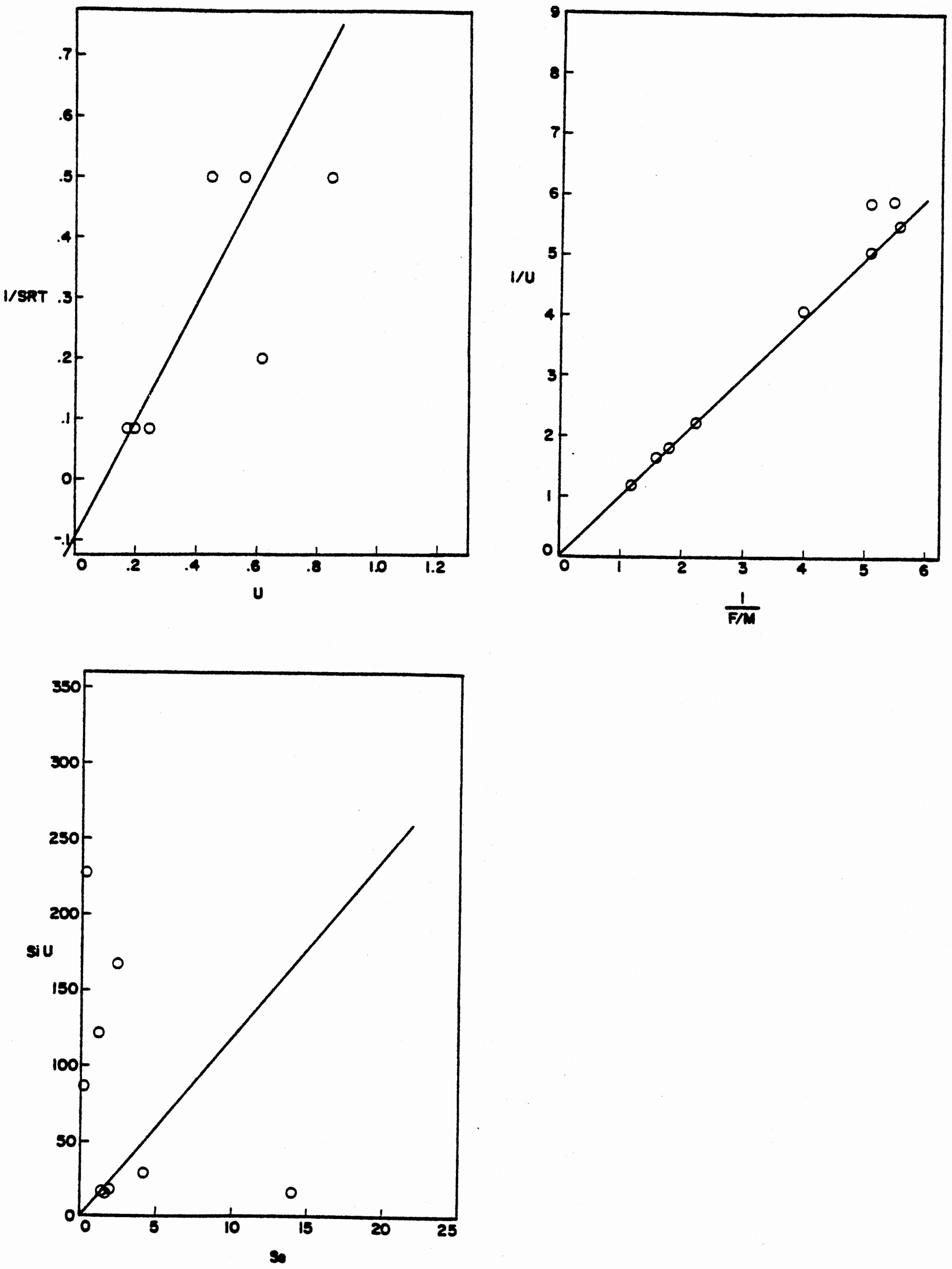

Figure 40. Biokinetic Plot; Starch, BOD

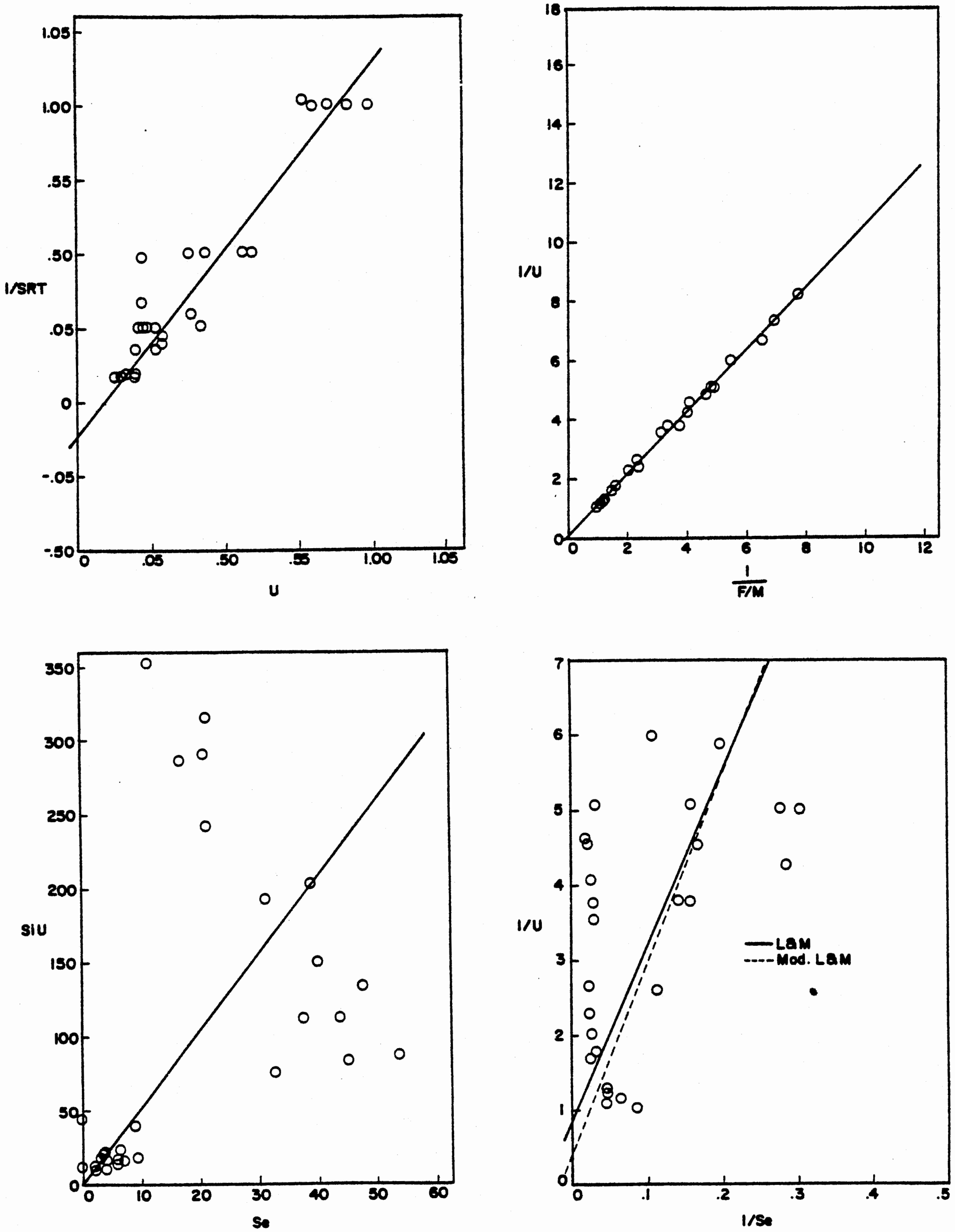

Figure 41. Biokinetic Plot; Sucrose, TOC

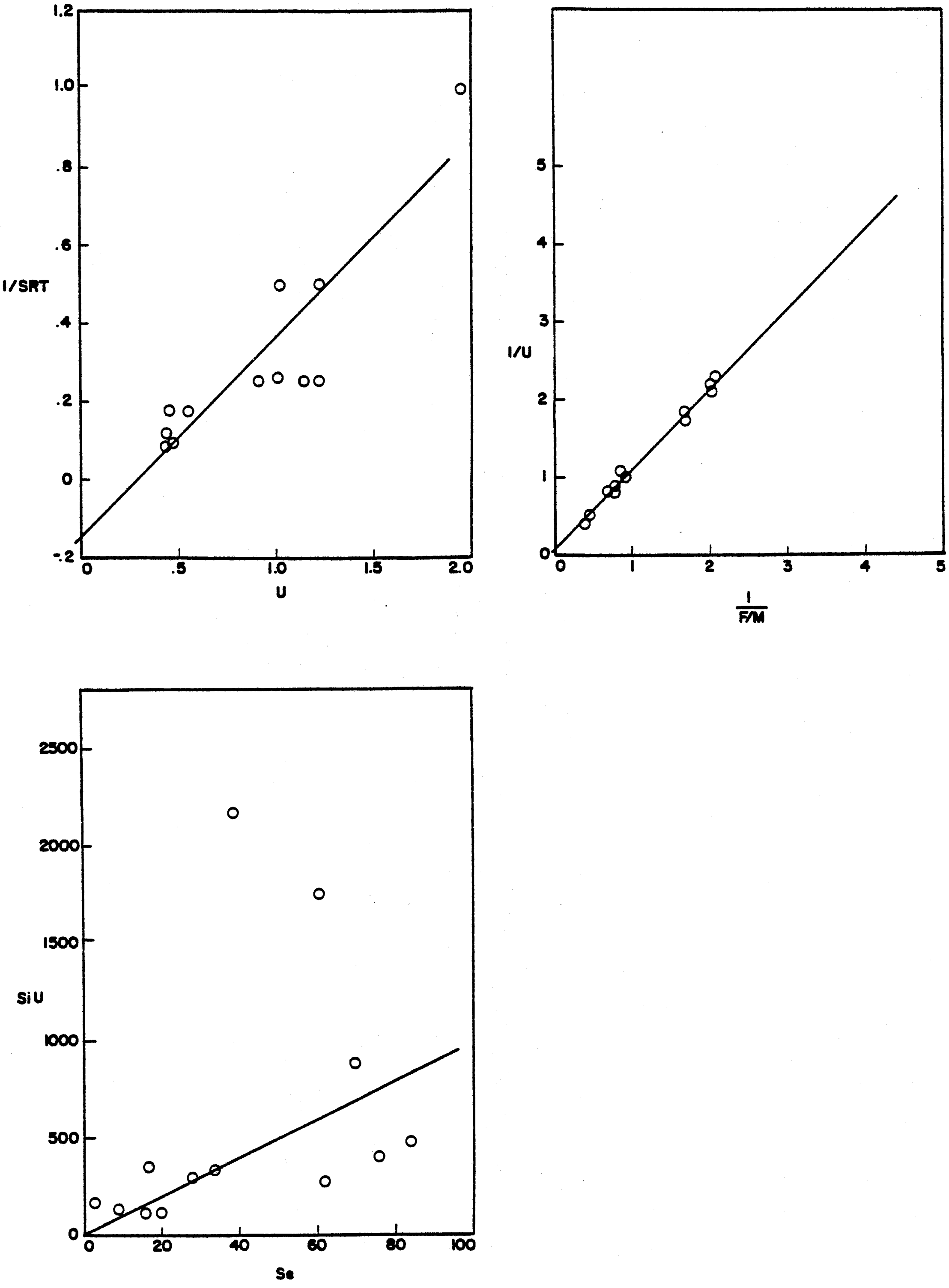

Figure 42. Biokinetic Plot; Sucrose, COD

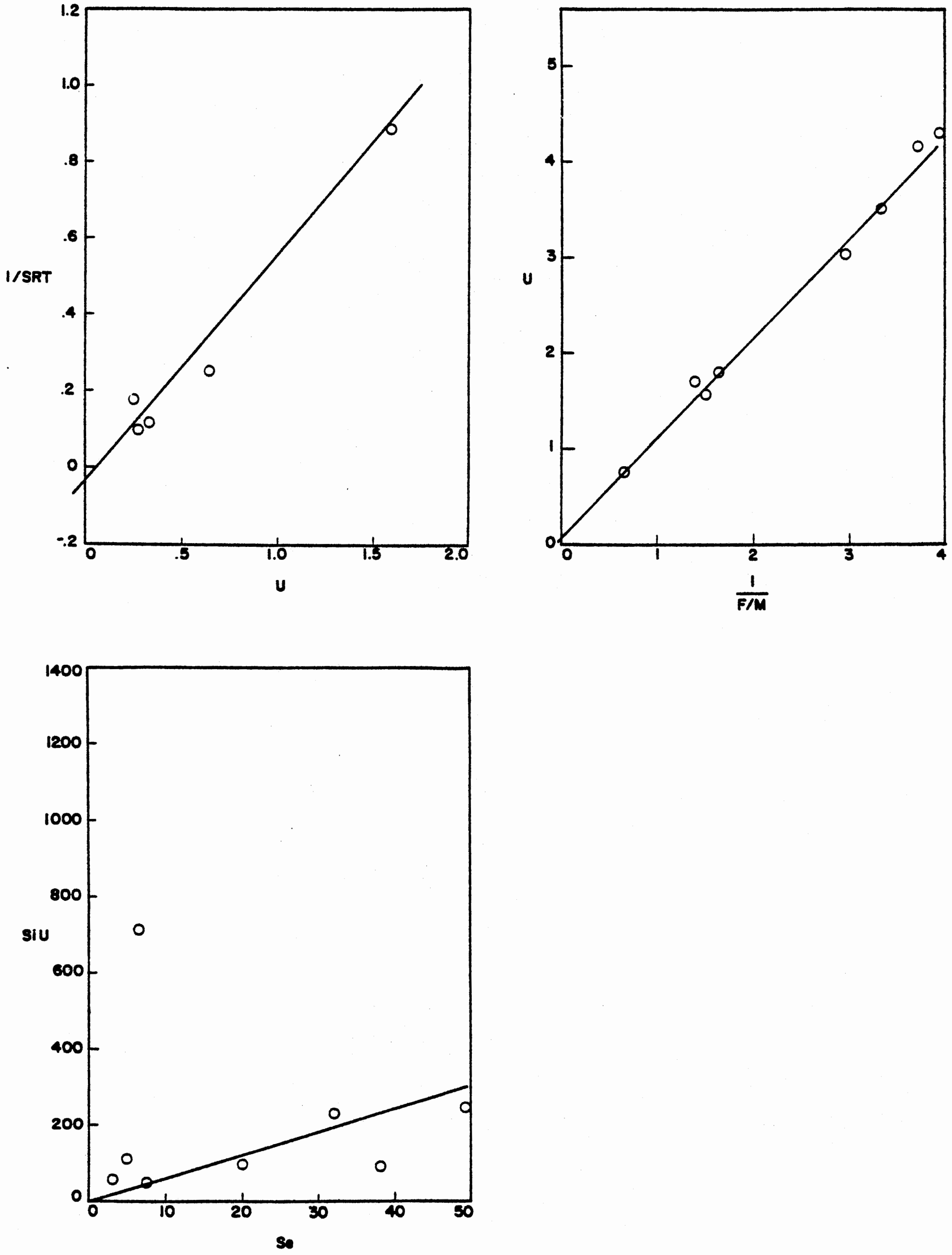

Figure 43. Biokinetic Plot; Sucrose, BOD

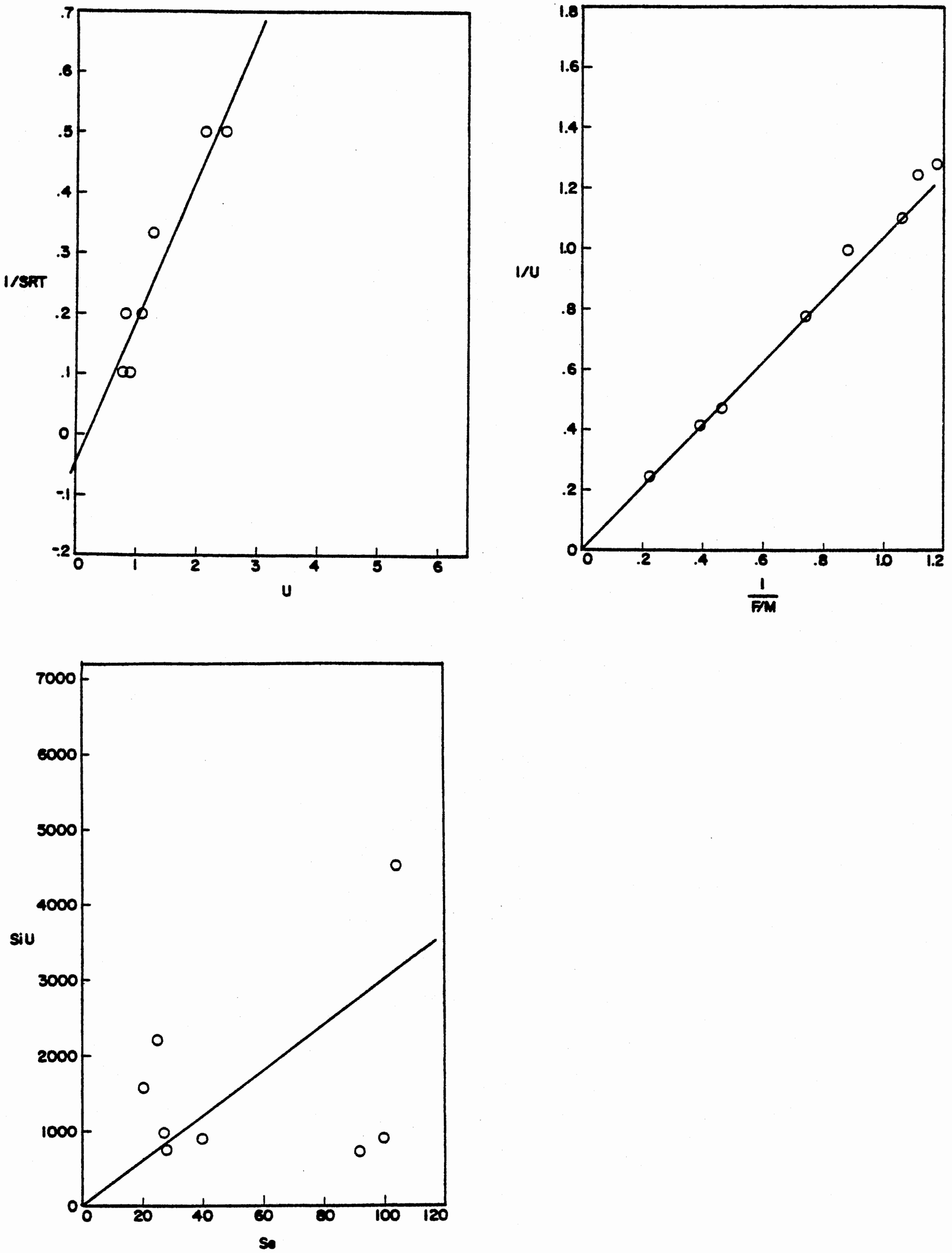

Figure 44. Biokinetic Plot; 2-Propanol, COD

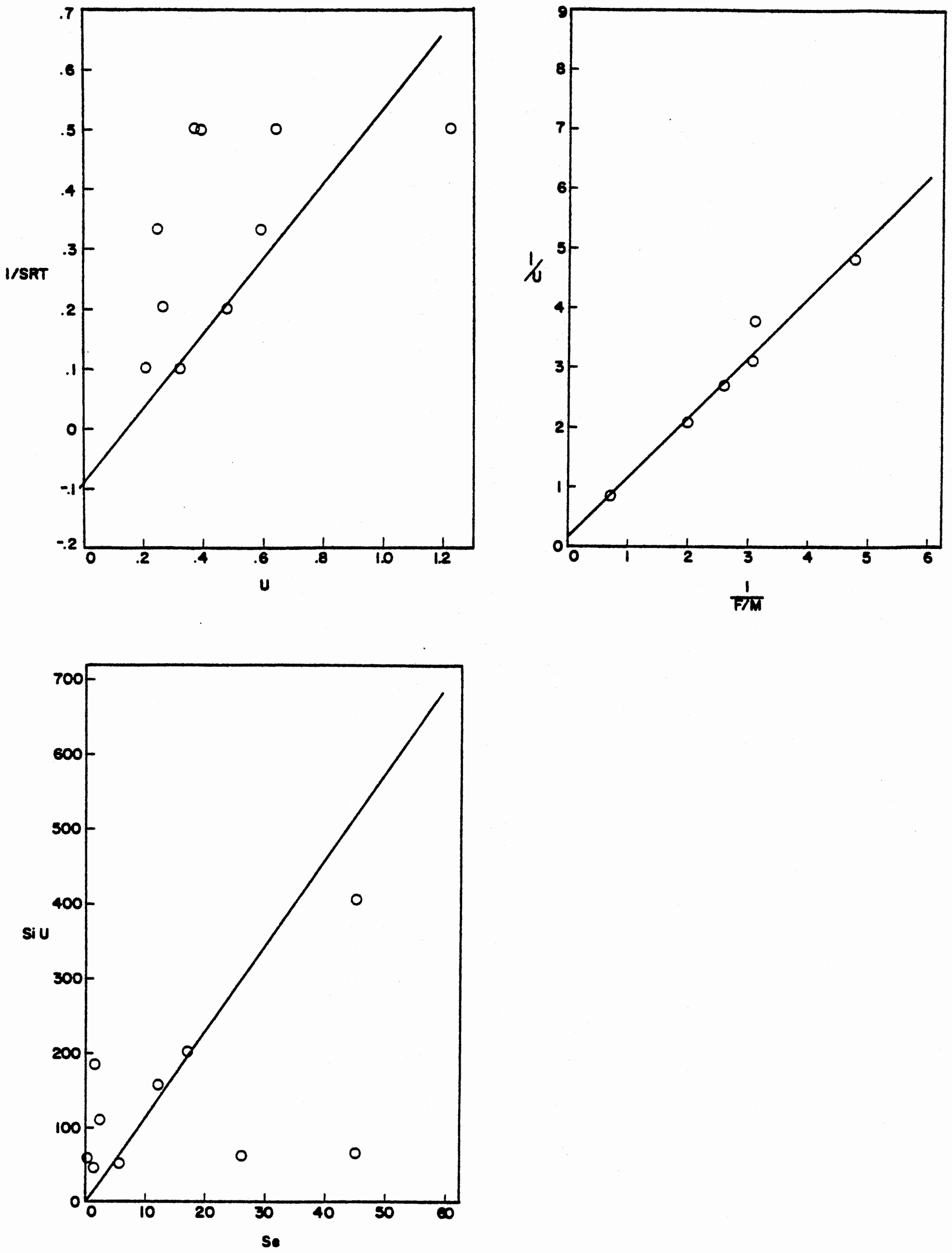

Figure 45. Biokinetic Plot; 2-Propanol, BOD

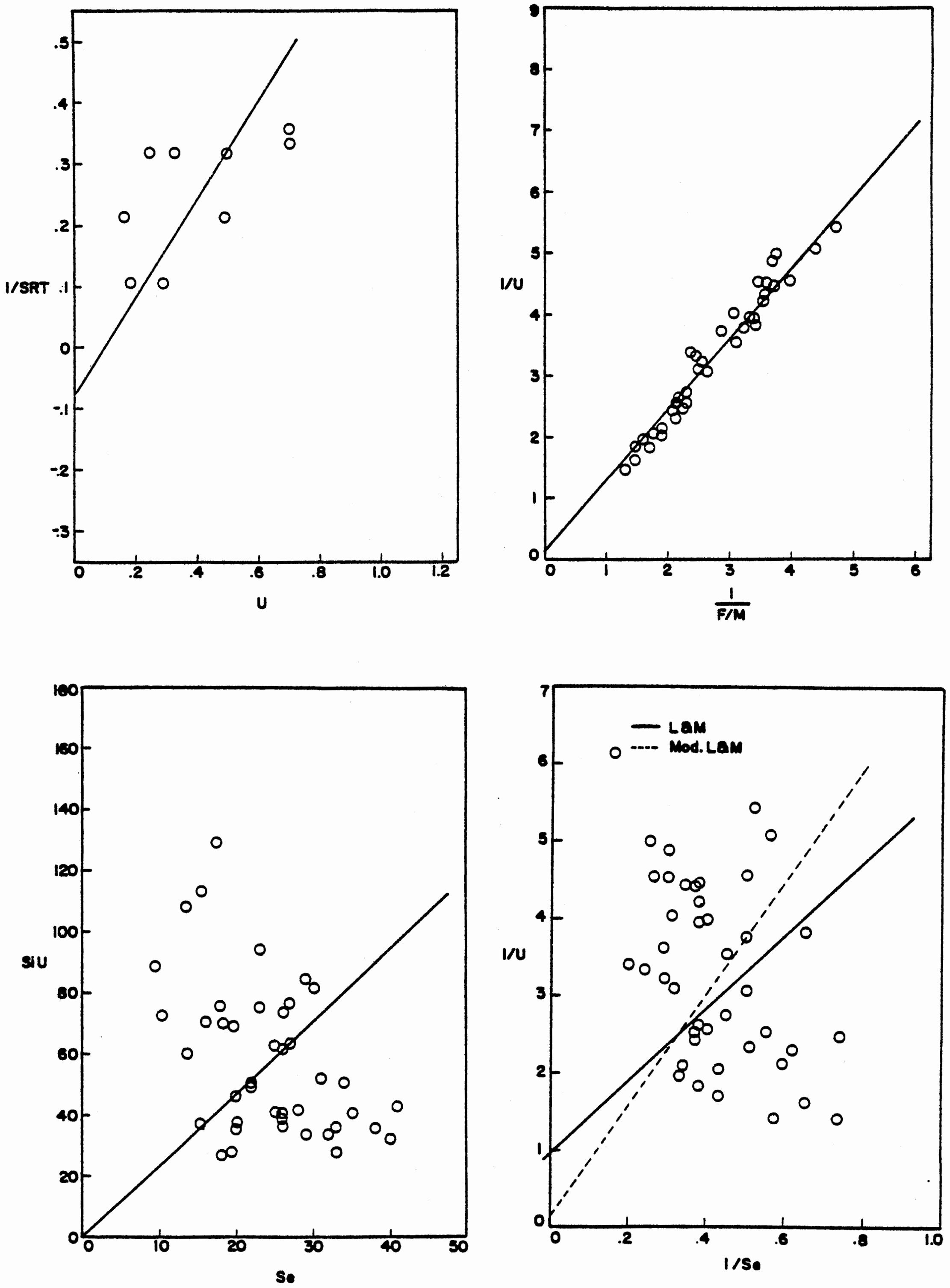

Figure 46. Biokinetic Plot; Oleic Acid, TOC

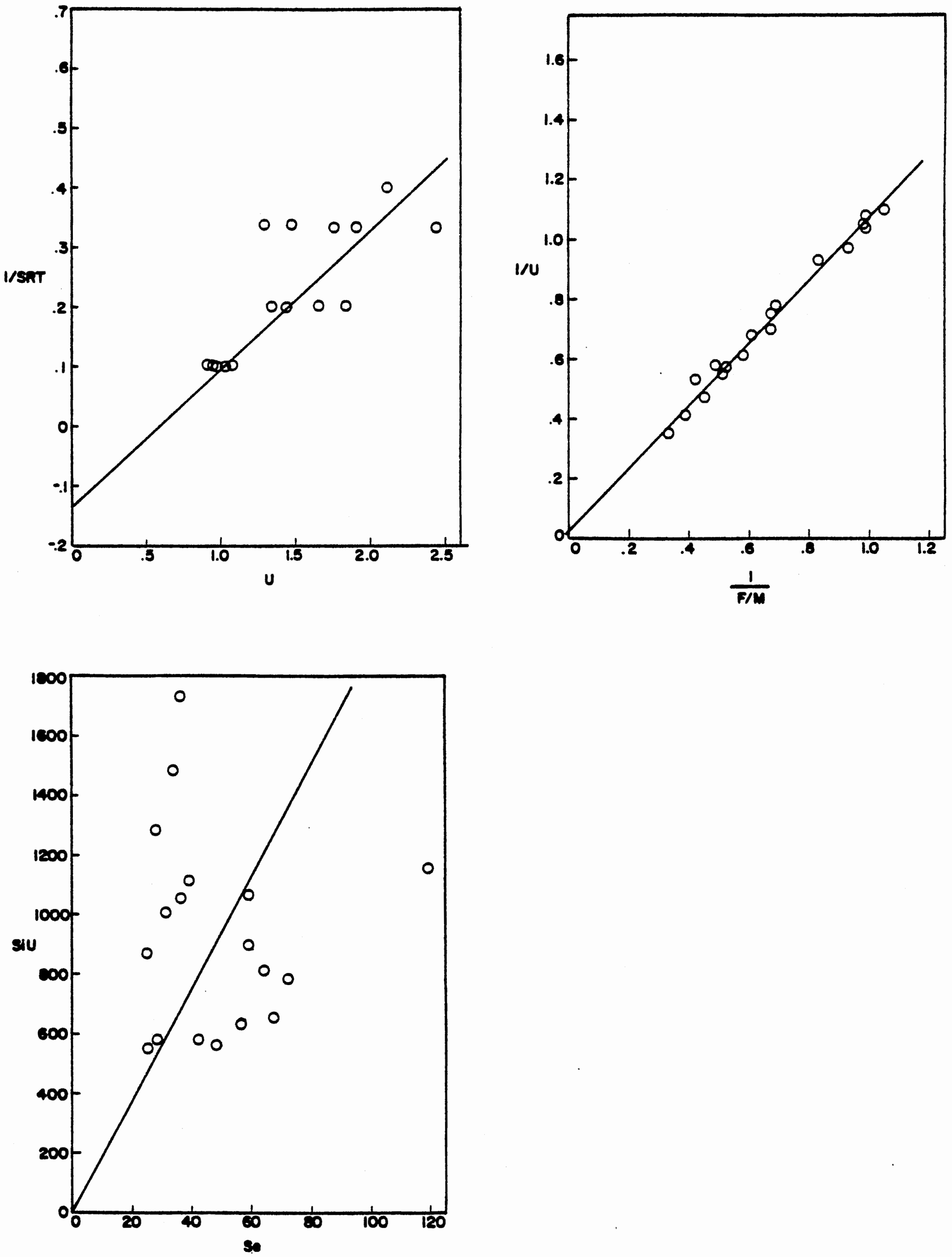

Figure 47. Biokinetic Plot; Oleic Acid, COD

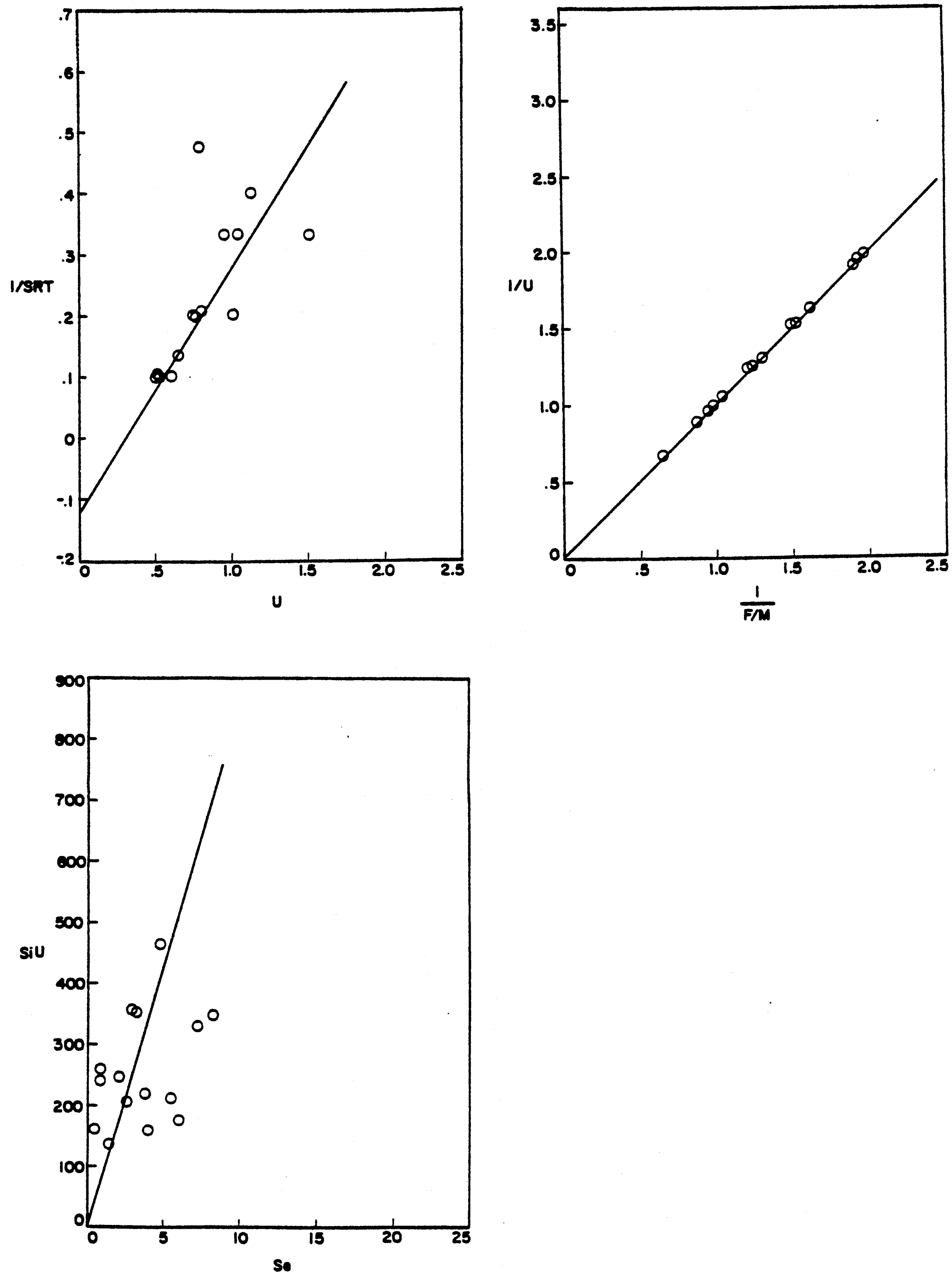

Figure 48. Biokinetic Plot; Oleic Acid, BOD

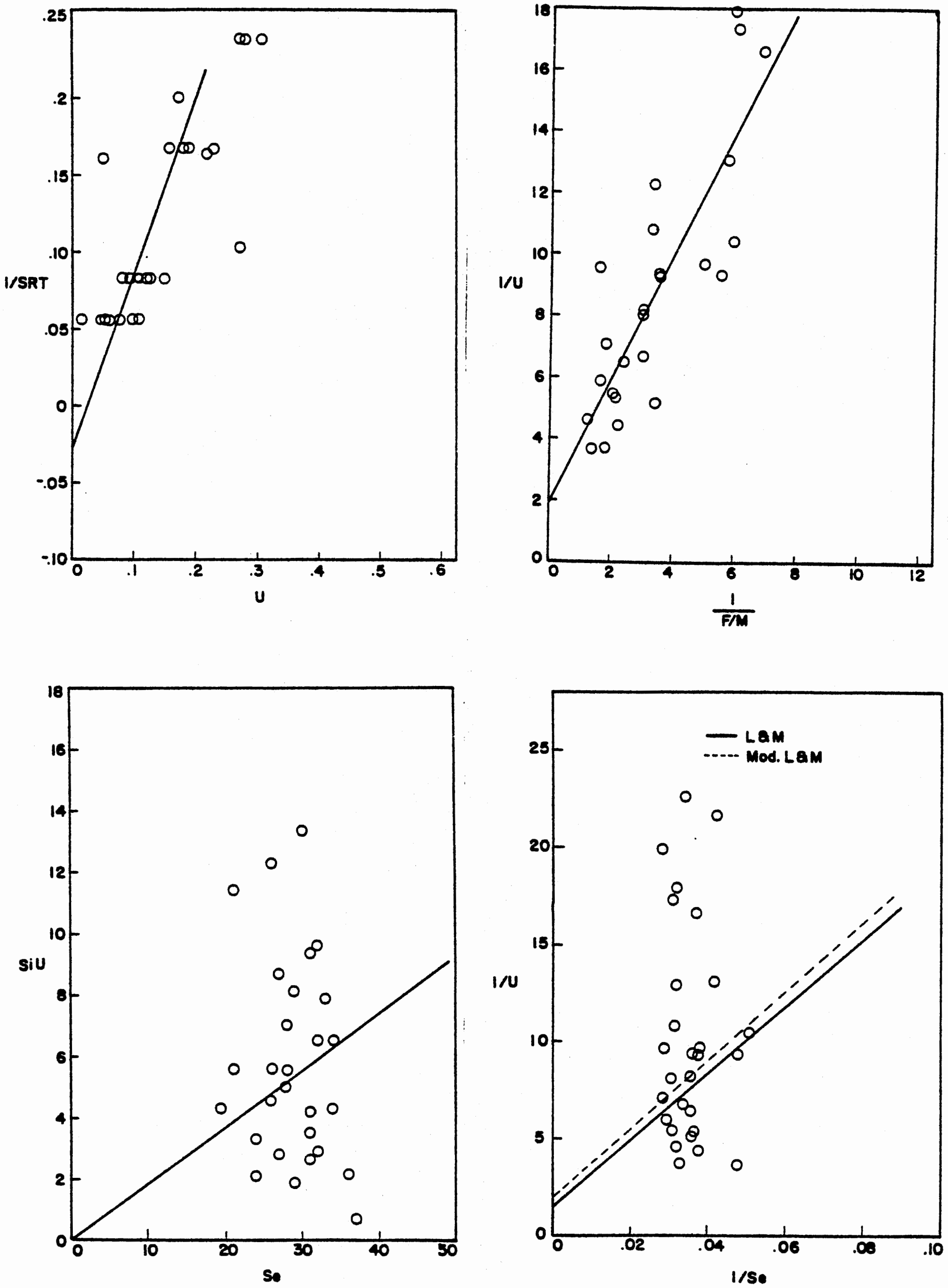

Figure 49. Biokinetic Plot; Cheer, TOC

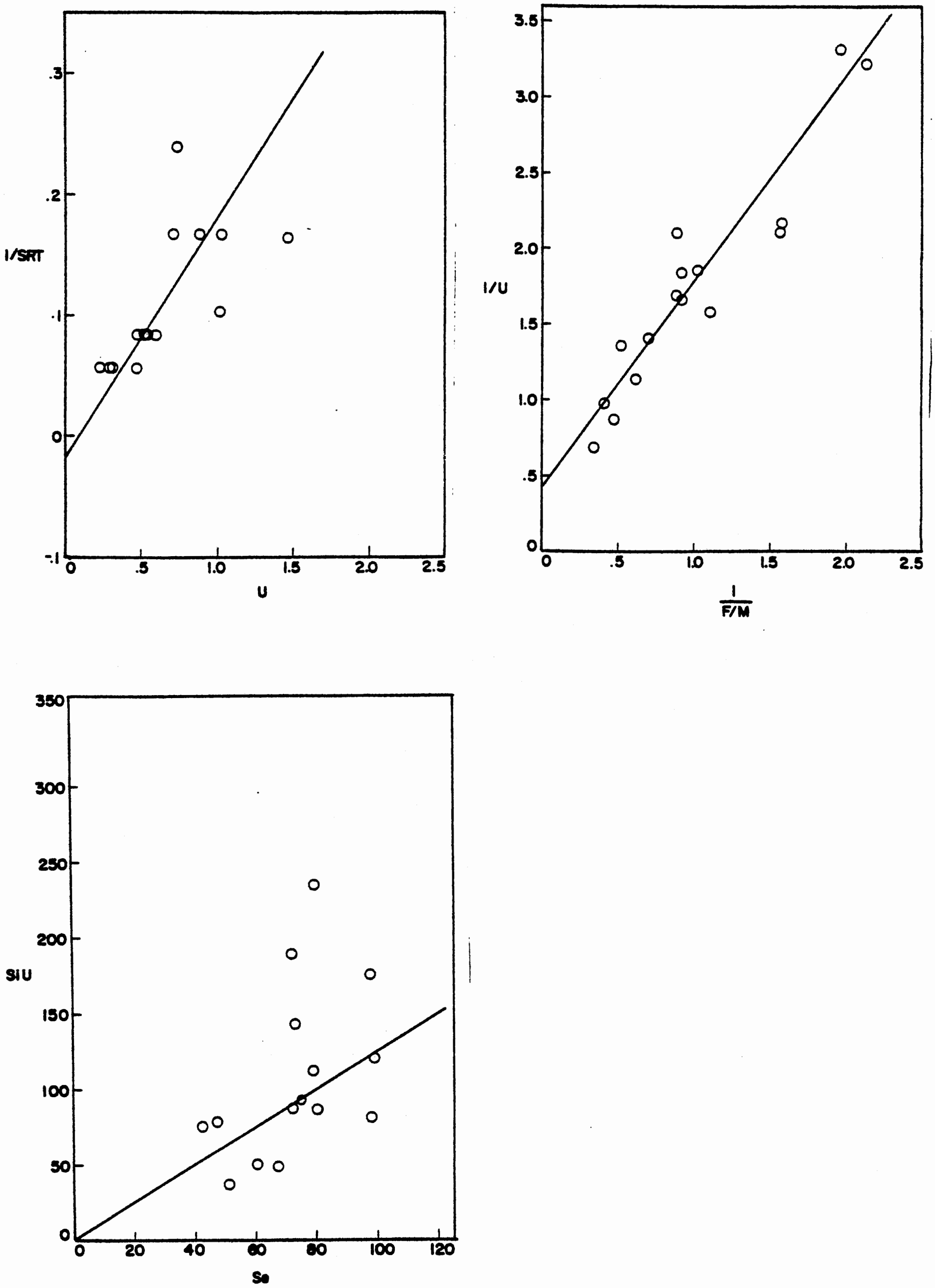

Figure 50. Biokinetic Plot; Cheer, COD

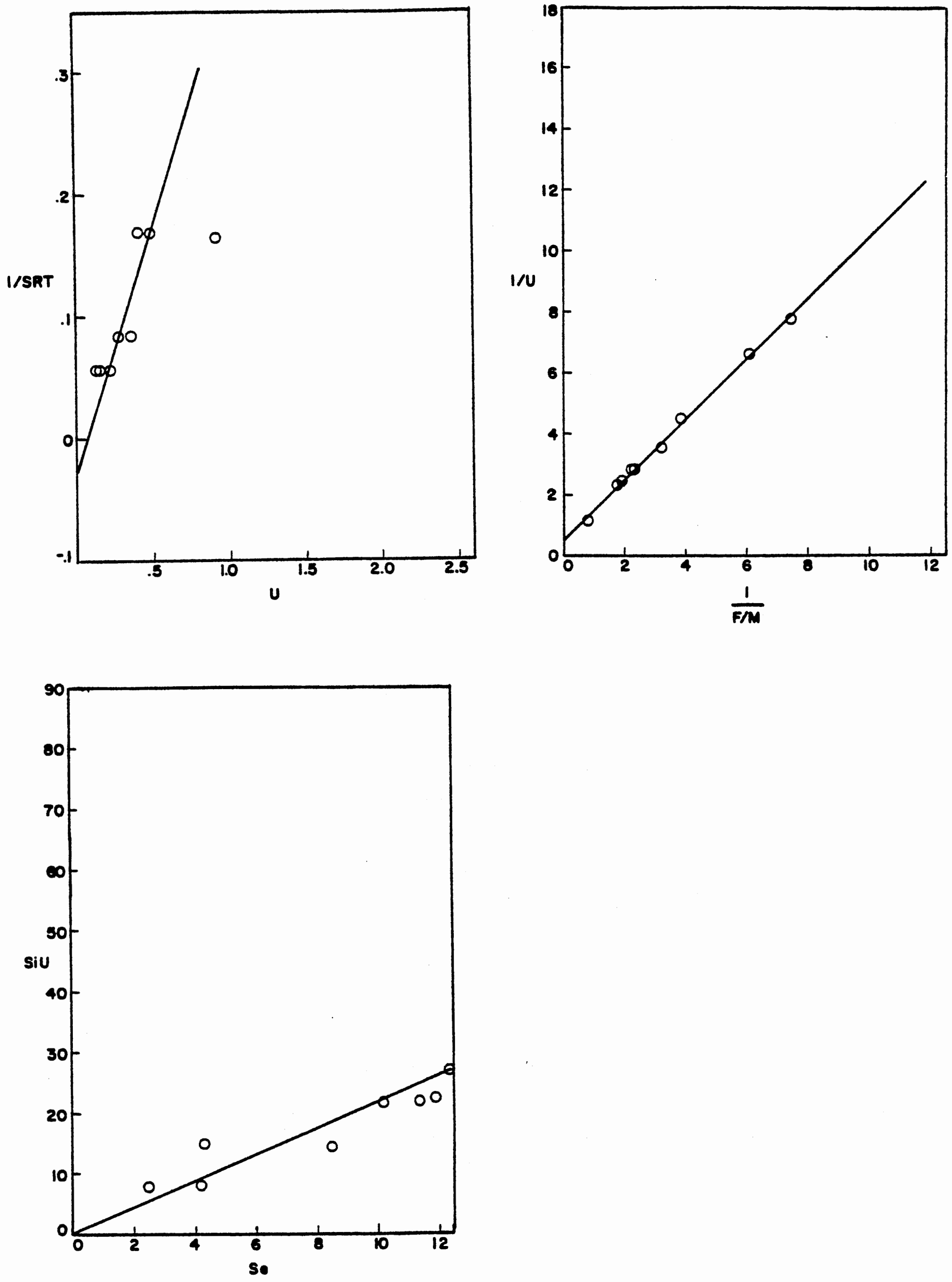

Figure 51. Biokinetic Plot; Cheer, BOD

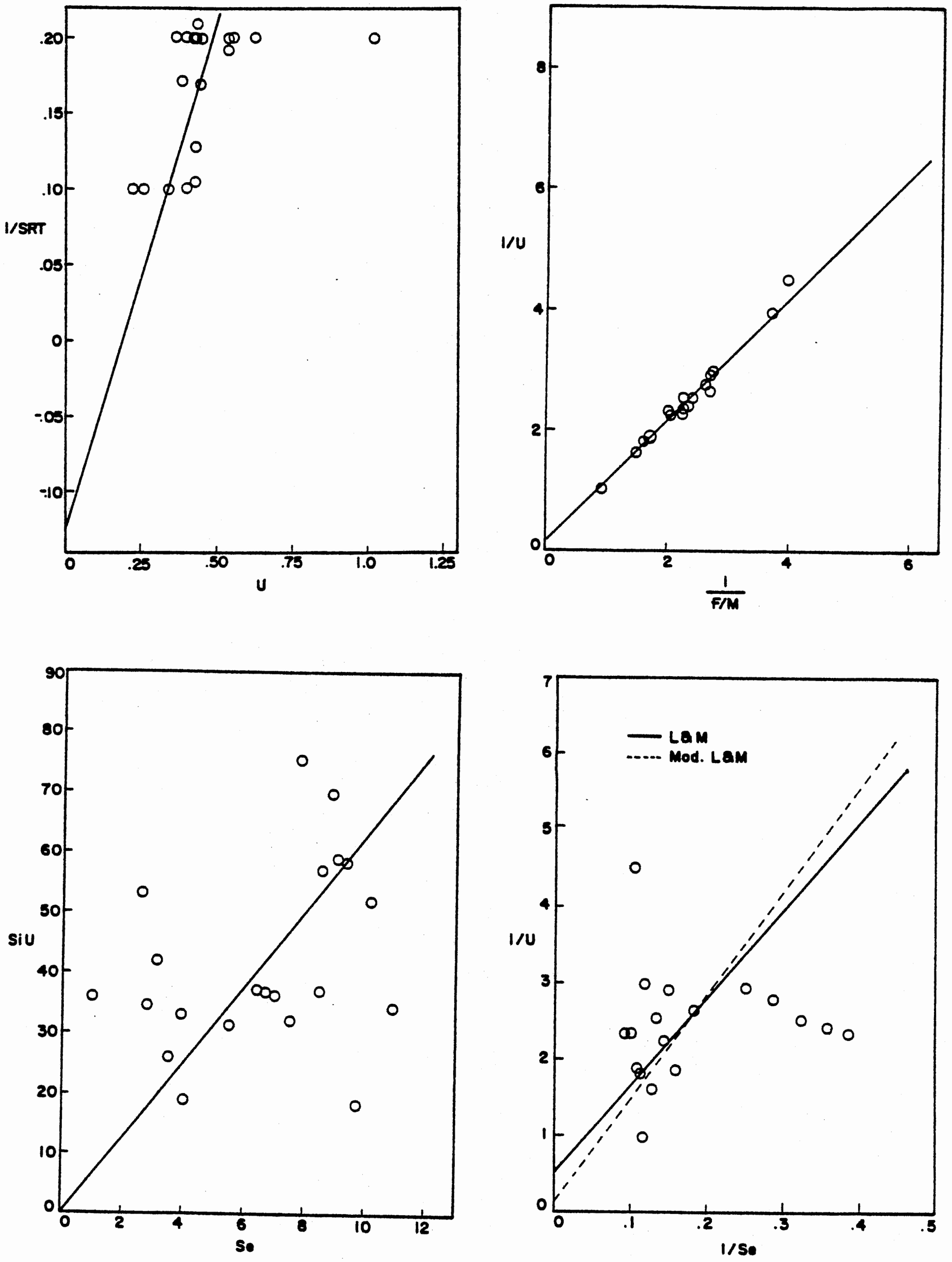

Figure 52. Biokinetic Plot; 2-Nitrophenol, TOC

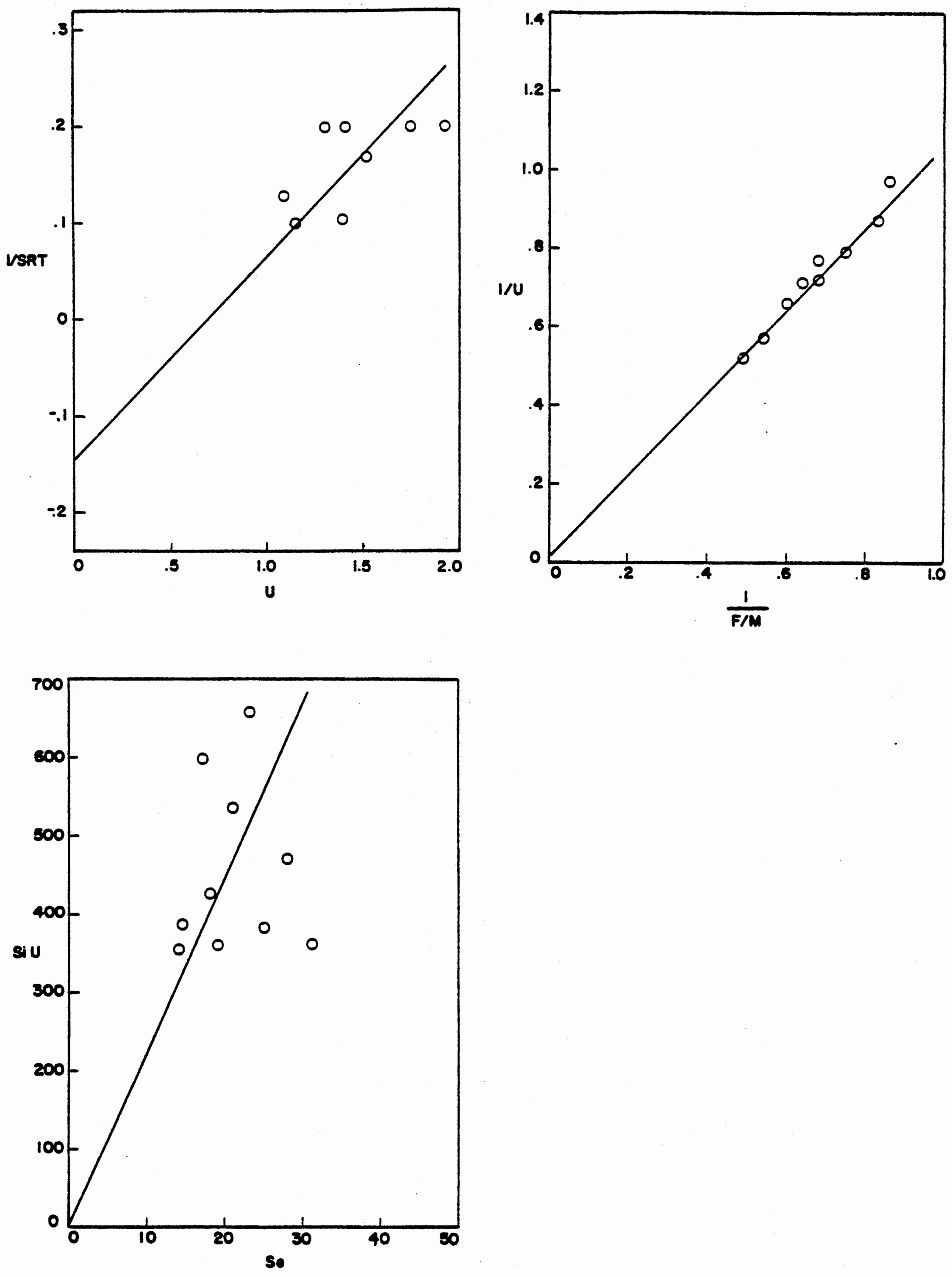

Figure 53. Biokinetic Plot; 2-Nitrophenol, COD

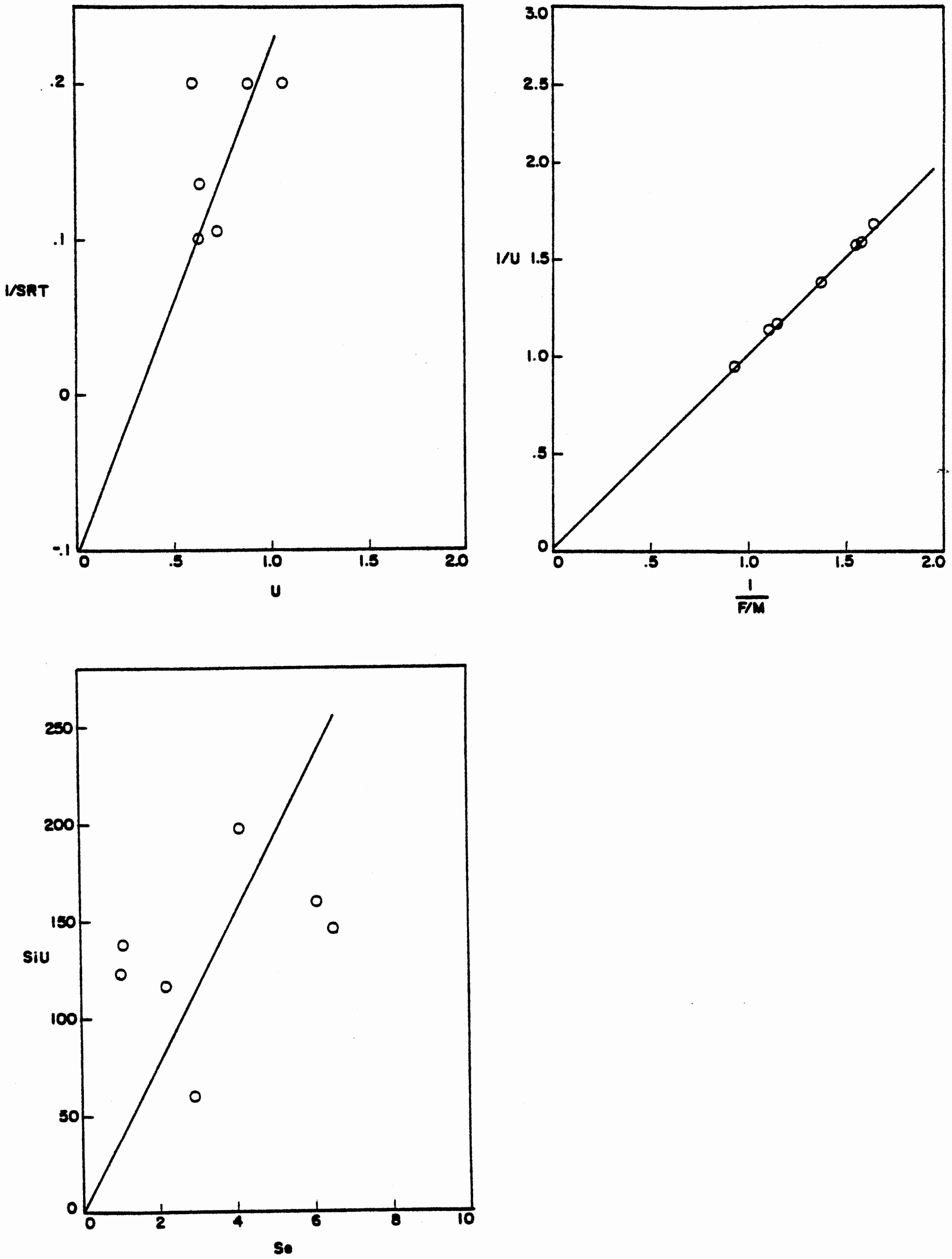

Figure 54. Biokinetic Plot; 2-Nitrophenol, BOD

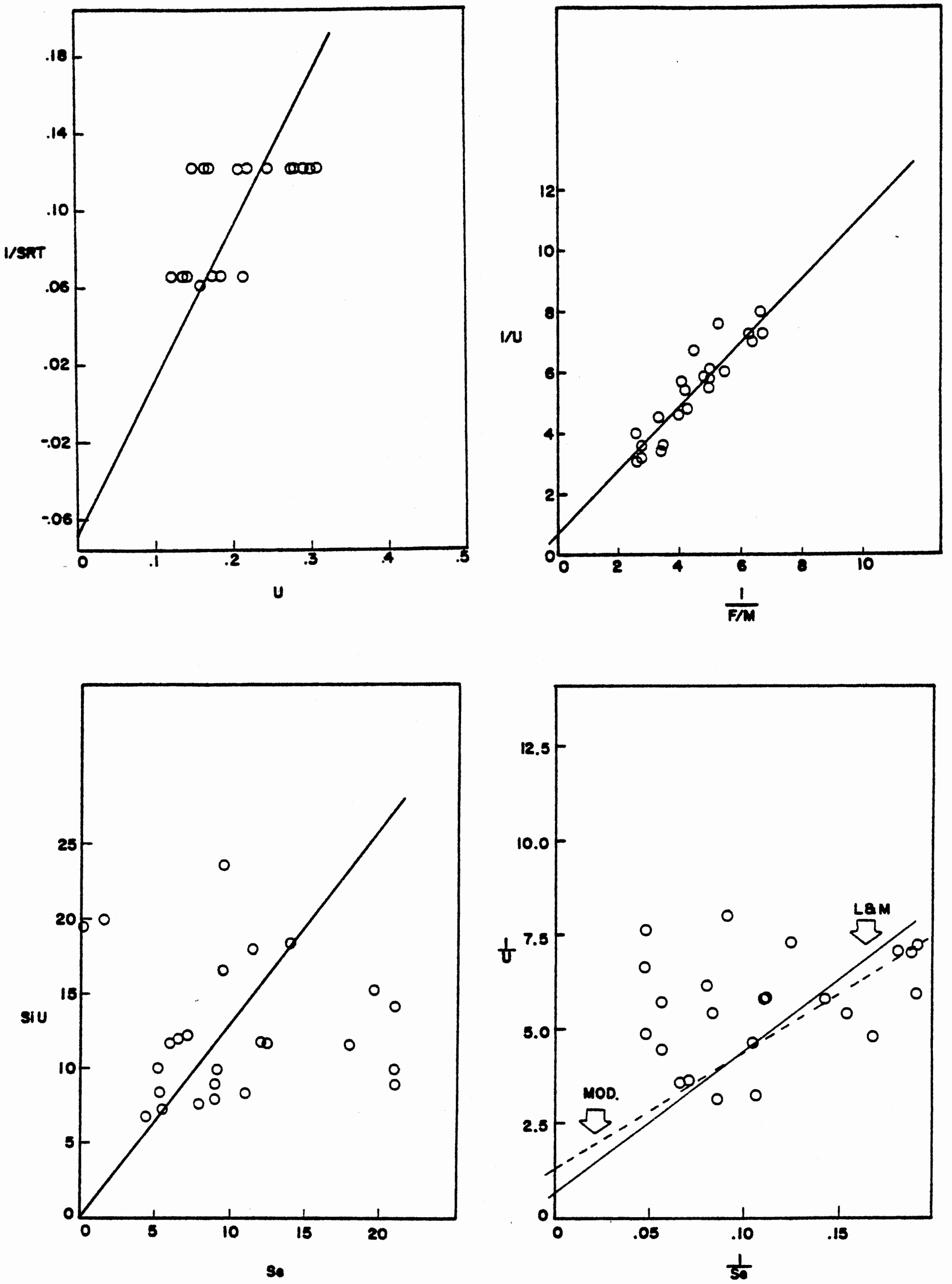

Figure 55. Biokinetic Plot; 4-Chloro-3-Methyl Phenol, TOC

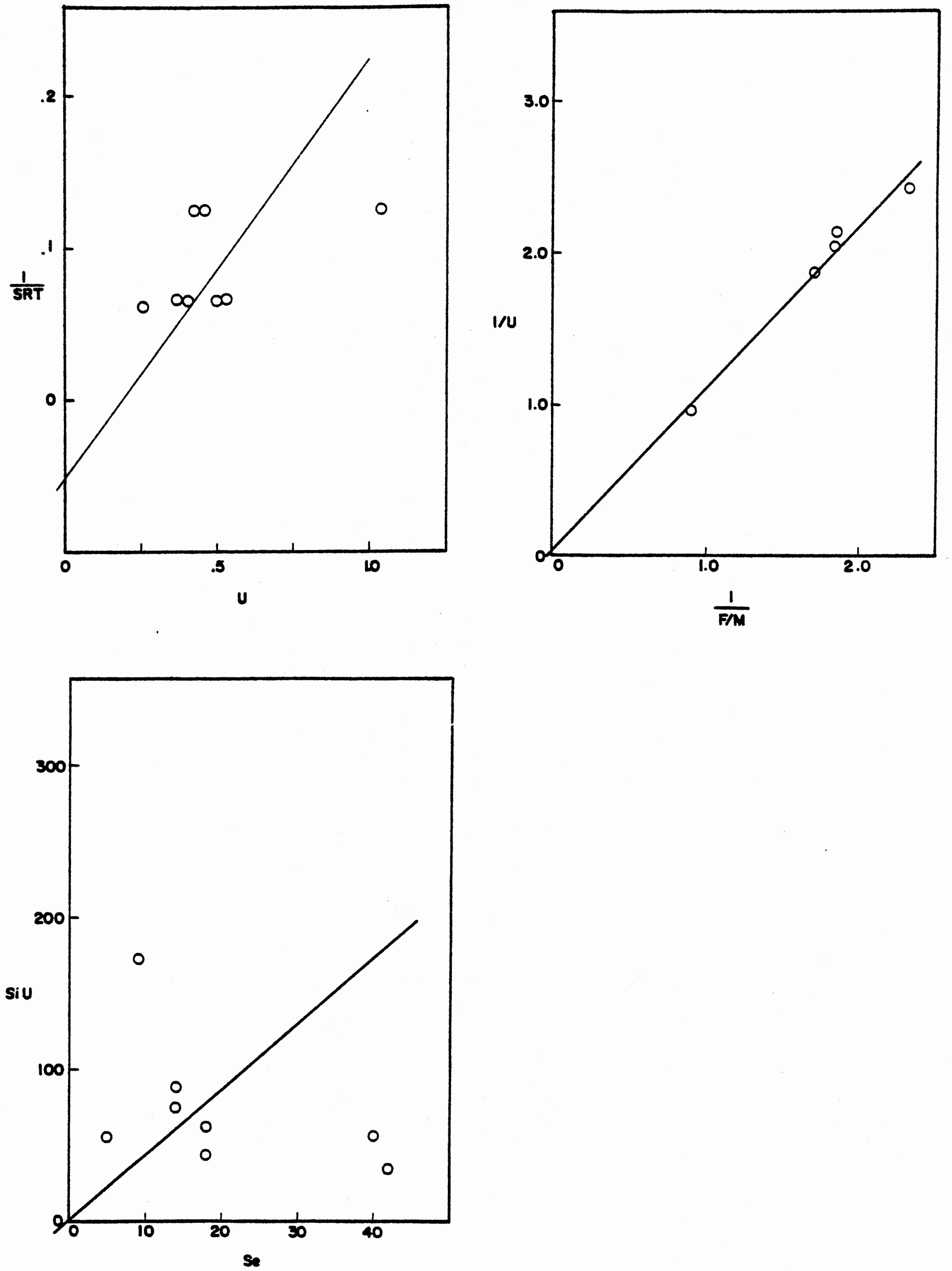

Figure 56. Biokinetic Plot; 4-Chloro-3-Methyl Phenol, COD

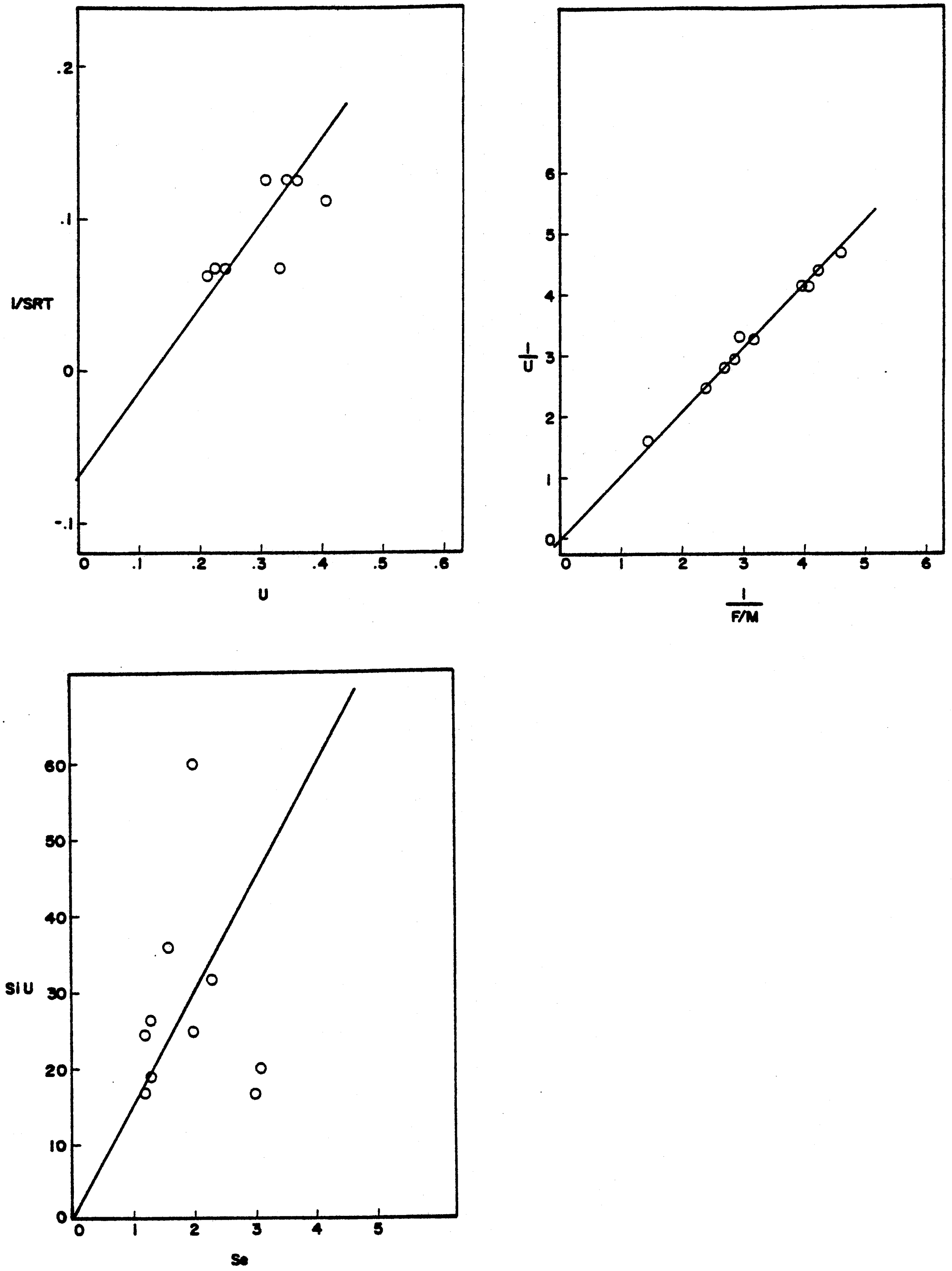

Figure 57. Biokinetic Plot; 4-Chloro-3-Methyl Phenol, BOD

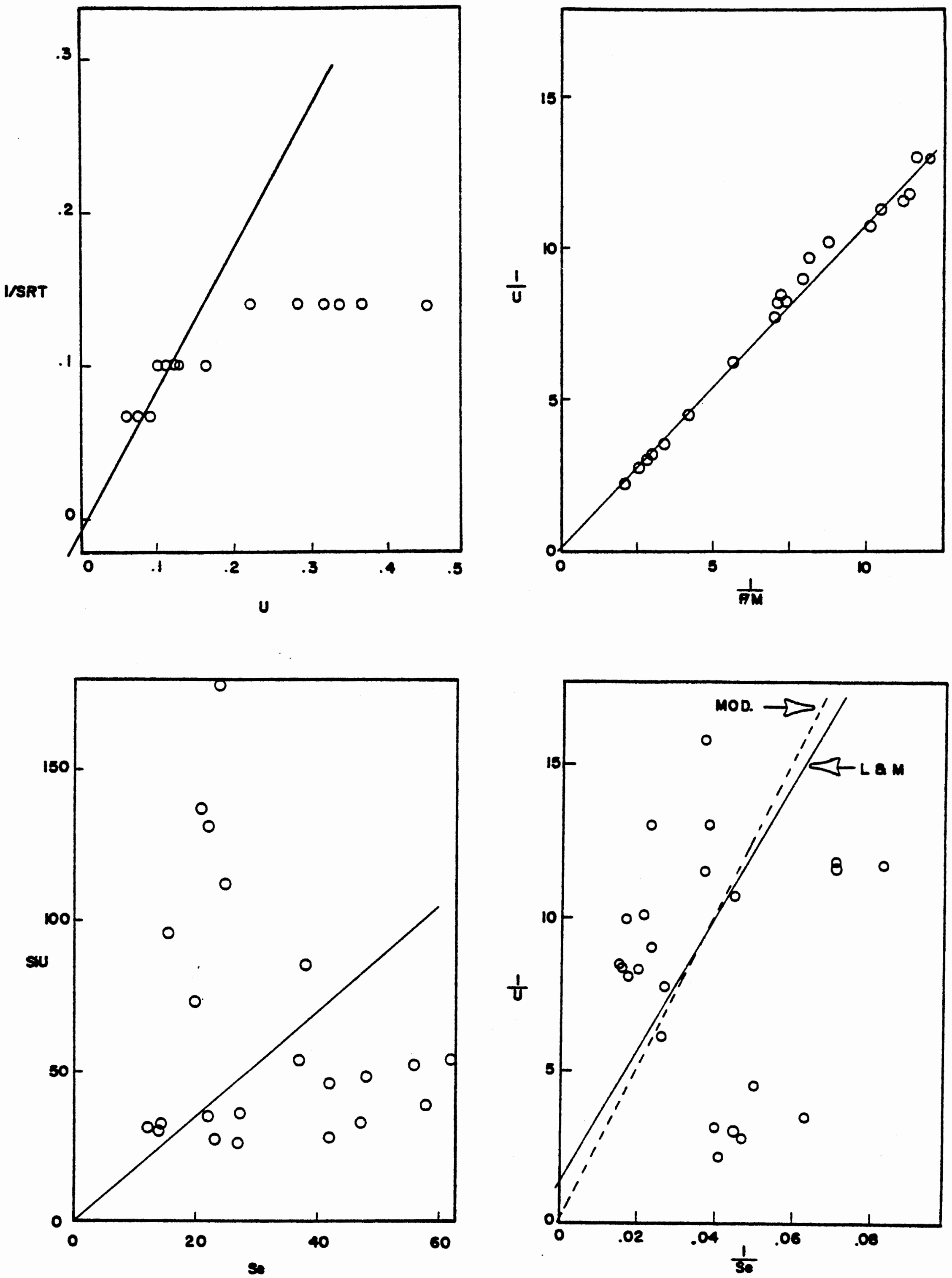

Figure 58. Biokinetic Plot; Combined Substrate Condition #1, TOC

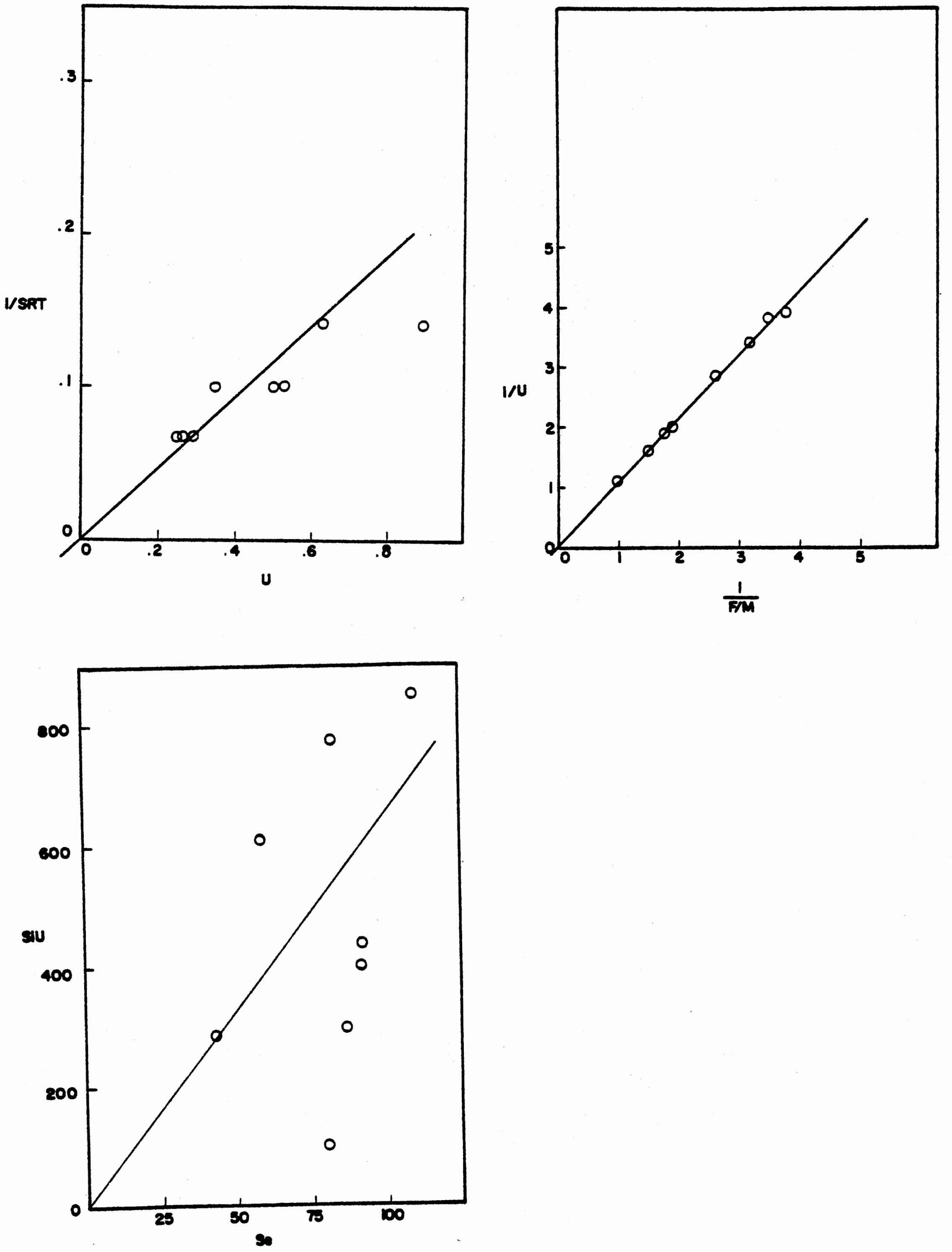

Figure 59. Biokinetic Plot; Combined Substrate Condition #1, COD

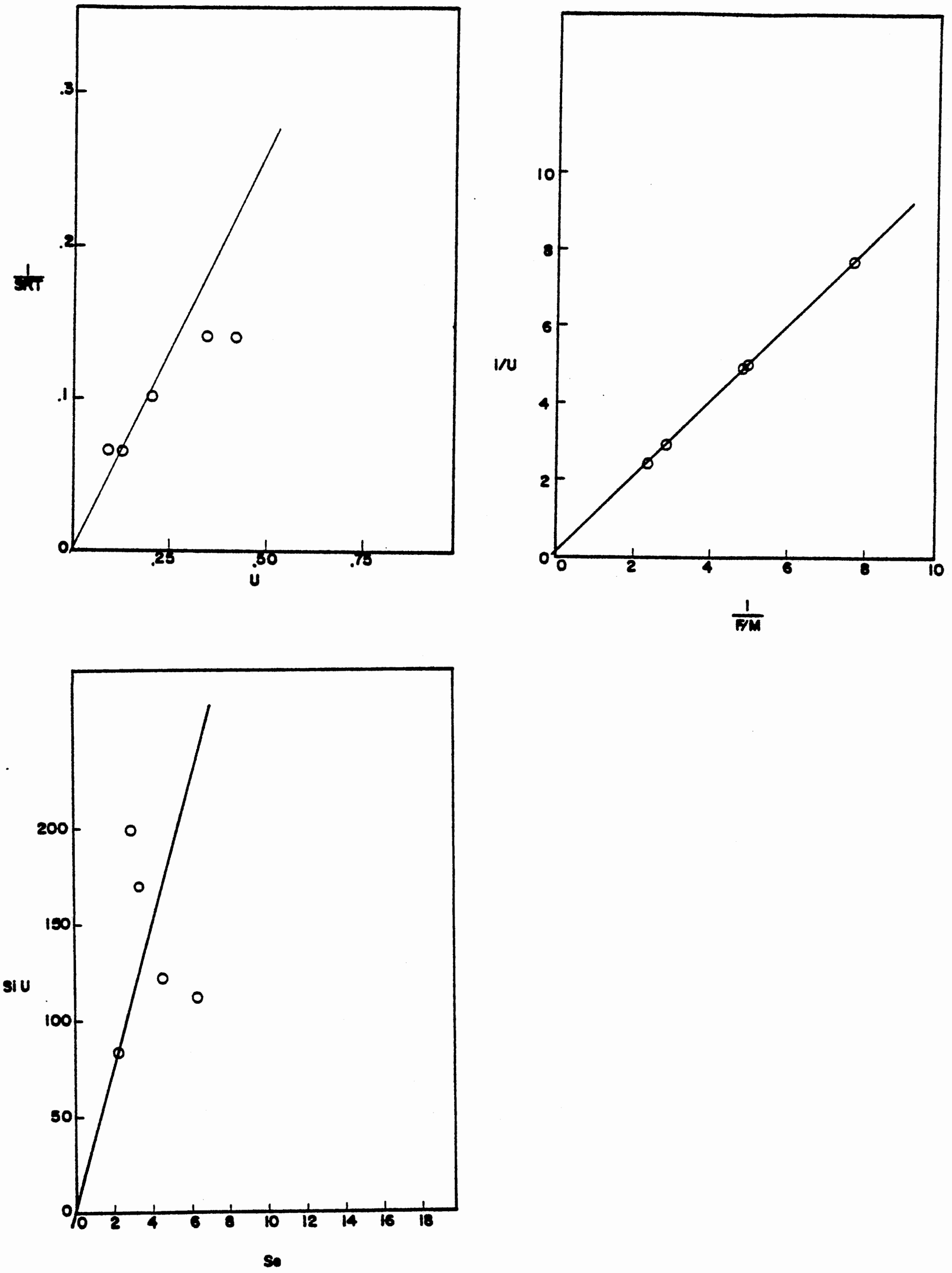

Figure 60. Biokinetic Plot; Combined Substrate Condition #1, BOD

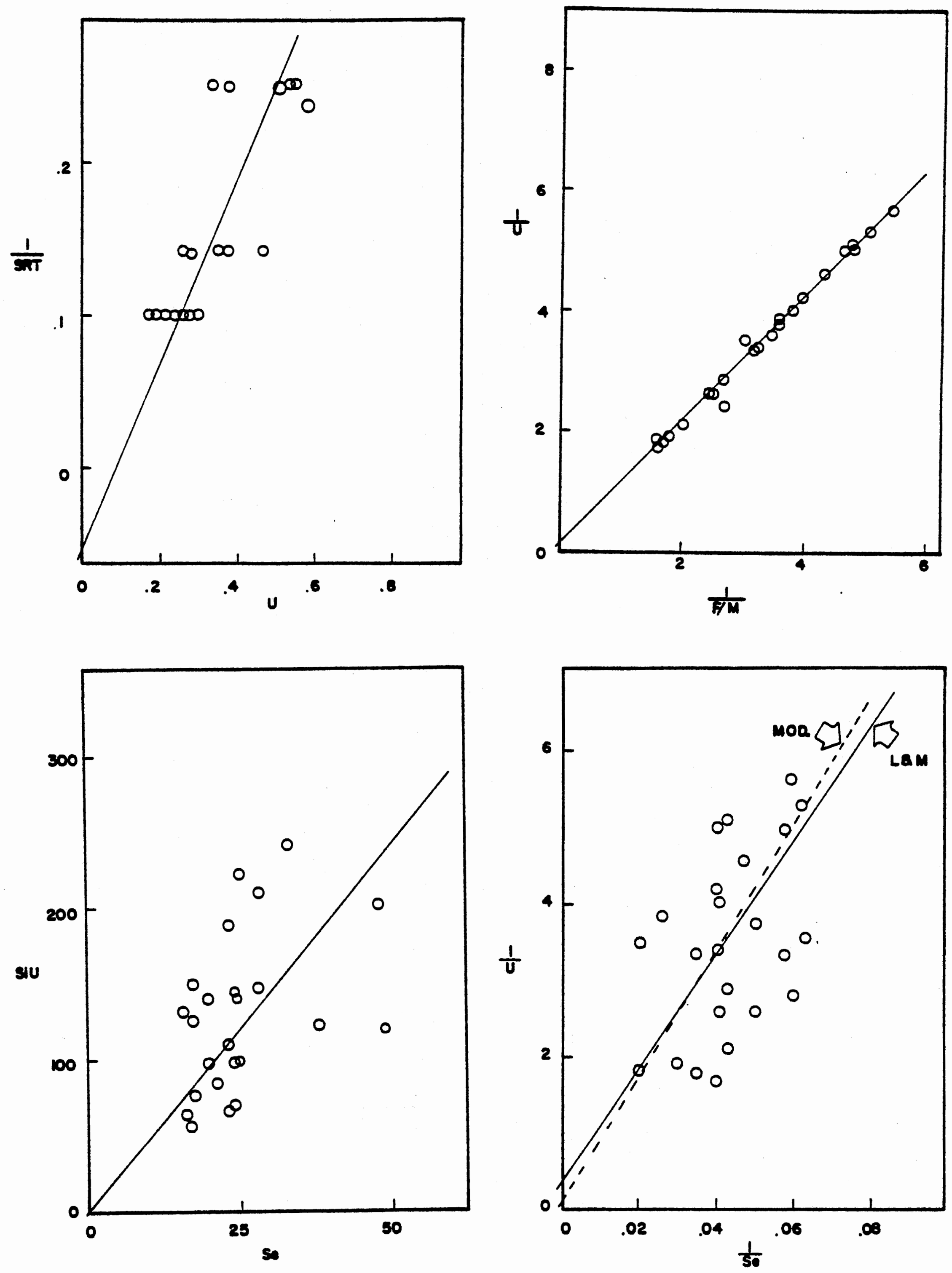

Figure 61. Biokinetic Plot; Combined Substrate Condition #2, TOC

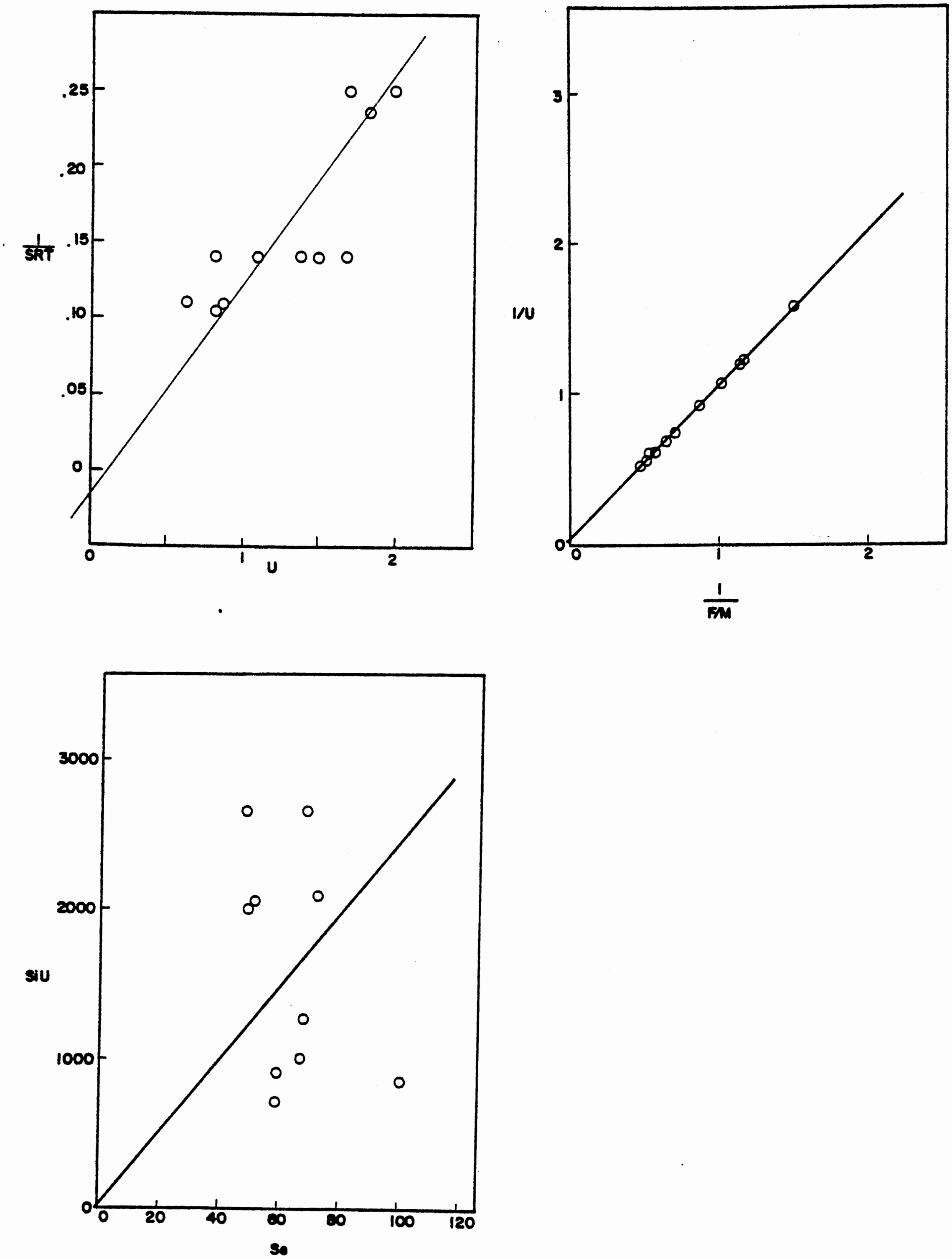

Figure 62. Biokinetic Plot; Combined Substrate Condition #2, COD

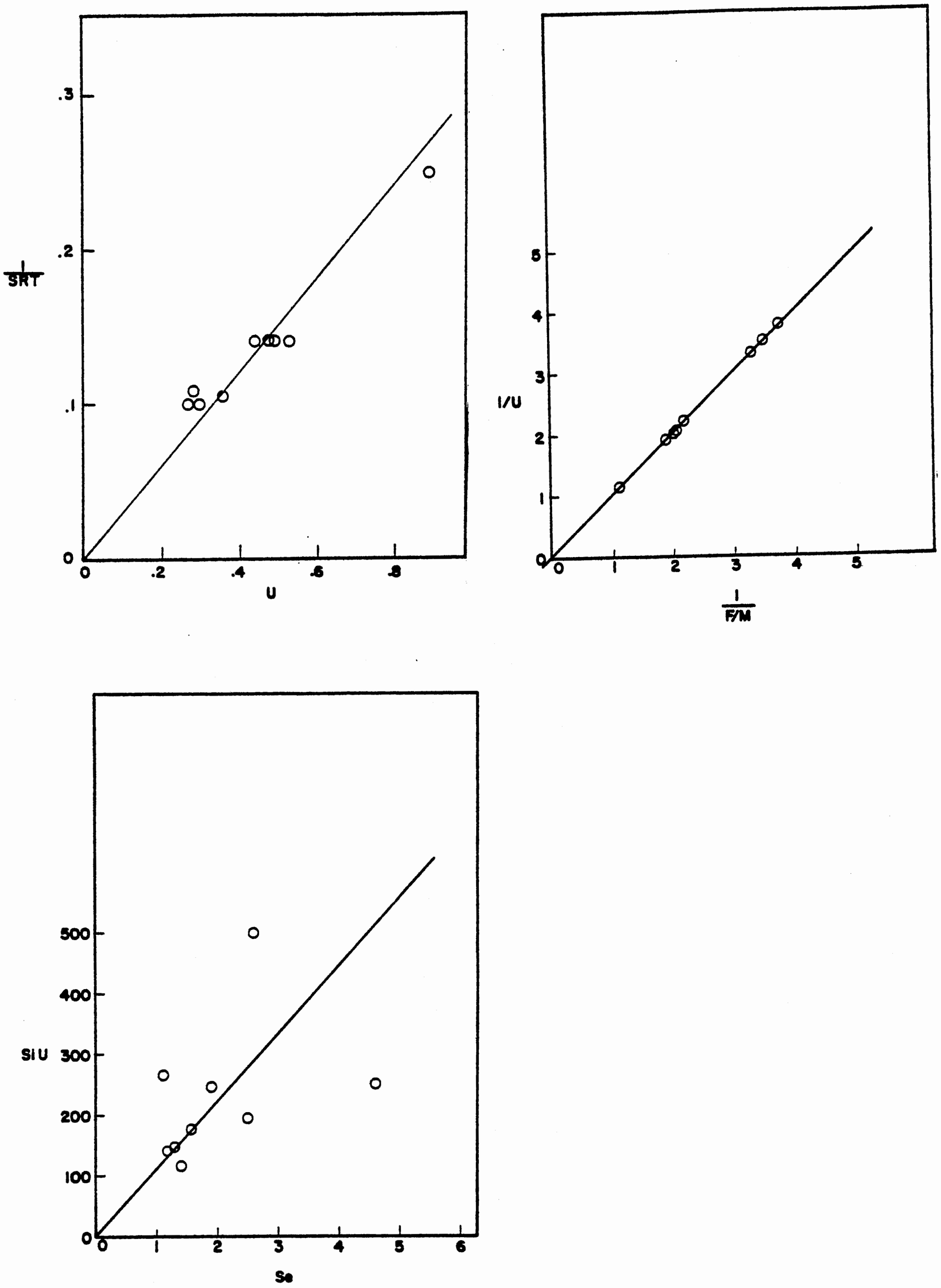

Figure 63. Biokinetic Plot; Combined Substrate Condition #2, BOD

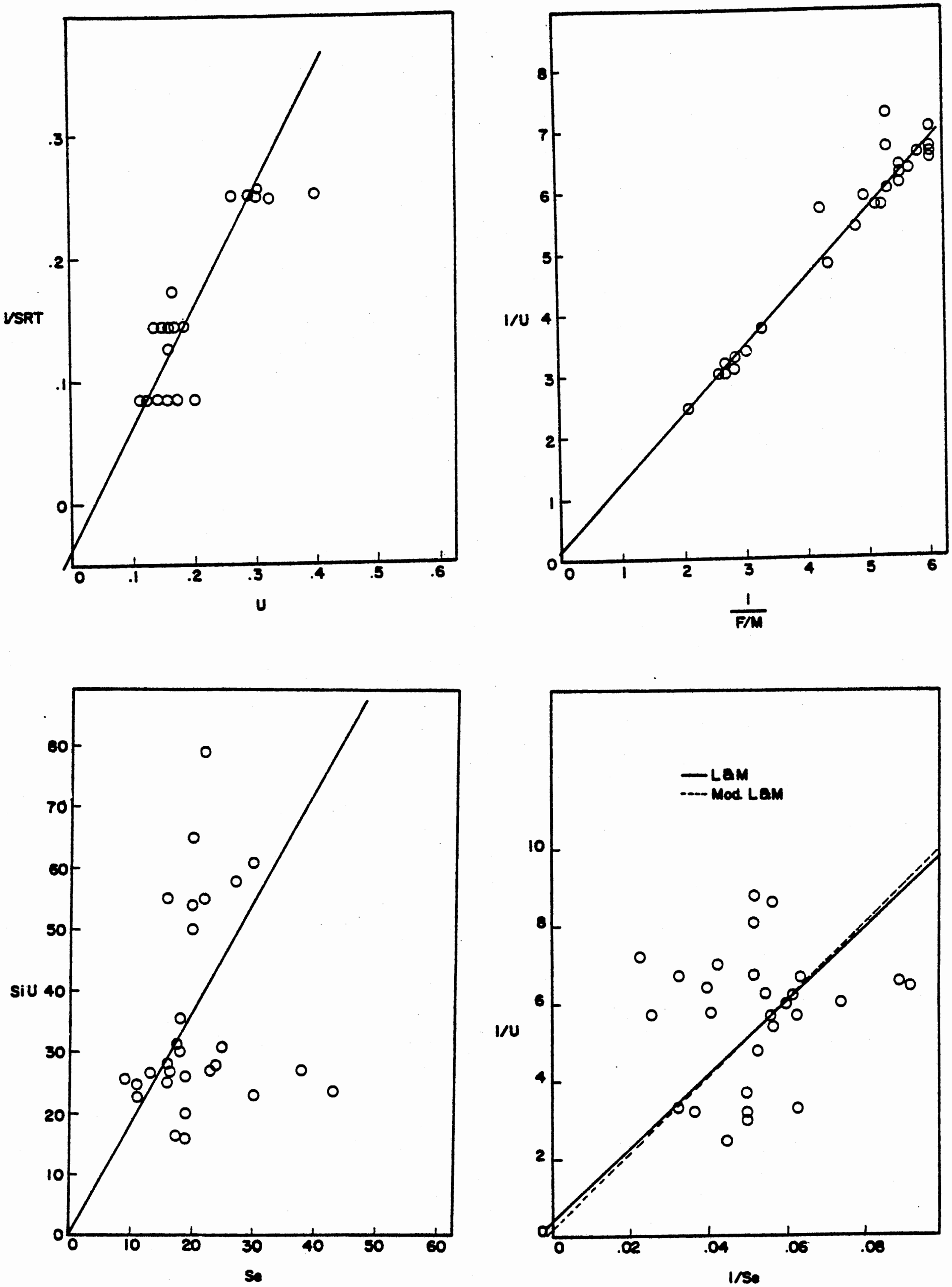

Figure 64. Biokinetic Plot; Combined Substrate Condition #3, TOC

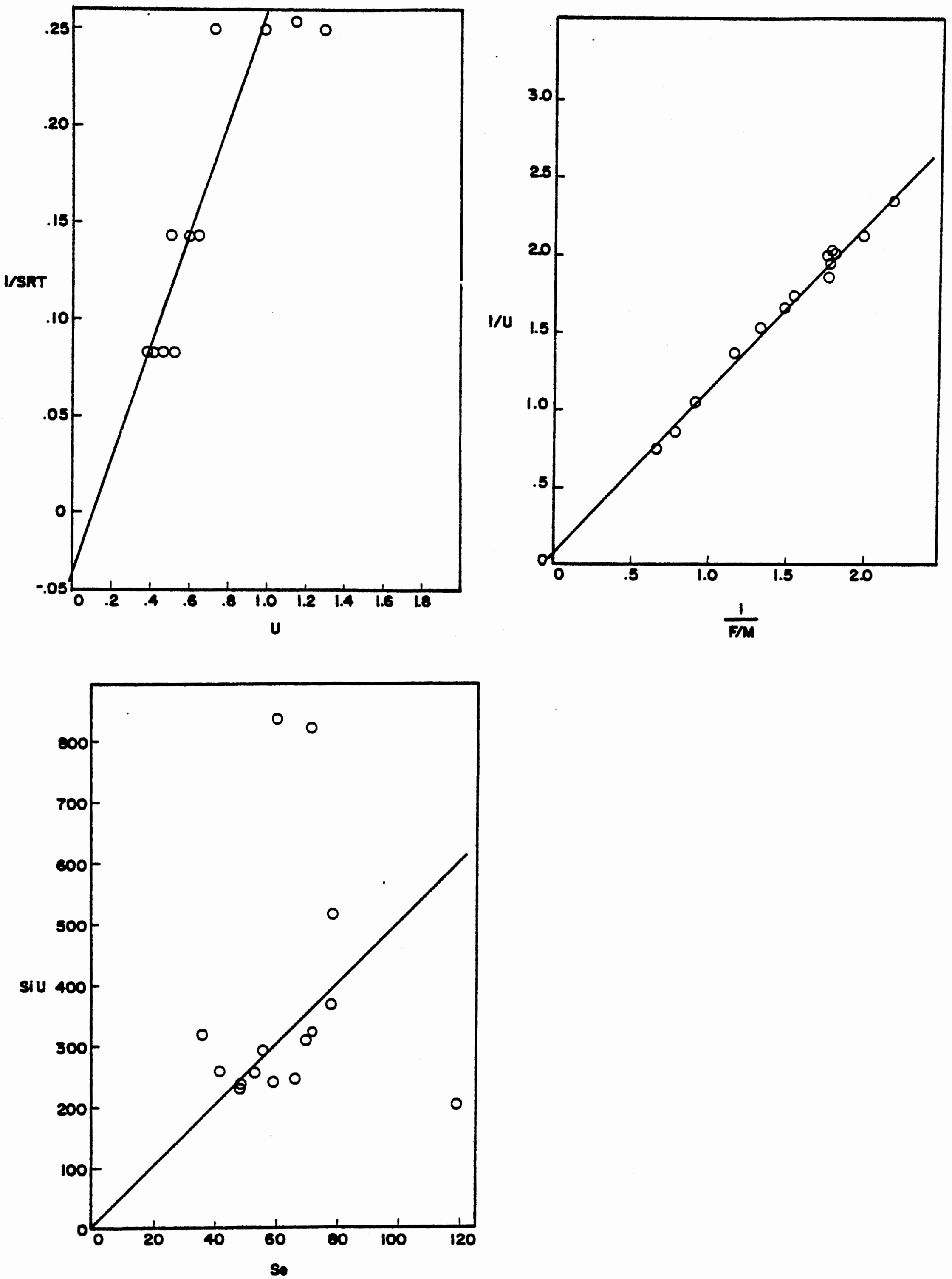

Figure 65. Biokinetic Plot; Combined Substrate Condition #3, COD

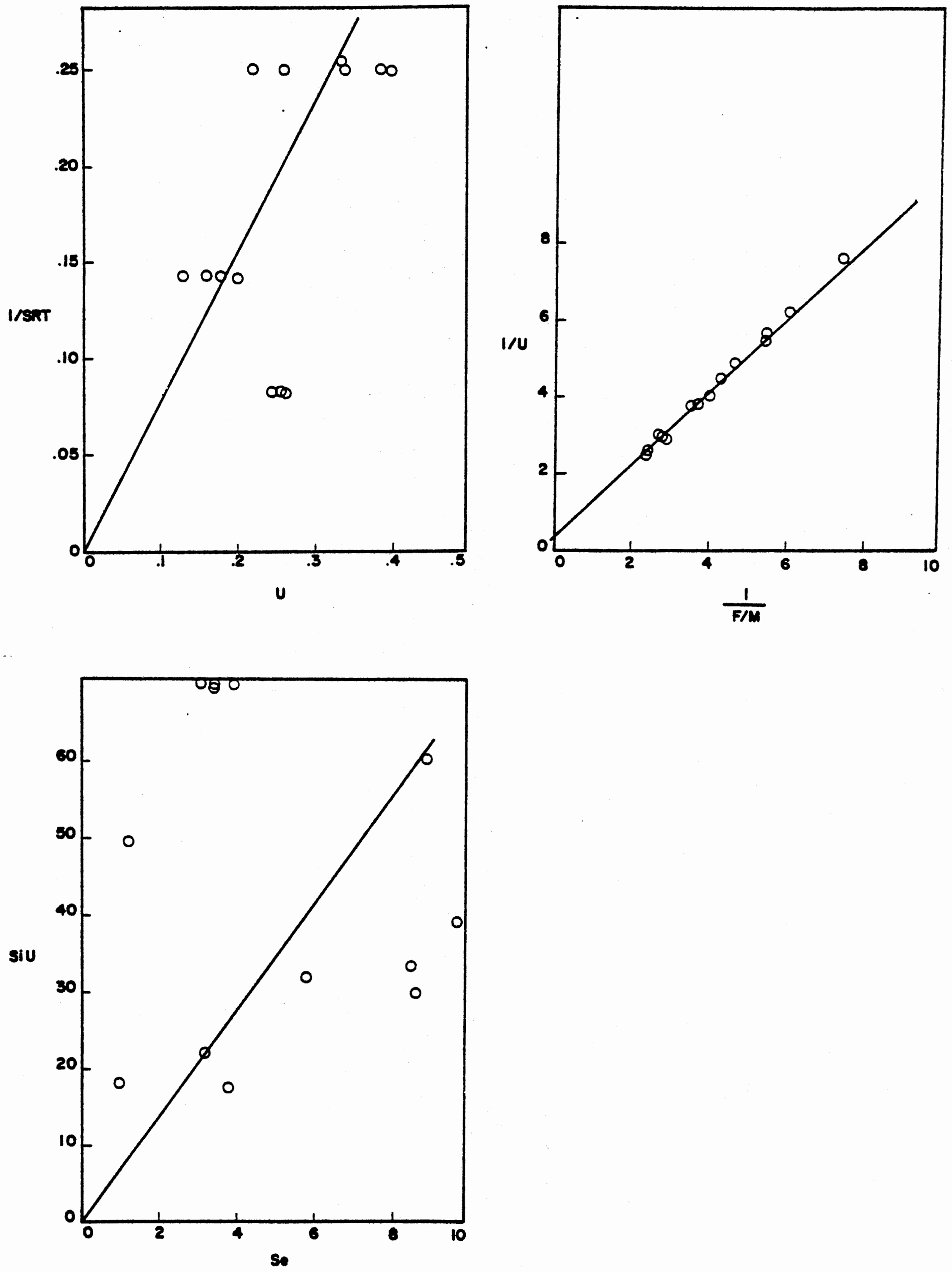

Figure 66. Biokinetic Plot; Combined Substrate Condition #3, BOD

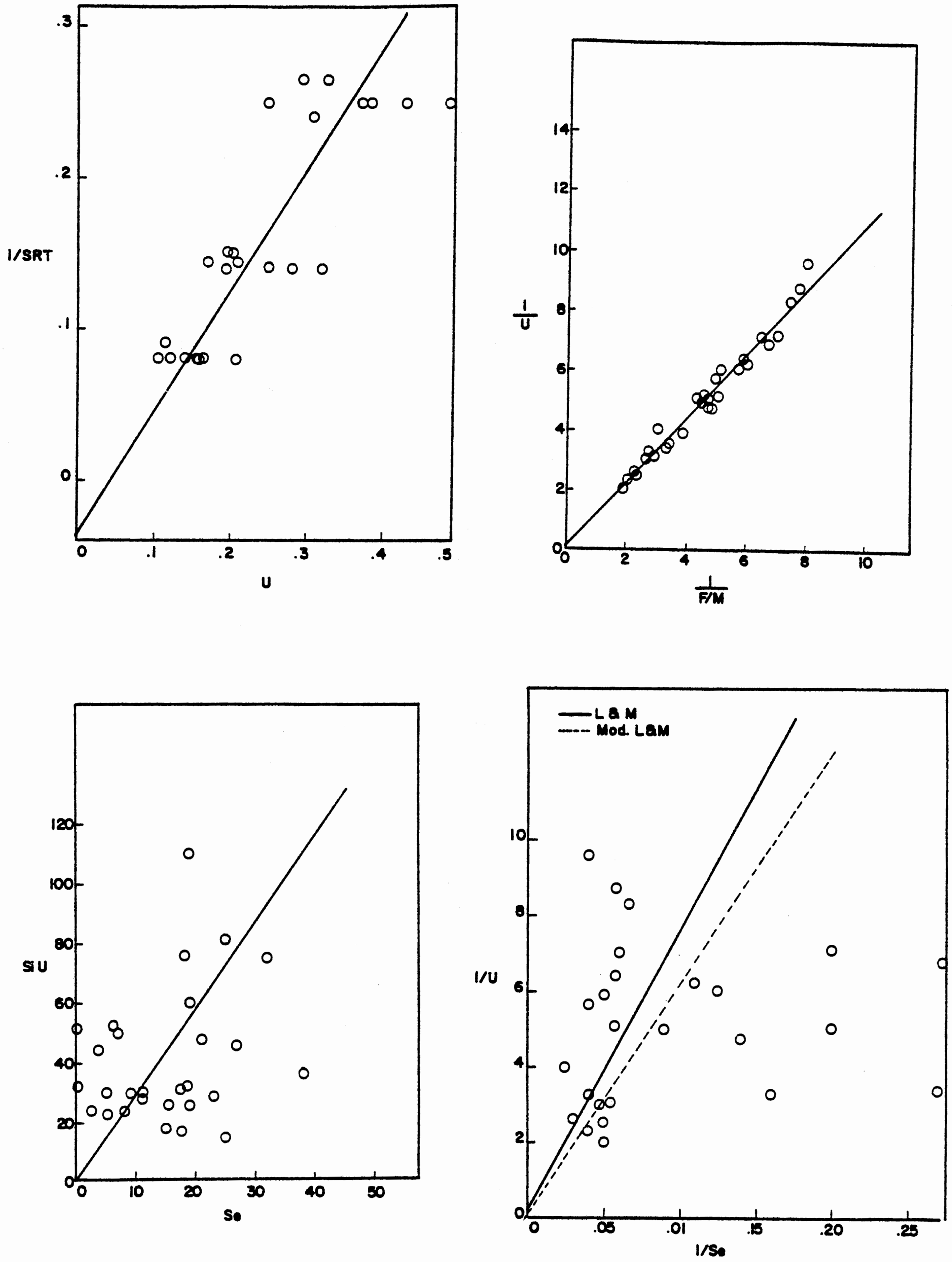

Figure 67. Biokinetic Plot; Combined Substrate Condition #4, TOC

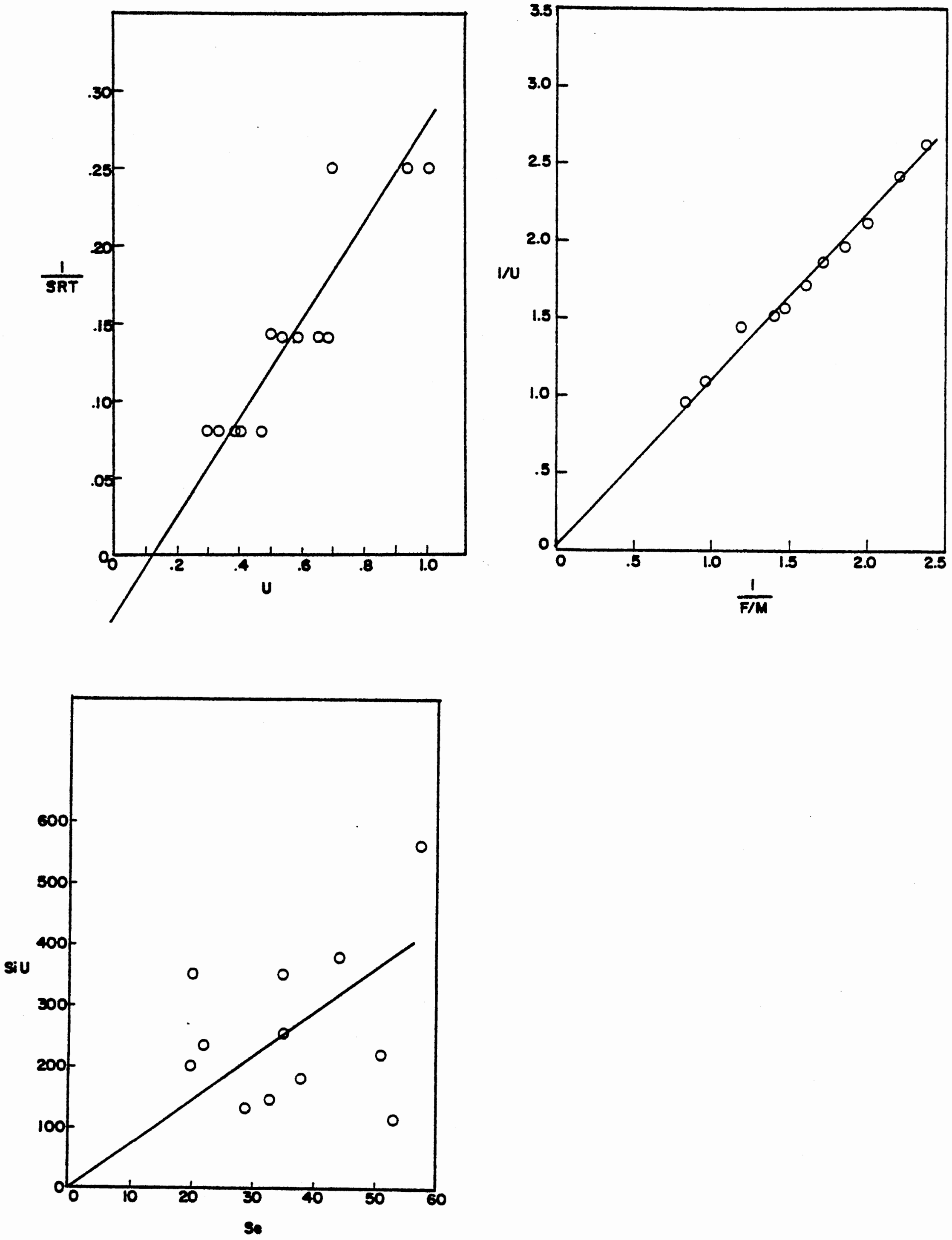

Figure 68. Biokinetic Plot; Combined Substrate Condition #4, COD

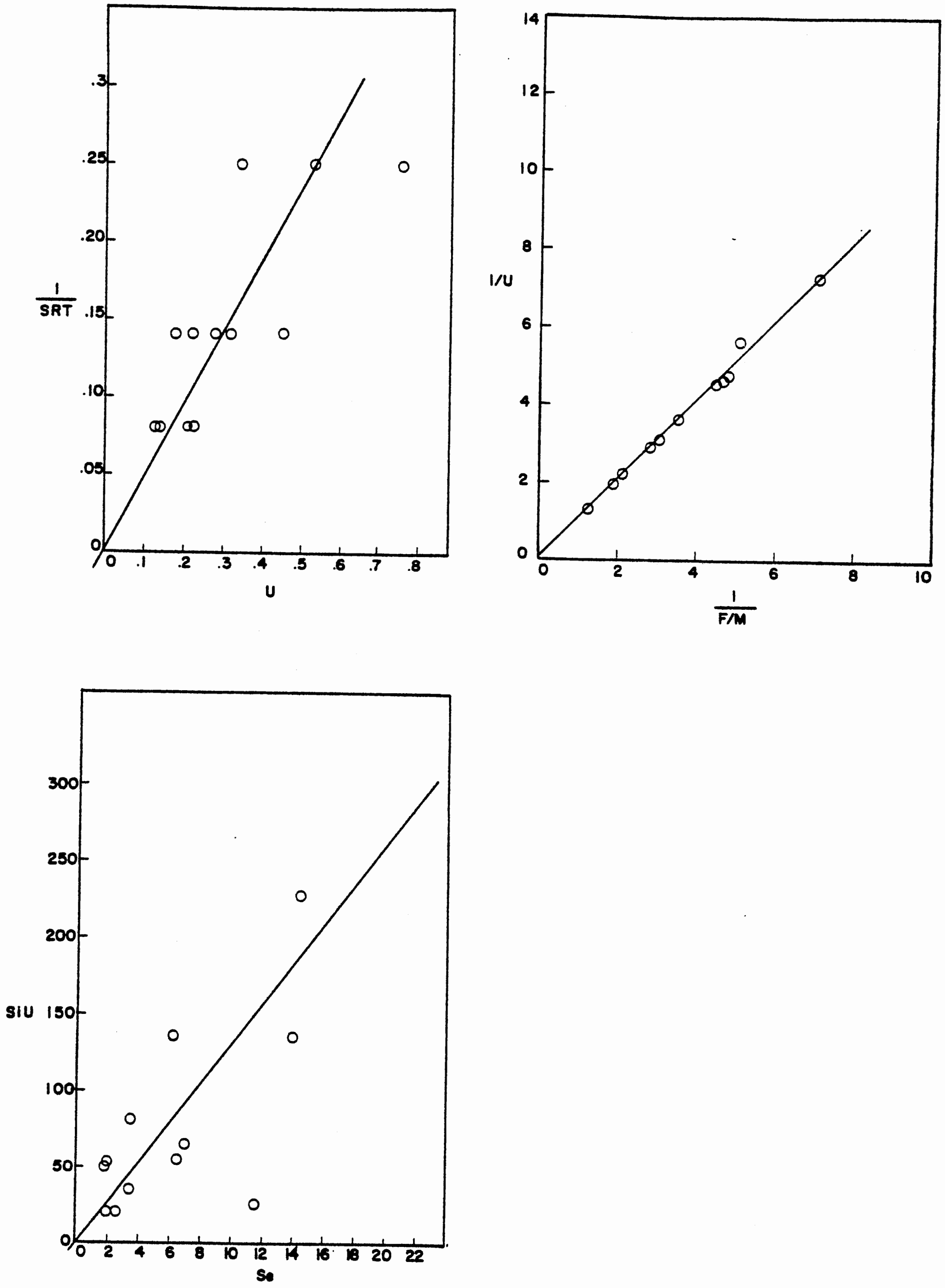

Figure 69. Biokinetic Plot; Combined Substrate Condition #4, BOD

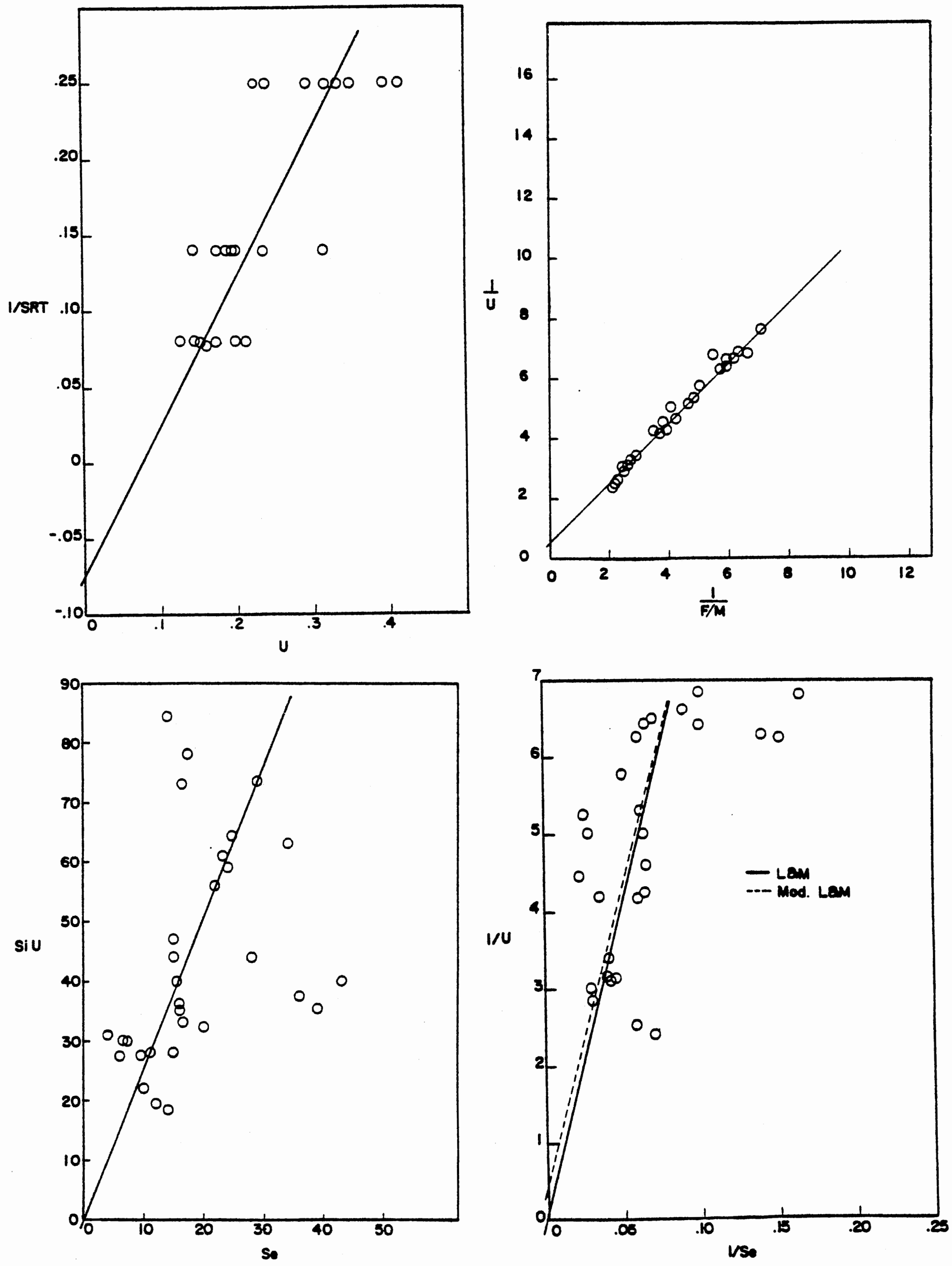

Figure 70. Biokinetic Plot; Combined Substrate Condition #5, TOC

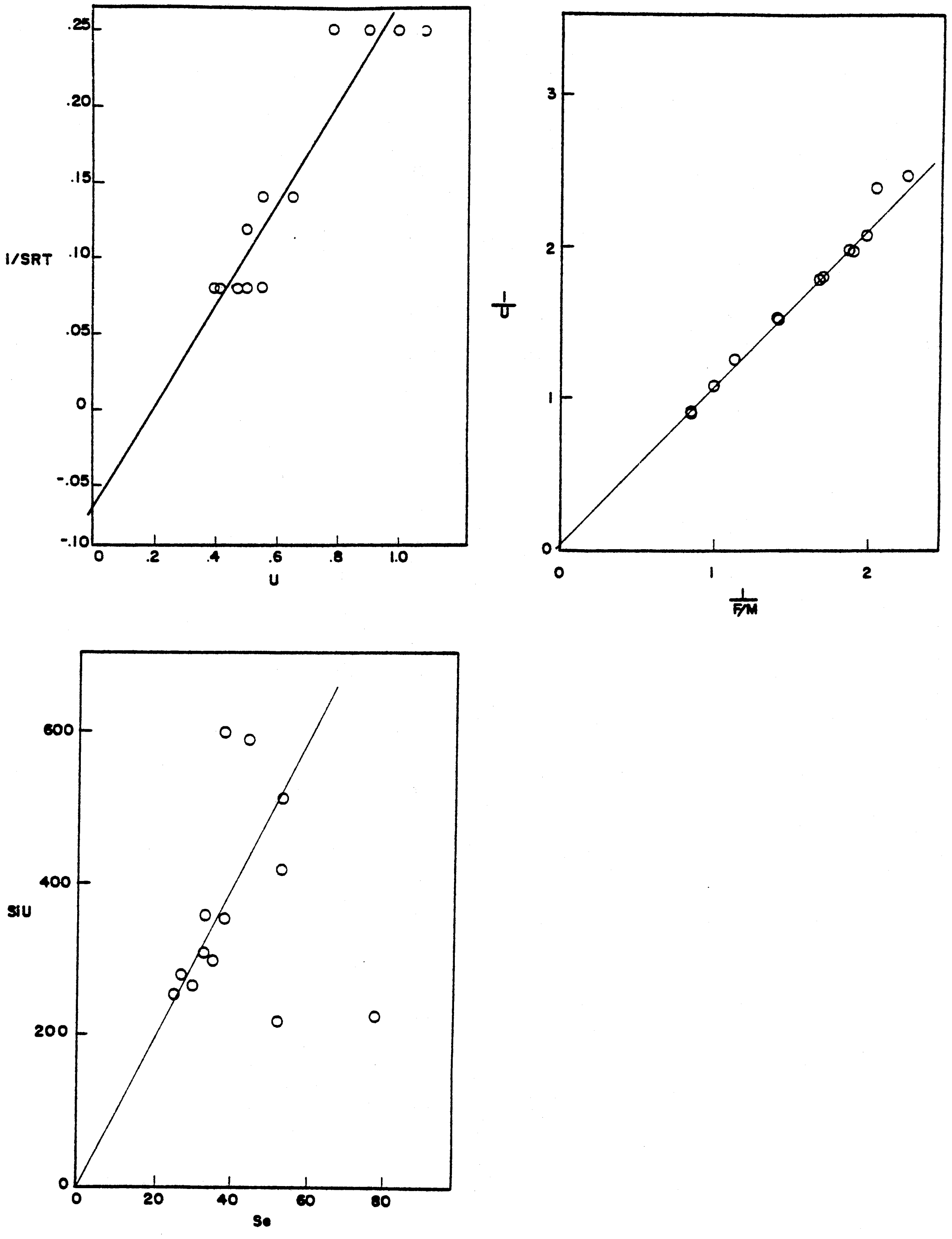

Figure 71. Biokinetic Plot; Combined Substrate Condition #5, COD

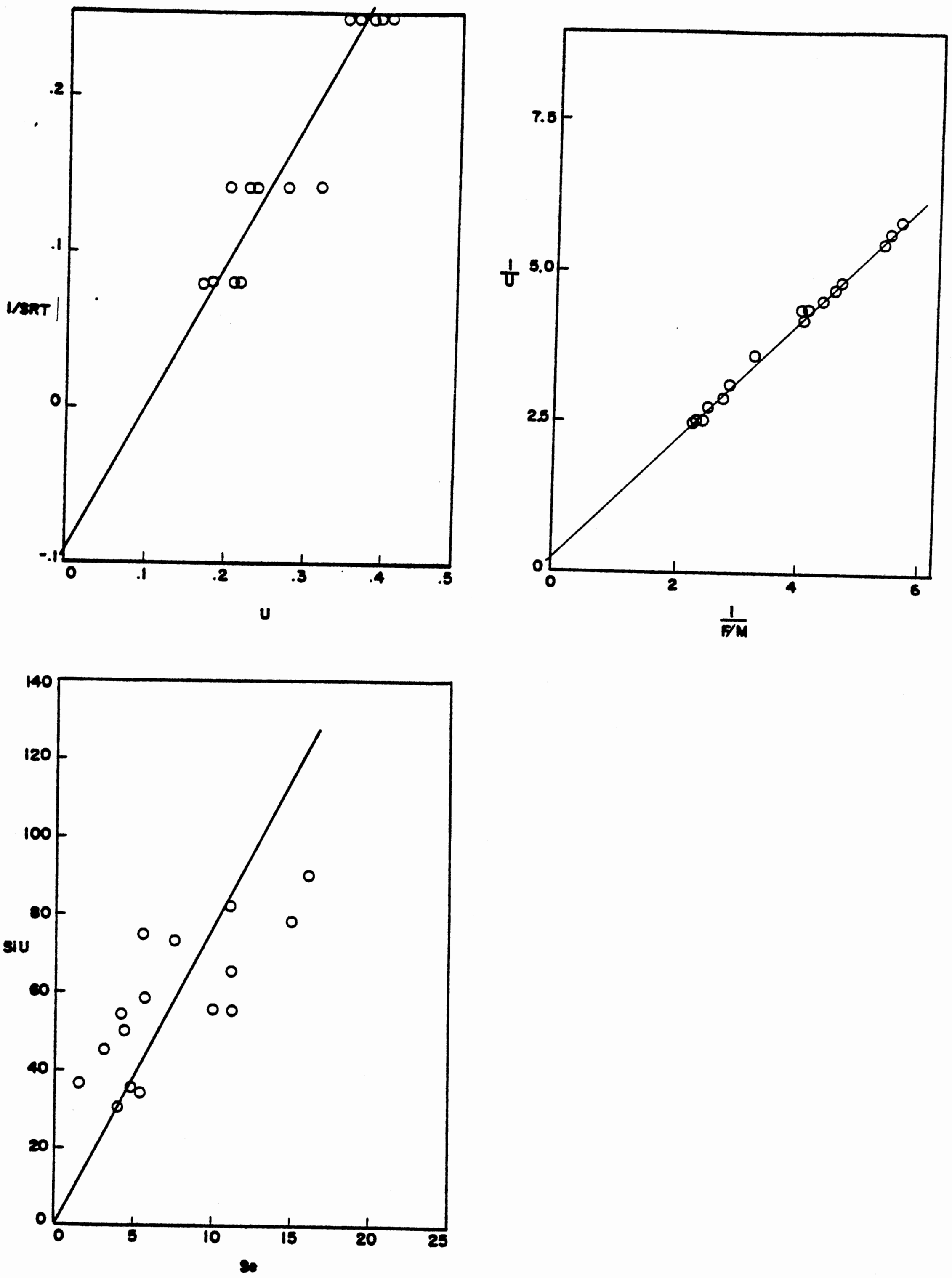

Figure 72. Biokinetic Plot; Combined Substrate Condition #5, BOD

APPENDIX B

HYPOTHETICAL BIOMASS AND EFFLUENT SUBSTRATE CONTRIBUTIONS FOR THE SPECIFIC CONSTITUENTS OF THE COMBINED UNIT WASTEWATERS UTILIZING THE DISCREET COMPOUND AND TOTAL VSS ASSUMPTIONS

TABLE LIII

DISCREET COMPOUND AND TOTAL VSS TREATABILITY ASSUMPTION ESTIMATES FOR SPECIFIC SUBSTRATE CONTRIBUTION OF BIOMASS (VSS) IN THE COMBINED UNIT MIXED LIQUORS (BASED UPON TOC)

	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
Influent Components	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
Condition #1	SRT = 7						SRT = 10						SRT = 15					
Albumen	660	679	496	499	660	679	930	958	792	792	930	958	1178	1213	1038	1037	1178	1214
Starch	1918	2040	1961	1994	1918	2041	2447	2619	2550	2581	2447	2619	2765	2972	2888	2918	2765	2972
Sucrose	1216	1249	1190	1174	1216	1250	1497	1544	1492	1476	1497	1545	1630	1686	1626	1608	1630	1687
Propanol	634	655	504	511	634	656	901	932	791	797	901	932	1158	1198	1049	1054	1158	1198
Oleic Acid	472	508	318	263	472	509	602	659	495	431	602	660	680	753	582	507	680	753
Cheer	539	252	620	501	539	253	819	810	1288	1209	819	811	1080	1409	1784	1721	1083	1409
Nitrophenol	258	256	215	216	258	256	317	315	279	278	317	315	343	342	304	301	343	342
Chloromethyl Phenol	139	140	0	0	139	141	186	189	63	54	186	189	217	222	96	82	217	222
Condition #2	SRT = 4						SRT = 7						SRT = 10					
Albumen	213	219	0	9	213	219	329	338	143	146	329	339	510	524	331	332	510	525
Starch	698	733	599	635	698	733	946	1006	881	912	946	1007	1342	1436	1314	1346	1342	1437
Sucrose	465	473	385	373	465	473	600	616	536	521	600	617	825	851	772	756	825	852
Propanol	331	341	179	188	331	342	511	528	378	385	511	528	797	824	675	681	797	824
Oleic Acid	289	300	65	45	289	301	393	424	235	182	393	424	558	610	425	369	558	611
Cheer	211	0	0	0	211	0	406	211	281	171	406	211	672	652	892	810	672	653
Nitrophenol	484	478	460	466	484	479	628	623	610	611	628	624	862	857	851	850	862	858
Chloromethyl Phenol	648	643	661	692	648	643	969	980	1037	1035	969	981	1431	1456	1557	1548	1431	1457

TABLE LIII (continued)

Influent Components	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
<u>Condition #3</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	76	78	0	0	76	79	112	115	0	0	112	115	204	210	0	0	204	210
Starch	249	261	91	127	249	262	320	340	172	204	320	340	506	542	374	406	506	543
Sucrose	306	311	214	202	306	311	374	384	288	273	374	384	562	581	487	469	562	581
Propanol	553	571	426	435	553	571	810	837	693	700	810	837	1501	1552	1412	1418	1501	1553
Oleic Acid	362	375	152	133	362	376	465	501	311	255	465	502	736	810	640	566	736	811
Cheer	56	0	0	0	56	0	103	52	0	0	103	53	207	238	0	0	207	238
Nitrophenol	72	70	12	18	72	71	88	87	34	35	88	87	132	131	81	79	132	131
Chloromethyl Phenol	85	87	0	0	85	84	120	121	0	0	120	121	201	205	71	59	201	206
<u>Condition #4</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	275	282	61	71	275	282	481	494	282	285	481	495	742	764	566	566	742	765
Starch	582	611	461	498	582	611	894	951	800	836	894	952	1195	1282	1138	1171	1195	1282
Sucrose	597	607	524	511	597	608	874	898	815	799	874	899	1111	1147	1069	1052	1111	1148
Propanol	140	144	0	0	140	144	245	253	69	76	245	253	383	396	222	228	383	396
Oleic Acid	54	56	0	0	54	36	84	90	0	0	84	90	112	122	0	0	112	123
Cheer	45	0	0	0	45	0	98	48	0	0	98	49	167	191	0	0	167	191
Nitrophenol	57	56	0	1	57	57	84	83	26	27	84	84	107	106	53	52	107	106
Chloromethyl Phenol	67	66	0	0	67	67	115	116	0	0	115	116	163	166	23	10	163	166
<u>Condition #5</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	173	178	0	0	173	178	341	351	100	103	341	351	456	469	262	262	456	469
Starch	362	380	206	244	362	380	622	661	472	511	622	662	723	776	616	648	723	776
Sucrose	375	381	281	268	375	382	612	628	520	502	612	629	679	701	611	593	679	701
Propanol	208	214	30	39	208	215	410	423	224	233	410	424	555	574	407	413	555	574

TABLE LIII (continued)

Influent Components	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
Condition #5 - Continued																		
Oleic Acid	128	132	0	0	128	133	220	237	0	0	220	238	256	282	69	0	256	282
Cheer	112	0	0	0	112	0	280	156	0	0	280	157	407	469	162	87	407	470
Nitrophenol	203	200	150	157	203	201	332	330	282	283	332	330	367	365	328	326	367	366
Chloromethyl Phenol	197	195	20	55	197	196	376	380	250	248	376	381	462	471	380	368	462	472

TABLE LIV

DISCREET COMPOUND AND TOTAL VSS TREATABILITY ASSUMPTION ESTIMATES FOR SPECIFIC SUBSTRATE CONTRIBUTION OF TOC IN THE COMBINED UNIT EFFLUENTS

Influent Components	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
<u>Condition #1</u>	SRT = 7						SRT = 10						SRT = 15					
Albumen	4.3	3.0	15.3	15.1	1.8	0.4	3.7	2.3	10.8	10.8	1.8	0.3	2.8	1.5	7.8	7.8	1.6	0.2
Starch	12.1	5.7	10.1	8.3	10.8	2.1	12.5	4.8	7.9	6.5	11.2	1.6	10.7	3.4	6.4	5.3	9.7	1.1
Sucrose	4.3	2.6	5.7	6.5	3.5	0.6	4.4	2.3	4.6	5.3	3.6	0.5	3.7	1.7	3.8	4.5	3.1	0.3
Propanol	3.1	1.8	11.0	10.6	1.6	0.2	2.8	1.4	7.8	7.5	1.7	0.2	2.1	0.9	5.6	5.4	1.4	0.1
Oleic Acid	5.7	3.5	15.0	18.2	4.8	0.3	5.8	2.9	11.1	14.3	5.0	0.3	5.0	2.1	8.7	11.7	4.4	0.2
Cheer	37.0	48.0	34.0	39.0	30.0	10.4	37.0	37.0	23.0	26.0	31.0	8.4	31.0	24.0	16.5	17.8	27.0	5.7
Nitrophenol	1.6	1.8	6.0	5.9	0.2	0.1	1.5	1.6	4.7	4.8	0.2	0.1	1.1	1.2	3.9	4.1	0.1	0.0
Chloromethyl Phenol	2.2	2.1	10.6	10.6	0.5	0.1	1.9	1.7	8.0	8.5	0.5	0.0	1.4	1.2	6.1	6.7	0.4	0.0
<u>Condition #2</u>	SRT = 4						SRT = 7						SRT = 10					
Albumen	3.2	2.5	26.0	25.0	1.0	0.2	2.2	1.5	14.8	14.7	0.9	0.1	2.0	1.3	11.0	10.9	0.9	0.1
Starch	7.1	4.4	14.8	12.0	5.7	1.1	6.2	2.8	9.8	8.1	5.3	0.6	6.7	2.6	8.0	6.6	5.9	0.5
Sucrose	2.5	1.9	8.2	0.9	1.8	0.3	2.2	1.3	5.6	6.4	1.7	0.2	2.4	1.2	4.6	5.3	1.9	0.2
Propanol	3.5	2.5	18.3	17.5	1.5	0.3	2.5	1.4	10.7	10.3	1.3	0.2	2.4	1.2	7.9	7.6	1.4	0.1
Oleic Acid	5.5	4.5	25.0	26.0	4.3	0.5	4.9	2.9	14.5	17.8	4.1	0.3	5.3	2.7	11.3	14.5	4.6	0.2
Cheer	34.0	46.0	46.0	46.0	24.4	11.1	28.4	35.9	33.2	37.5	22.9	7.2	30.1	30.7	23.8	26.1	25.5	6.4
Nitrophenol	5.8	6.5	9.0	8.2	1.1	1.1	4.1	4.5	5.9	5.8	0.8	0.6	3.9	4.2	4.8	4.9	0.8	0.5
Chloromethyl Phenol	22.0	22.0	21.0	18.0	7.7	5.8	15.1	14.4	10.9	11.0	5.8	3.5	14.3	13.1	8.1	8.6	5.9	3.0

TABLE LIV (continued)

Influent Components	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
<u>Condition #3</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	1.2	0.9	9.4	9.4	0.3	0.0	0.7	0.5	8.0	8.0	0.3	0.0	0.6	0.4	9.0	9.0	0.3	0.0
Starch	2.6	1.6	14.9	12.1	2.0	0.3	2.0	0.9	9.9	8.1	1.7	0.1	2.1	0.8	7.1	5.9	1.9	0.1
Sucrose	1.7	1.3	8.2	9.1	1.2	0.2	1.3	0.8	5.6	6.4	1.0	0.1	1.4	0.7	4.2	4.9	1.1	0.1
Propanol	6.0	4.2	18.6	17.7	3.4	1.4	3.8	2.2	10.8	10.4	2.5	0.8	3.4	1.5	6.7	6.4	2.5	0.6
Oleic Acid	7.0	5.8	25.2	26.8	5.7	1.4	5.5	3.3	14.6	17.9	4.8	0.7	5.9	2.7	9.9	13.0	5.2	0.6
Cheer	9.2	12.6	12.6	12.6	6.5	1.7	6.9	8.8	10.8	10.8	5.5	0.9	7.2	6.4	12.0	12.0	6.1	0.7
Nitrophenol	9.0	1.0	9.1	8.3	0.1	0.0	0.5	0.6	5.9	5.8	0.1	0.0	0.5	0.5	4.3	4.4	0.1	0.0
Chloromethyl Phenol	2.9	3.0	10.5	10.5	0.6	0.2	1.8	1.7	9.0	9.0	0.4	0.1	1.6	1.4	7.0	7.6	0.5	0.1
<u>Condition #4</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	4.1	3.3	26.3	25.3	1.5	0.6	2.9	2.0	15.1	14.9	1.3	0.4	2.2	1.3	9.3	9.3	1.2	0.2
Starch	5.8	3.6	15.0	12.2	4.8	1.3	5.3	2.4	9.9	8.2	4.6	0.8	5.0	1.8	7.1	5.9	4.5	0.6
Sucrose	3.2	2.5	8.3	9.2	2.5	0.9	2.9	1.7	5.6	6.4	2.4	0.5	2.7	1.3	4.2	4.9	2.3	0.4
Propanol	1.5	1.0	14.9	14.9	0.6	0.1	1.1	0.6	10.9	10.5	0.6	0.1	0.9	0.4	6.7	6.5	0.5	0.0
Oleic Acid	1.0	0.8	5.6	5.6	0.8	0.0	0.9	0.6	5.5	5.5	0.8	0.0	0.9	0.4	5.5	5.5	0.8	0.0
Cheer	7.1	9.8	9.8	9.8	5.0	1.1	6.2	7.9	9.6	9.6	4.9	0.7	5.7	5.2	9.6	9.6	4.9	0.5
Nitrophenol	0.7	0.8	8.4	8.3	0.1	0.0	0.5	0.5	5.9	5.8	0.0	0.0	0.4	0.4	4.3	4.5	0.0	0.0
Chloromethyl Phenol	2.3	2.3	8.1	8.1	0.4	0.1	1.6	1.5	8.0	8.0	0.4	0.1	1.3	1.1	7.1	7.6	0.4	0.1
<u>Condition #5</u>	SRT = 4						SRT = 7						SRT = 12					
Albumen	2.5	2.0	19.8	19.8	0.8	0.2	1.7	1.2	14.5	14.3	0.7	0.1	1.3	0.8	9.2	9.2	0.7	0.1
Starch	3.5	2.2	14.9	12.1	2.8	0.5	3.2	1.4	9.7	8.0	2.7	0.3	3.1	1.1	7.1	5.9	2.7	0.2
Sucrose	1.9	1.5	8.2	9.1	1.5	0.4	1.7	1.0	5.5	6.3	1.4	0.2	1.7	0.8	4.2	4.9	1.4	0.1

TABLE LIV (continued)

	Predictive Technique Employed																	
	Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS		Discreet Compound				Tot. VSS	
Influent Components	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK	K+S	ECK	L+M	Mod. L+M	K+S	ECK
<u>Condition #5</u> - Continued																		
Propanol	2.1	1.5	18.6	17.7	0.9	0.2	1.5	0.9	10.5	10.1	0.8	0.1	1.3	0.6	6.6	6.4	0.8	0.1
Oleic Acid	2.3	1.9	12.7	12.7	1.8	0.2	2.1	1.3	12.7	12.7	1.8	0.1	2.0	1.0	9.9	12.8	1.8	0.1
Cheer	17.2	23.5	23.5	23.5	12.4	5.8	15.0	18.8	23.5	23.5	12.2	3.8	14.0	12.6	19.8	21.6	12.1	2.7
Nitrophenol	2.3	2.6	9.1	8.3	0.4	0.3	1.7	1.8	5.8	5.7	0.3	0.2	1.3	1.4	4.3	4.4	0.2	0.1
Chloromethyl Phenol	6.4	6.5	21.2	18.3	1.7	1.0	4.5	4.3	10.7	10.8	1.4	0.6	3.6	3.2	7.0	7.5	1.3	0.4

APPENDIX C

BIOKINETIC PLOTS IN TERMS OF SPECIFIC SUBSTRATE FOR CHEER AND OLEIC ACID

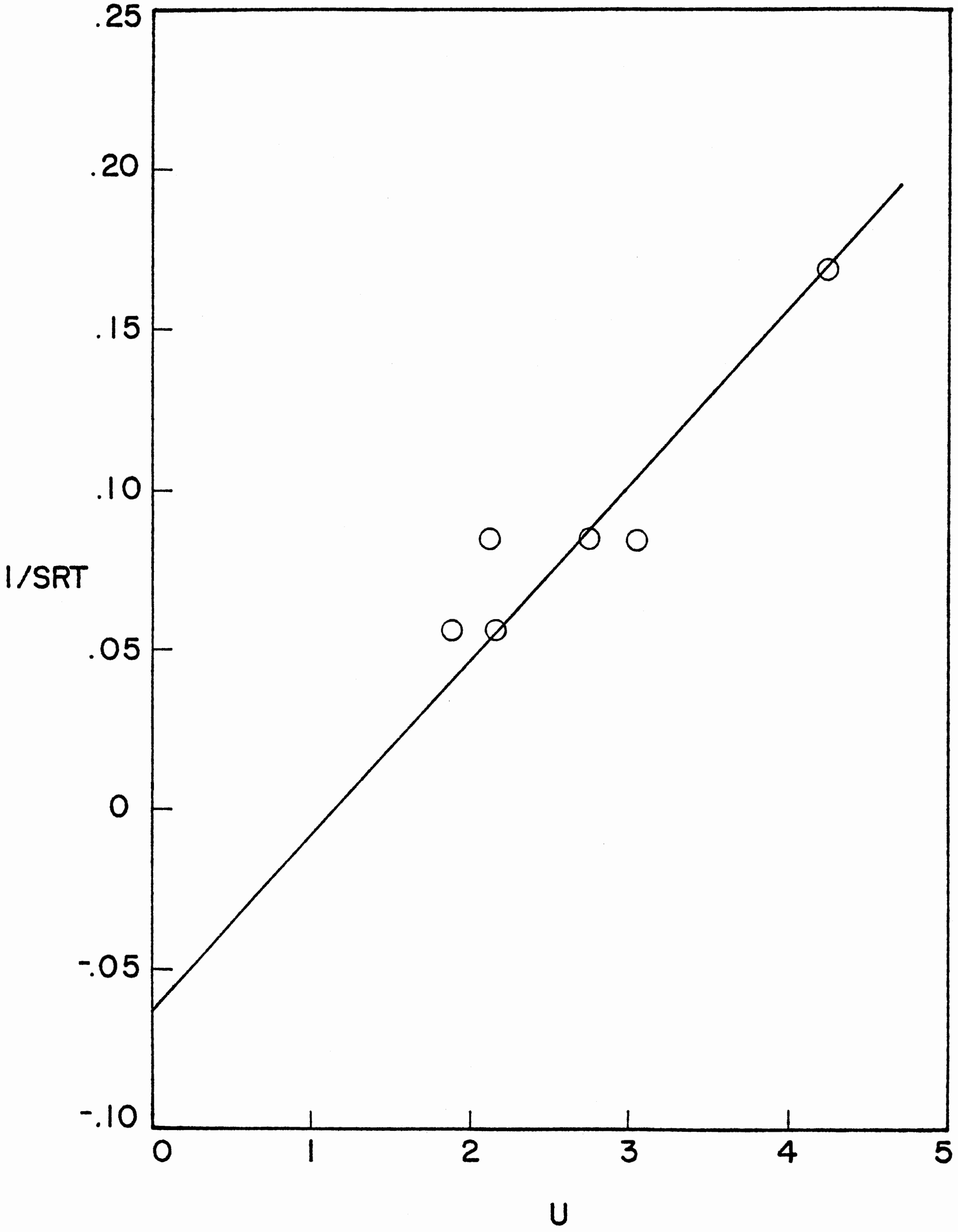

Figure 73. Biokinetic Plot for Determinations of Y_t and k_d in Terms of Cheer Concentration and VSS

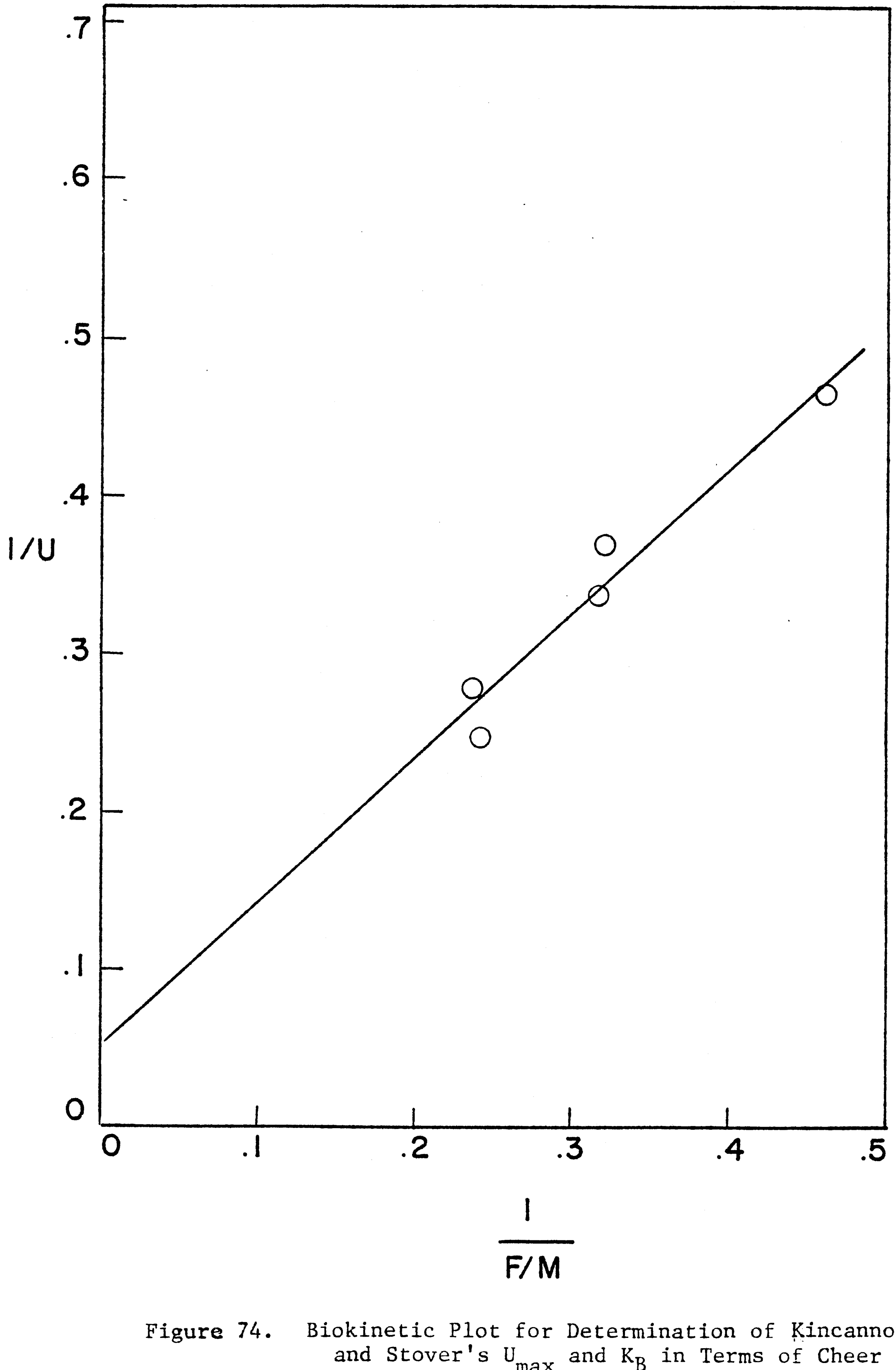

Figure 74. Biokinetic Plot for Determination of Kincannon and Stover's U_{max} and K_B in Terms of Cheer Concentration and VSS

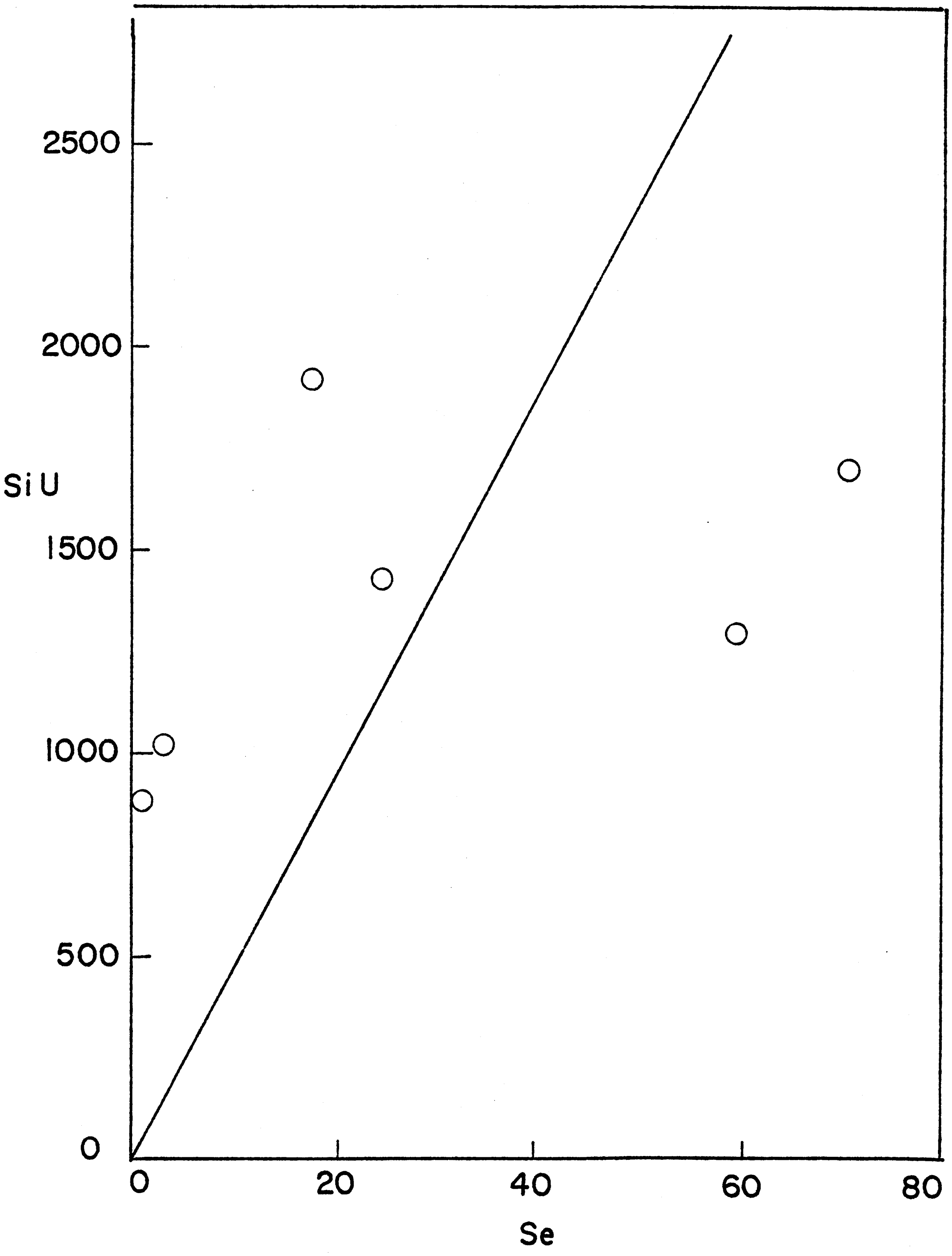

Figure 75. Biokinetic Plot for Determination of Eckenfelder's k_e' in Terms of Cheer Concentration and VSS

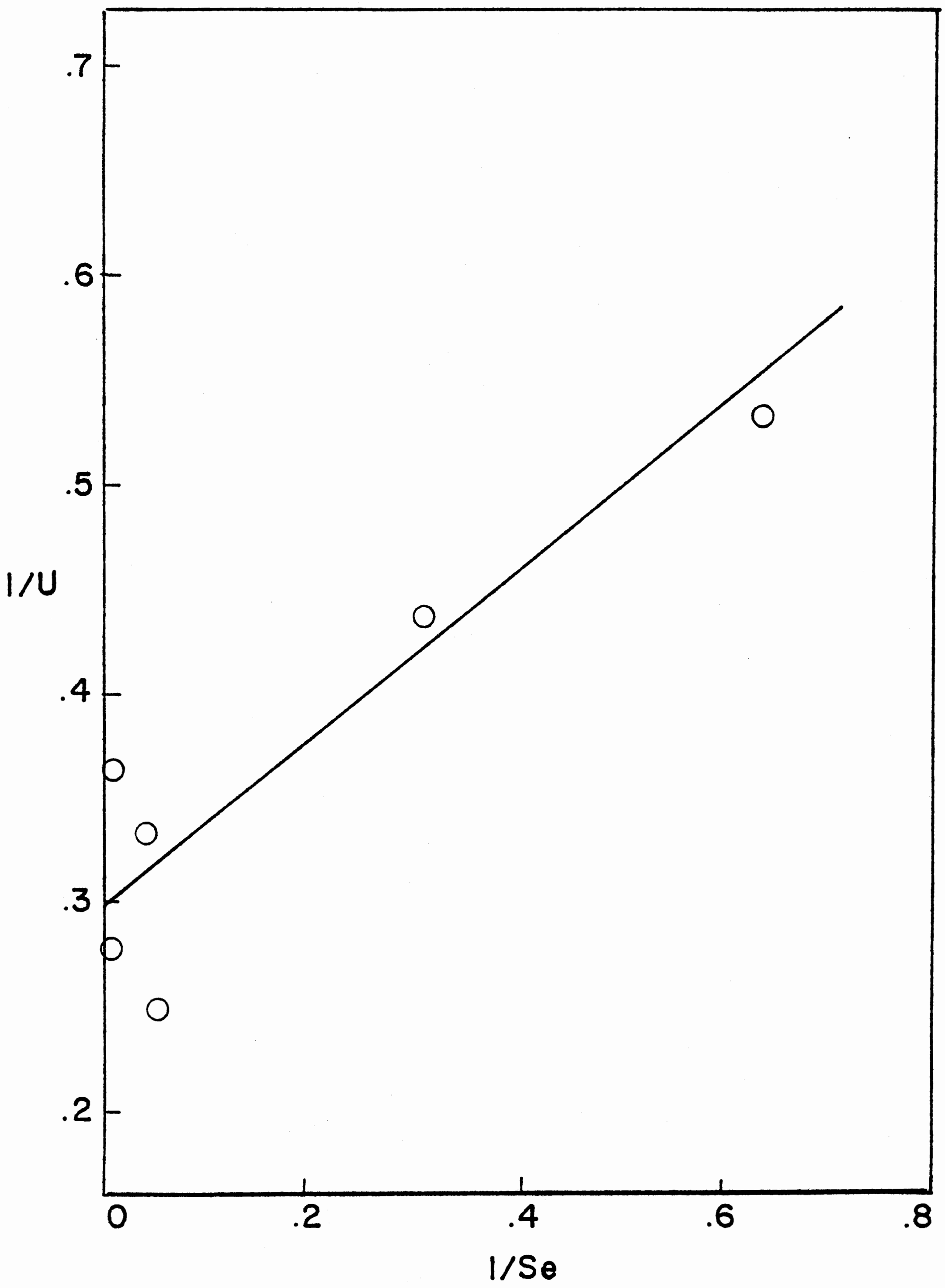

Figure 76. Biokinetic Plot for Determination of Lawrence and McCarty's k and K_s in Terms of Cheer Concentration and VSS

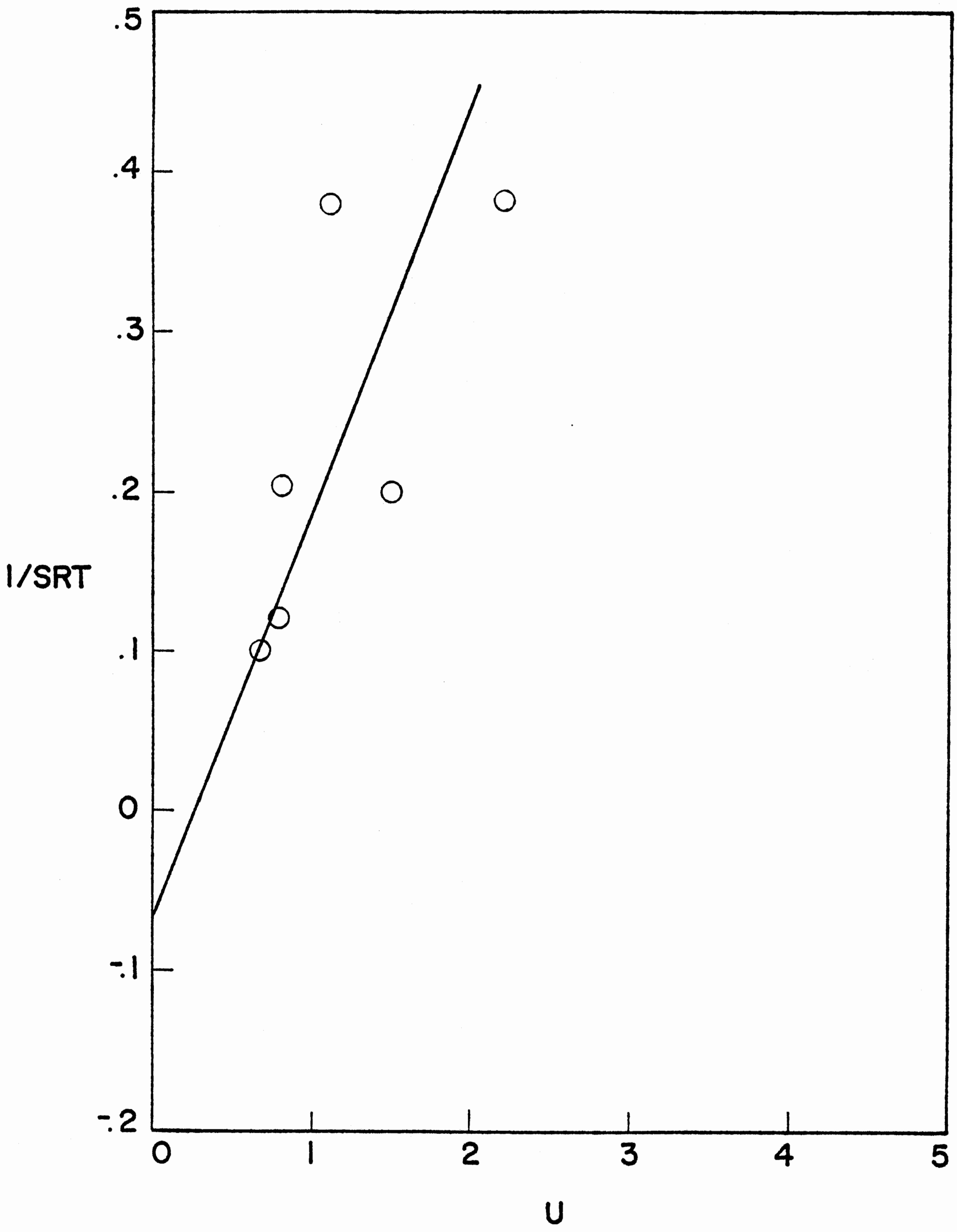

Figure 77. Biokinetic Plot for Determination of Y_t and k_d in Terms of Oleic Acid Concentration and VSS

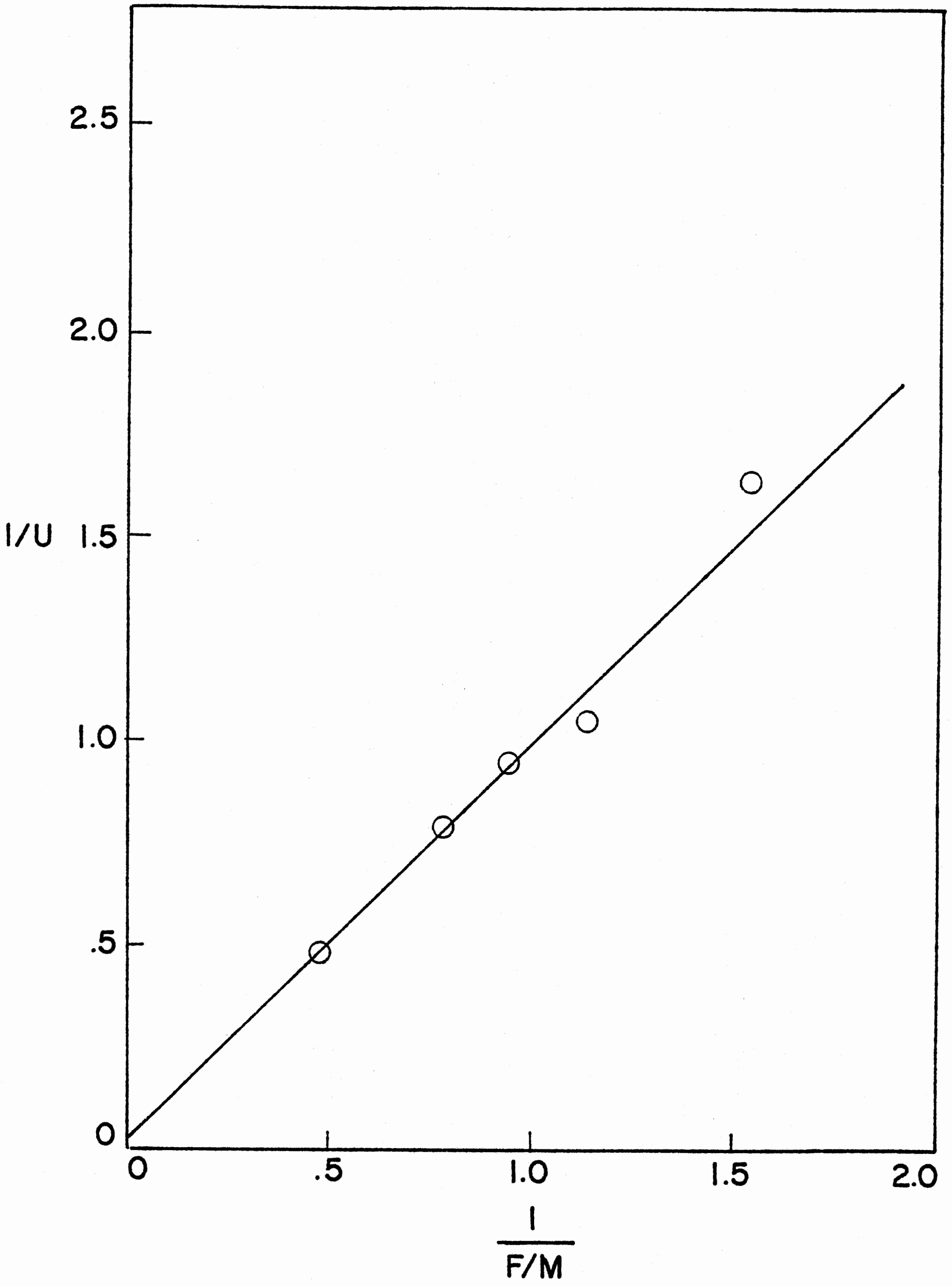

Figure 78. Biokinetic Plot for Determination of Kincannon and Stover's U_{max} and K_B in Terms of Oleic Acid Concentration and VSS

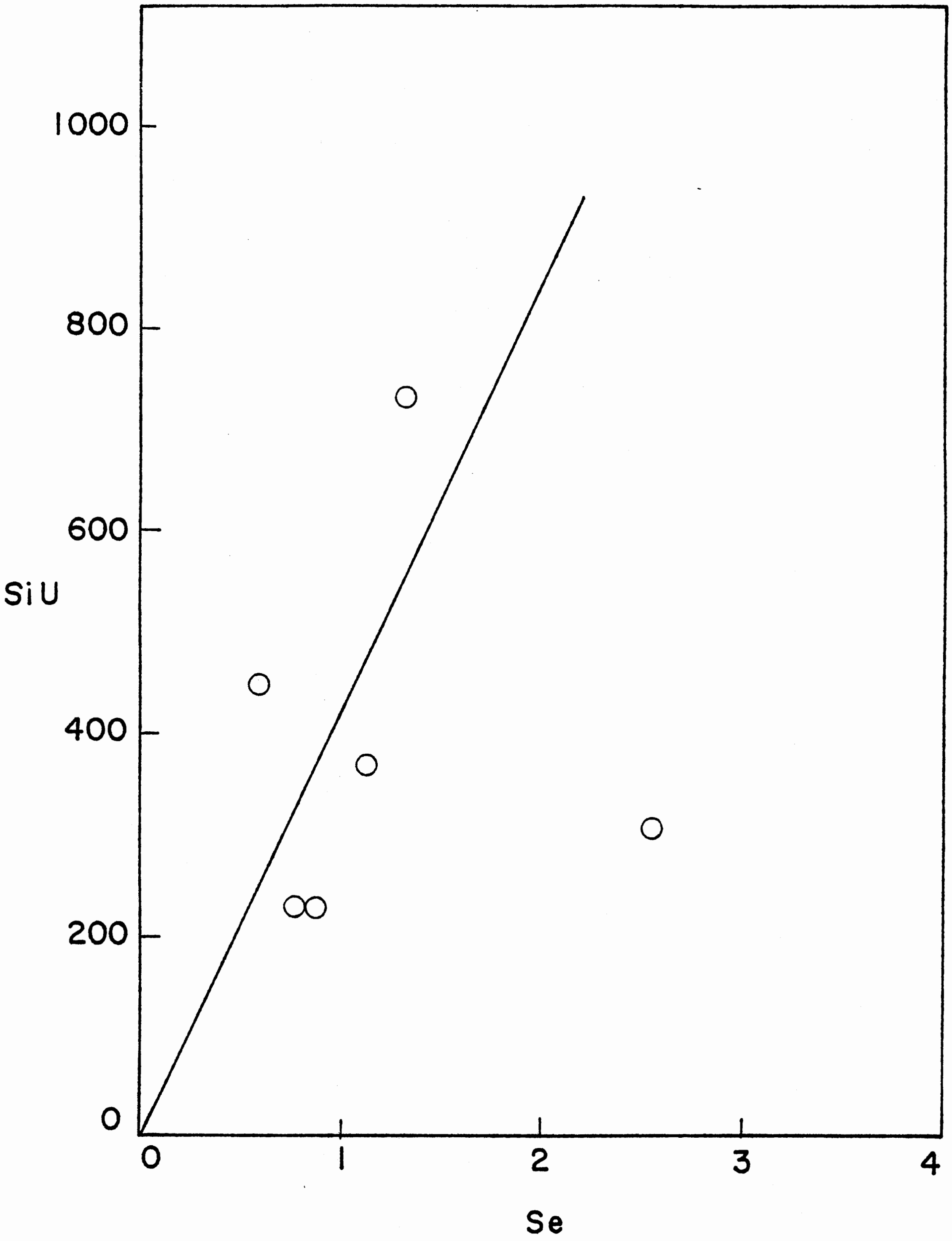

Figure 79. Biokinetic Plot for Determination of Eckenfelder's k_e' in Terms of Oleic Acid Concentration and VSS

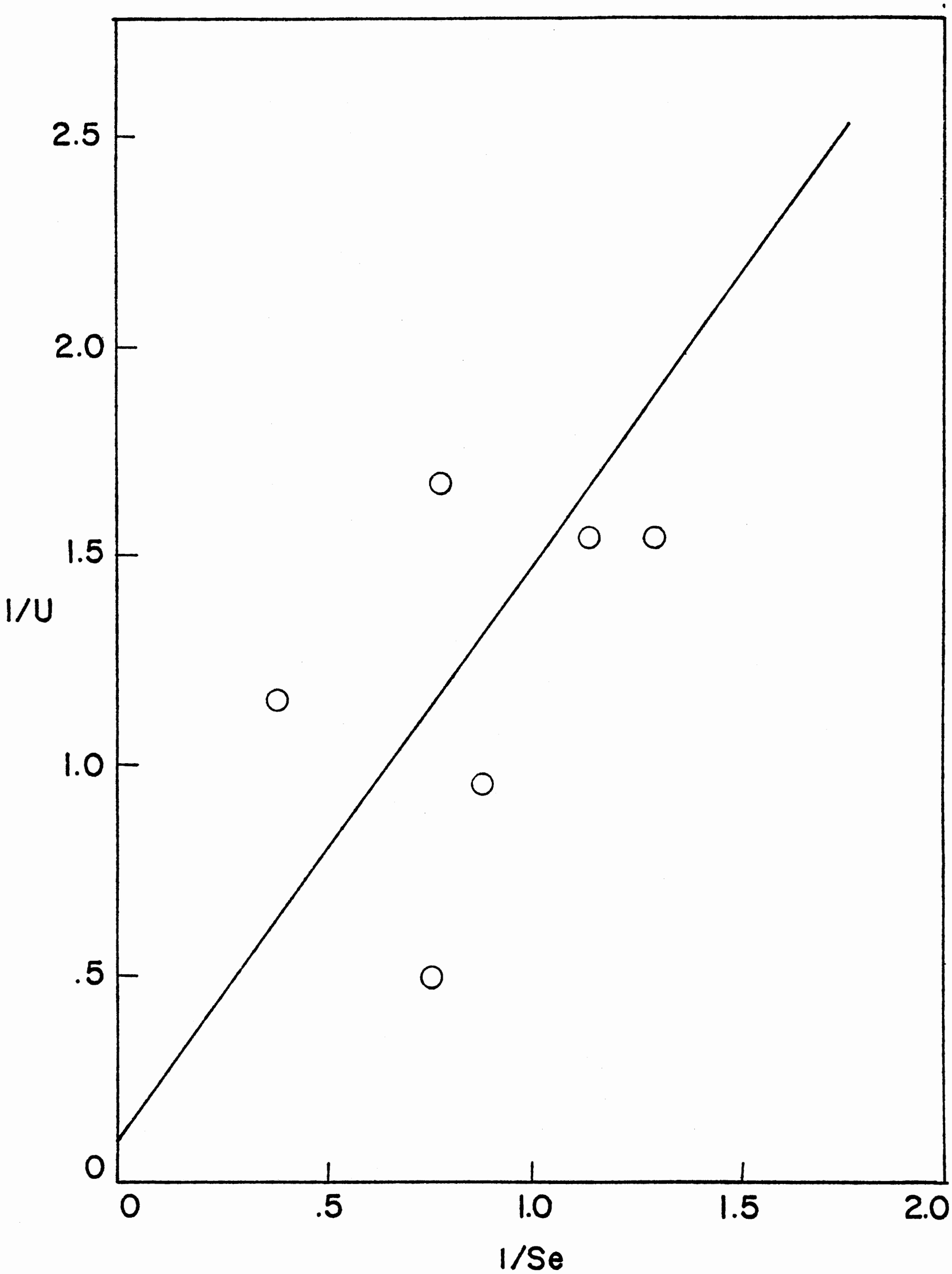

Figure 80. Biokinetic Plot for Determination of Lawrence and McCarty's k and K_s in Terms of Oleic Acid Concentration and VSS

APPENDIX D

STATISTICAL CALCULATIONS

% ERROR

TABLE LV

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); EFFLUENT SUBSTRATE CONCENTRATION IN TERMS OF TOC SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	82	35	2.5	24	31	48
Eckenfelder	10	48	- 41	14	- 23	39
Lawrence/McCarty	- 50	22	- 37	16	- 42	19
Mod. Lawrence/ McCarty	- 59	17	- 45	13	- 50	15
Discreet Cmpd. Trt.						
Kincannon/Stover	211	67	52	40	109	93
Eckenfelder	189	110	28	37	85	105
Lawrence/McCarty	374	223	365	100	368	147
Mod. Lawrence/ McCarty	387	204	316	98	341	141
Total VSS Trt.						
Kincannon/Stover	114	31	5.2	32	44	62
Eckenfelder	- 40	25	- 78	8.4	- 64	24

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LVI

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); MIXED LIQUOR VSS IN TERMS OF THE TOC SUBSTRATE PARAMETER

Assumption Model	High S_i		Low S_i		Overall	
	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	14	33	- 8.7	9.4	- 0.6	23
Eckenfelder	19	34	- 4.6	9.3	3.7	23
Lawrence/McCarty	23	36	- 5.0	9.2	5.2	26
Mod. Lawrence/ McCarty	24	37	- 4.8	9.2	5.5	26
Discreet Cmpd. Trt.						
Kincannon/Stover	2.1	29	- 15	9.0	- 8.9	19
Eckenfelder	2.2	26	- 14	9.8	- 8.0	18
Lawrence/McCarty	- 10	24	- 47	13	- 35	22
Mod. Lawrence/ McCarty	- 13	21	- 46	12	- 34	22
Total VSS Trt.						
Kincannon/Stover	1.2	29	- 15	9.0	- 9.3	19
Eckenfelder	2.1	26	- 13	9.8	- 8.0	18

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LVII

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); EFFLUENT SUBSTRATE CONCENTRATION IN TERMS OF COD SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	26	28	- 27	29	- 8.1	38
Eckenfelder	5.4	36	- 40	25	- 24	36
Discreet Cmpd. Trt.						
Kincannon/Stover	163	58	37	60	82	84
Eckenfelder	178	96	41	74	90	104
Total VSS Trt.						
Kincannon/Stover	43	23	- 23	29	0.4	42
Eckenfelder	- 54	15	- 79	11	- 70	17

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LVIII

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); MIXED LIQUOR VSS IN TERMS OF THE COD SUBSTRATE PARAMETER

Assumption Model	High S_i		Low S_i		Overall	
	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	8.4	40	-20	13	-8.4	29
Eckenfelder	6.3	35	-16	8.2	-4.1	29
Discreet Cmpd. Trt.						
Kincannon/Stover	0.2	36	-22	7.4	-13	25
Eckenfelder	-1.4	33	-21	6.7	-14	23
Total VSS Trt.						
Kincannon/Stover	0.2	36	-22	7.4	-13	25
Eckenfelder	-1.4	33	-21	7.2	-14	23

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LIX

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); EFFLUENT SUBSTRATE CONCENTRATION IN TERMS OF BOD SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	219	177	- 12	60	80	165
Eckenfelder	179	174	- 35	35	50	153
Discreet Cmpd. Trt.						
Kincannon/Stover	673	457	66	69	310	416
Eckenfelder	693	470	55	58	310	430
Total VSS Trt.						
Kincannon/Stover	55	80	- 51	31	- 8.5	76
Eckenfelder	12	59	- 74	13	- 40	57

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LX

STATISTICAL EVALUATION OF SIMULTANEOUS PREDICTIVE TECHNIQUES (WITH RESPECT TO X AND S_e); MIXED LIQUOR VSS IN TERMS OF THE BOD SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	- 4.5	33	- 27	21	- 18	28
Eckenfelder	- 4.3	33	- 27	21	- 18	28
Discreet Cmpd. Trt.						
Kincannon/Stover	- 5.3	32	- 28	21	- 19	27
Eckenfelder	- 5.6	31	- 28	20	- 19	27
Total VSS Trt.						
Kincannon/Stover	- 5.3	32	- 28	21	- 19	27
Eckenfelder	- 5.6	31	- 28	20	- 19	27

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LXI

STATISTICAL EVALUATION OF DEPENDENT PREDICTIVE TECHNIQUES; EFFLUENT SUBSTRATE CONCENTRATION BASED UPON OBSERVED MIXED LIQUOR VSS IN TERMS OF THE TOC SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	96	49	0.5	23	27	52
Eckenfelder	35	73	- 43	16	- 15	58
Discreet Cmpd. Trt.						
Kincannon/Stover	219	78	46	40	108	101
Eckenfelder	192	130	19	35	84	113

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LXII

STATISTICAL EVALUATION OF DEPENDENT PREDICTIVE TECHNIQUES; MIXED LIQUOR VSS BASED UPON OBSERVED EFFLUENT TOC IN TERMS OF TOC SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
All Models	20	36	- 9.0	9.6	1.4	26
Discreet Cmpd. Trt.						
Kincannon/Stover	21	35	- 9.5	9.7	1.6	26
Eckenfelder	21	35	- 10.7	9.9	0.4	26
Lawrence/McCarty	22	35	- 11.6	11.1	0.4	27
Mod. Lawrence/ McCarty	22	35	12.2	11.6	- 0.1	27

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LXIII

STATISTICAL EVALUATION OF DEPENDENT PREDICTIVE TECHNIQUES; EFFLUENT SUBSTRATE CONCENTRATION BASED UPON OBSERVED MIXED LIQUOR VSS IN TERMS OF THE COD SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
Kincannon/Stover	37	38	- 31	28	- 6.9	45
Eckenfelder	30	76	- 50	23	- 21	61
Discreet Cmpd. Trt.						
Kincannon/Stover	176	92	25	53	79	100
Eckenfelder	188	146	22	66	83	126

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

TABLE LXIV

STATISTICAL EVALUATION OF DEPENDENT PREDICTIVE TECHNIQUES; MIXED LIQUOR VSS BASED UPON OBSERVED EFFLUENT COD IN TERMS OF COD SUBSTRATE PARAMETER

	High S_i		Low S_i		Overall	
Assumption Model	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]	Mean Errors[1]	S.D. of Errors[2]
Weighted Constant						
All Models	17	42	- 22	13	- 0.8	32
Discreet Cmpd. Trt.						
Kincannon/Stover	17	43	- 22	12	- 8.2	32
Eckenfelder	17	42	- 22	12	- 8.2	32

[1] Mean percent error of predictive results for the fourteen combined substrate test conditions evaluated.

[2] Standard deviation of percent errors of predictive results for the fourteen combined substrate test conditions evaluated.

VITA 3

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Doctor of Philosophy

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