A STUDY OF THE CONVECTIVE LEIDENFROST PHENOMENON

By

LESLIE GERALD RESTER

Bachelor of Science

Mississippi State University

State College, Mississippi

1966

Submitted to
the Faculty of the Graduate College of the
Oklahoma State University in partial
fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1968

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Thesis Approved:

Kenneth J. Bell
Thesis Adviser

Robert L. Robinson Jr.

N. Durham
Dean of the Graduate College

PREFACE

The motion of small liquid masses in film boiling has been investigated for water and benzene. Experimental distance-time data were obtained for the motion of droplets down an inclined surface. Terminal velocities and drag coefficients were calculated from the experimental data.

I have greatly appreciated the advice and guidance given by Dr. Kenneth J. Bell during my thesis work. I would like to express my gratitude to the members of my graduate committee, to fellow graduate students, and to the staff members of the School of Chemical Engineering.

Financial support and equipment funds were gratefully received from the United States Army Research Office in Durham, North Carolina.

I am greatly indebted to my parents for their constant encouragement and financial support during my college career. Without their support, my studies would not have been possible.

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CHAPTER I

INTRODUCTION

The film boiling regime is characterized by the existence of a thin vapor film between the liquid and the hot surface. Numerous studies have been made of the process in which small liquid masses exist in film boiling on a hot surface. The first to investigate the phenomenon was J. G. Leidenfrost (1) in 1756. Because of his initial observations, the film boiling of small liquid masses has become known as the Leidenfrost Phenomenon.

Some of the more recent studies include the work of Baumeister (2), Gottfried (3), Lee (4), Patel (5), and Wachters (6). These studies were concerned with the experimental measurement and theoretical analysis of the evaporation time for both small and extended stationary "Leidenfrost" masses. The value of the previous studies is that stability criteria and mathematical models for momentum and heat and mass transfer have been tested.

The previous studies have shown that the droplet is supported by a vapor layer produced by the evaporation of liquid from the bottom of the mass. Heat transfer to the liquid droplet is by conduction and by radiation to the surface of the droplet. Normally, the temperature within the droplet is at or slightly below the saturation temperature of the liquid. The loss of mass from the droplet is predominantly through the supporting vapor layer. However, the diffusive mass transfer from the top of the droplet becomes significant for the longer evaporation times. Droplet evaporation time is a maximum when the difference between surface temperature and liquid saturation temperature is at the minimum value that still supports film boiling.

The area of engineering application for the Leidenfrost Phenomenon is large. The poor heat transfer characteristic of film boiling can be used to advantage when designing cryogenic equipment. Another area of application is the cooling of a high temperature surface by spraying a liquid upon the surface. Spray cooling could be used to cool a nuclear reactor when normal coolant flow is lost or to cool a rocket nozzle or a steel billet.

In all of the above applications the liquids considered are moving across a surface. Thus, a basic study of the effect of motion upon a small film boiling mass would be of considerable value in the design of the high temperature equipment mentioned above. The present work is the first of a series on the "Convective Leidenfrost Phenomenon." This initial study will be concerned with small liquid masses flowing down a very hot surface. The major objective is to obtain a general appreciation of the variables governing the motion of the droplet. The main variables to be investigated are droplet size, surface temperature, and effective gravitational force acting on the droplet. Also, the determination of droplet drag coefficients at terminal velocity is desired.

CHAPTER II

THEORETICAL TREATMENT

The problem to be considered is the motion of a liquid droplet down an inclined, high-temperature surface. The temperature of the surface is such that the droplet is in the Leidenfrost regime. A one-dimensional momentum balance for the droplet, Figure 1, yields the expression:

$$\frac{d(mu)}{dt} = F_g - F_b - F_d$$

$$= mg(\sin\Theta) - mg(\rho/\rho_\ell)\sin\Theta - F_d \qquad (1)$$

where t = Time

m = Droplet mass

u = Droplet velocity

F_g = Net gravitational force acting on droplet parallel to the surface

F_b = Buoyant force acting on droplet

F_d = Drag force acting on droplet

g = Acceleration of gravity

ρ = Density of gas surrounding droplet

ρ_ℓ = Density of droplet

Θ = Surface inclination

The common definition of a drag coefficient [e.g., Bird (7)] for an object in a flow stream is:

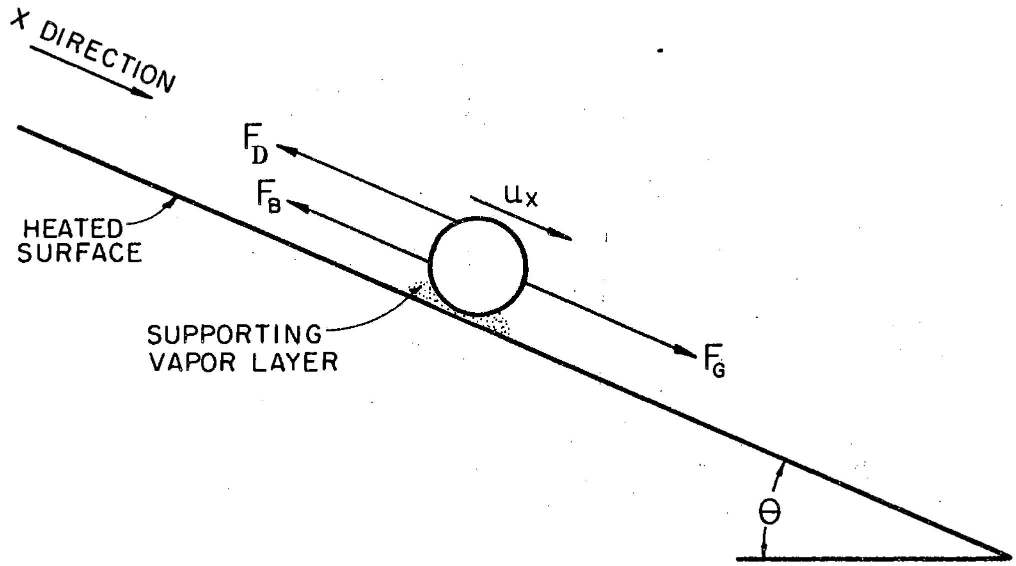

Figure 1. Forces Acting upon Droplet

$$C = 2F_d/A\rho u^2 \tag{2}$$

where A is the characteristic area of the droplet. To simplify the selection of a characteristic area, a spherical droplet will be assumed with the volume of the sphere equal to that of the droplet. This assumption is very good for droplets less than about 0.05 milliliters. The characteristic area is taken to be that of a circle of the same diameter as the sphere.

Another simplifying assumption is to neglect the decrease in mass of the droplet while flowing down the surface. This assumption can be partially justified by comparing total evaporation times for stationary droplets to the time period considered in this analysis. The experimental investigation will consider the time required for a droplet to start from rest, reach terminal velocity, and travel at the terminal velocity for a few seconds. Normally, for a surface inclination greater than one degree, the time interval considered is less than five seconds. The time period considered is one-half the total evaporation time for a 0.00658 gram benzene mass and one-twelfth the evaporation time for a 0.01536 gram water mass (4). For larger masses (0.04 grams and larger), the maximum evaporation for the time interval considered is about ten percent of the initial droplet mass (5). However, the motion of the droplet is expected to decrease the thickness of the supporting vapor layer, and to increase the evaporation rate by increasing the heat transfer to the bottom of the droplet. Also, the motion of the droplet should increase the diffusive mass transfer from the upper surface of the droplet.

Using the two assumptions discussed above and noticing that

$\rho/\rho_\ell << 1.0$ at one atmospheric pressure, Equation (1) becomes:

$$\frac{du}{dt} + \frac{3C\rho u^2}{4D\rho_\ell} = g(\sin\Theta) \qquad (3)$$

where D is the spherical droplet diameter. If a velocity-time relation is known, the drag coefficient can be calculated by using Equation (3).

For the case when the droplet moves at the terminal velocity, Equation (3) reduces to:

$$C = \frac{4D\rho_\ell g(\sin\Theta)}{3\rho u^2} \qquad (4)$$

If distance-time data are obtained for the motion of the droplet, a plot of distance versus time should approach a straight line as the acceleration of the droplet approaches zero. The slope of the straight line is the terminal velocity. Equation (4) can then be used to calculate the drag coefficient.

CHAPTER III

EXPERIMENTAL APPARATUS

The apparatus consists essentially of a resistance-heated longitudinally-split tube. A schematic diagram is shown in Figure 2. Detail drawings of the split-tube and its supporting cradle are shown in Figures 3 and 4.

The split-tube was made from an annealed 1 inch OD, 14 BWG steel tube. Care was taken not to damage the inside surface of the tube when splitting on a band saw and when brazing the copper electrode connectors and supports to the outside. Inside surface roughness of the tube in the axial direction was measured with a profilometer and found to average 80 microinches. This measurement was made after the tube was mounted and cleaned.

Transite was used to support the tube in the cradle. As can be seen in Figure 3, one end of the tube is free to slide in the Transite support as the tube expands or contracts. Supports for the middle of the tube were Transite blocks which could be adjusted until the tube was level in the cradle.

The two cradle supports are shown in Figure 4. These supports have the simplicity of a three-point suspension, and the stability of a four-point suspension. The elevating mechanism was capable of inclining the tube to a maximum of eight degrees from horizontal.

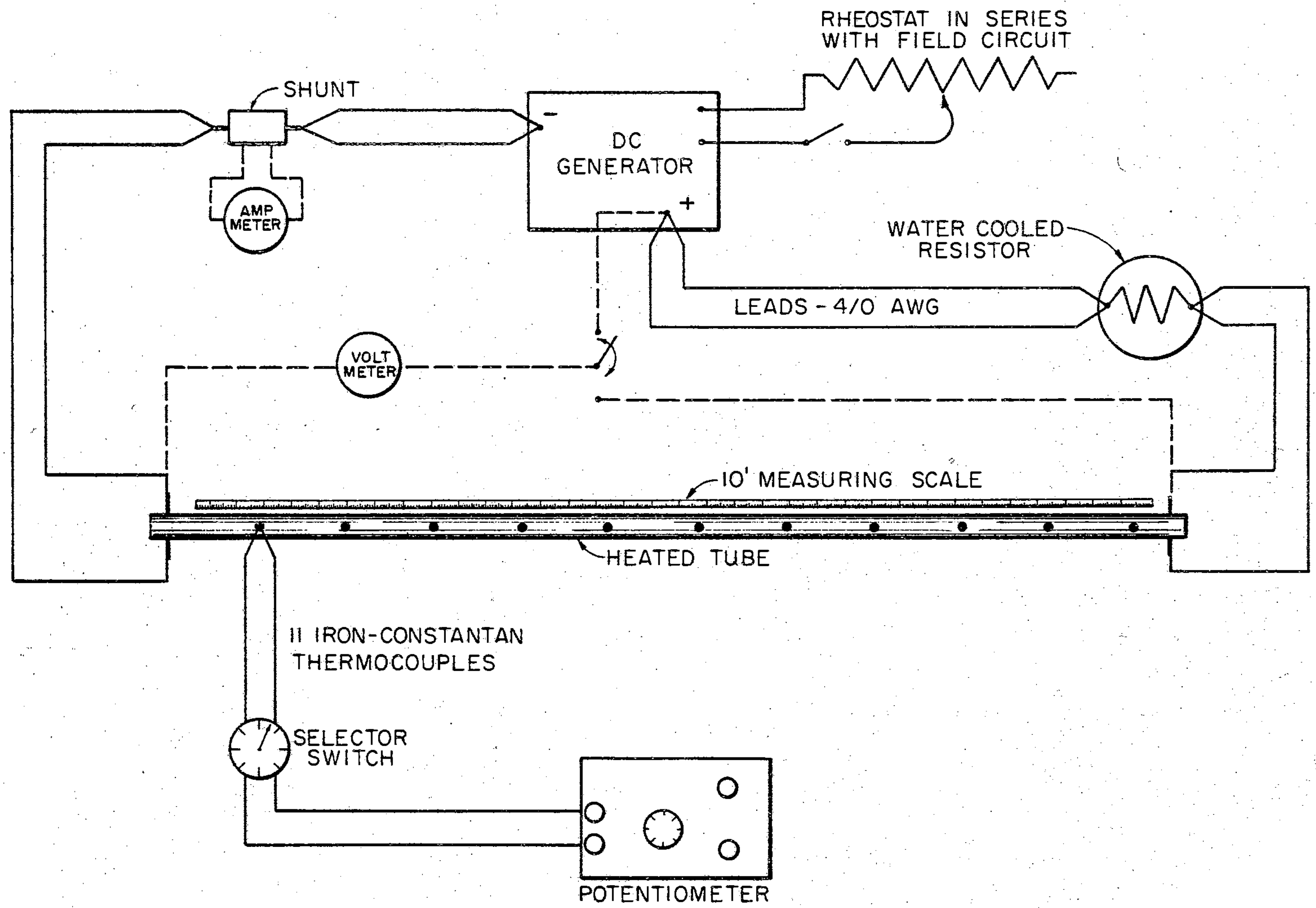

Figure 2. Schematic of Apparatus

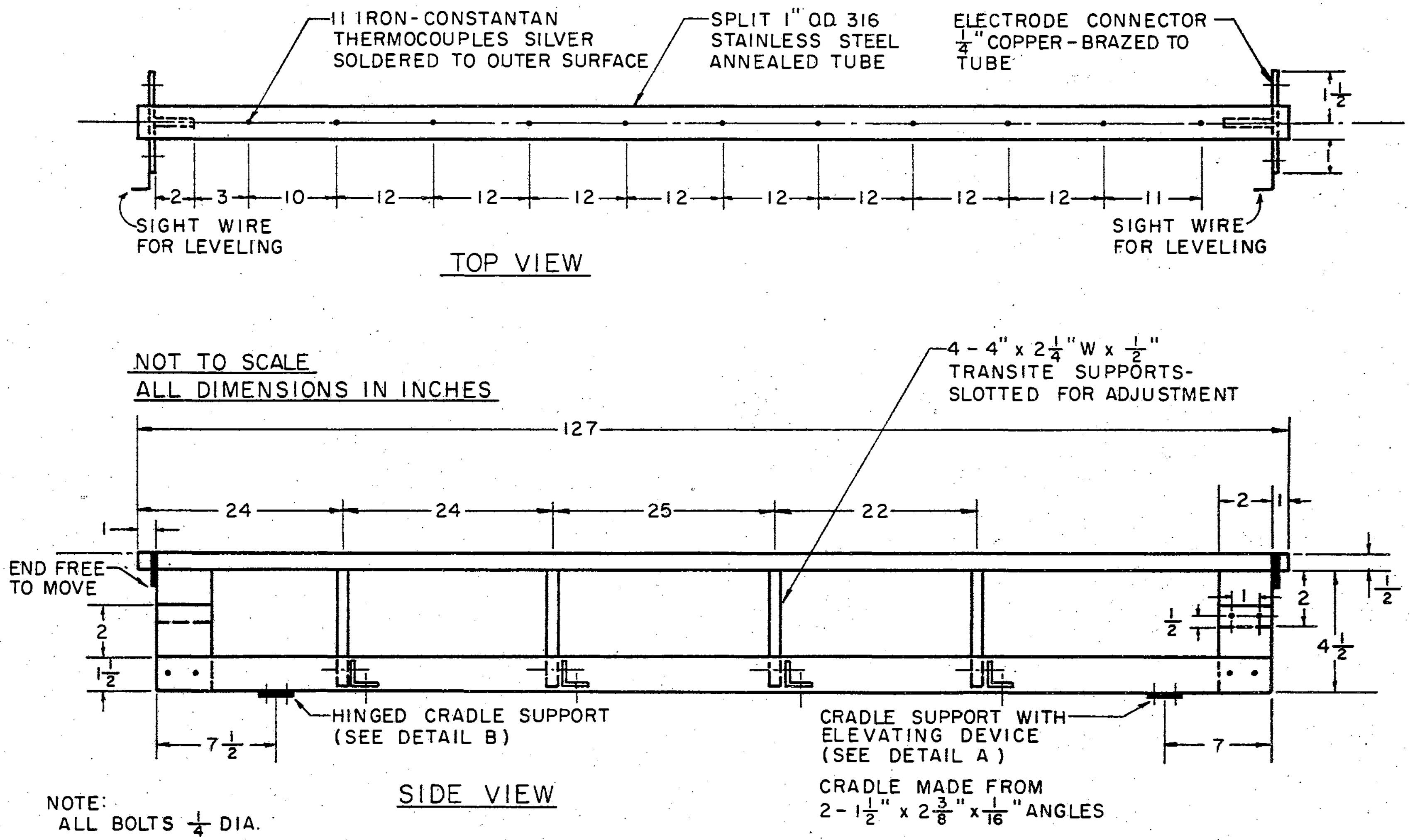

Figure 3. Mounting of Split Tube

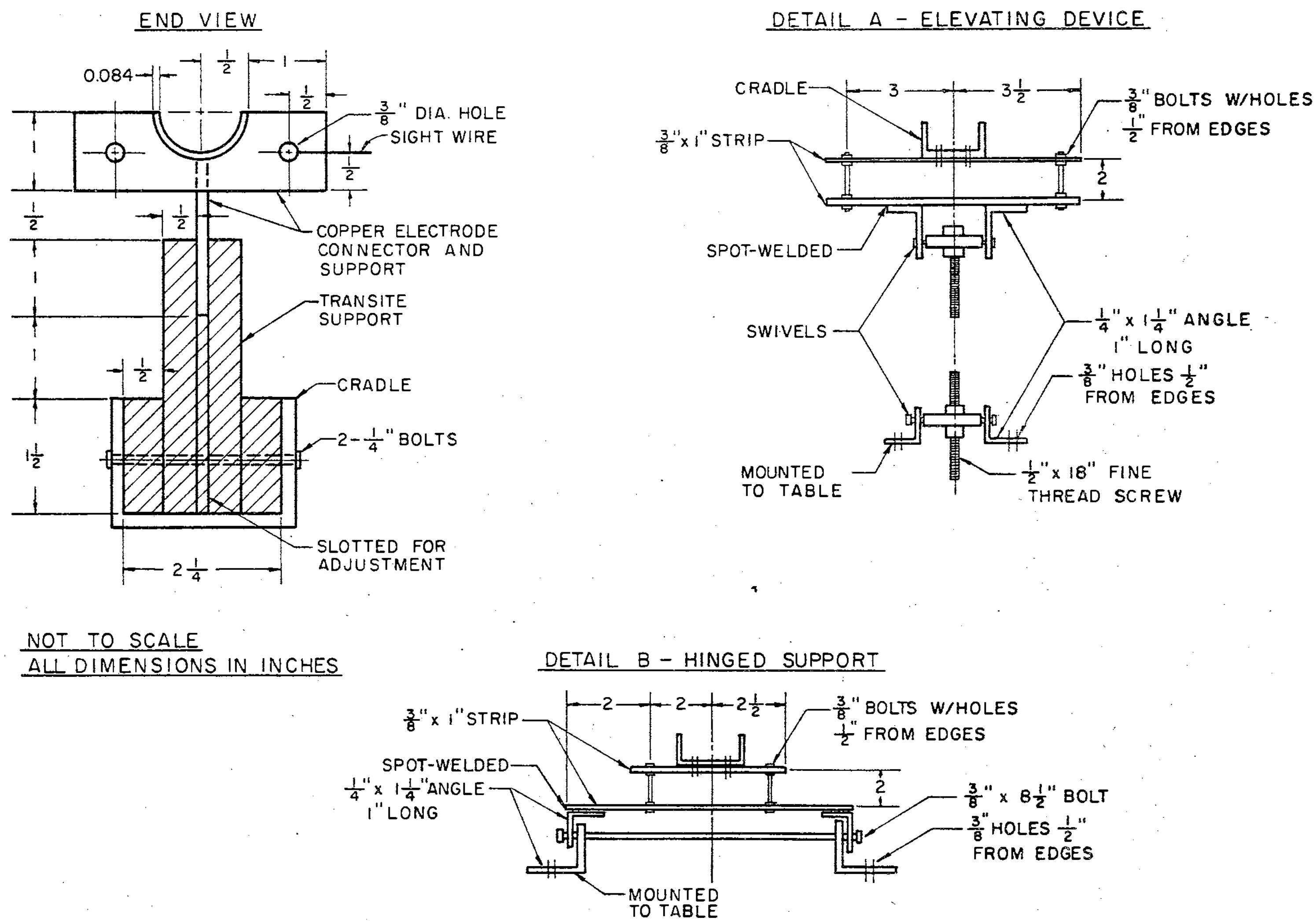

Figure 4. Further Details of Apparatus

The power source for heating the split tube was a Lincoln-weld SA-750 direct current generator. The maximum power output was a nominal 25 kilowatts. The generator was equipped with a power output controller. However, due to the low circuit resistance, the desired current control could not be obtained using the output controller. The required current range was from 100 to 350 amperes. The tube resistance was 0.033 ohm at 30°C. A water cooled resistor of 0.065 ohm was added to the circuit as shown in Figure 2. Also, a variable 93 ohm, 2 ampere rheostat was connected in series with the generator field and with the output controller. This arrangement gave the desired control.

The electrical leads used to connect the equipment were No. 4/0. A shunt with a 100 millivolt voltage drop at 1000 amperes was used to measure current. Triplett Model 625 DC volt- and ampere-meters were used.

Eleven 20 BWG iron-constantan thermocouples were silver soldered to the outside center of the tube. A high temperature silver solder with a melting point of about 1500°F was used. Spacing of the thermocouples is shown in Figure 3. An asbestos tape one-sixteenth of an inch thick was wrapped around each thermocouple where contact was made with the tube and continued along the thermocouple for three-fourths of an inch. A two-gang, eleven position rotary switch was used to select a particular thermocouple. The e.m.f. output from the thermocouples was measured using a Leeds and Northrup No. 8687 potentiometer with an ice bath reference junction.

Droplet masses were deposited upon the hot surface using a

Hamilton No. 750 0.5 milliliter syringe. A ringstand with a buret clamp was used to hold the syringe at a 45 degree angle above the tube. To avoid rapid heating of the syringe and contents when in this position, an asbestos shield was placed between the tube and syringe. Size 15, 21, and 27 needles were used in depositing the various masses. These needles had square tips and were bent so that their tips were perpendicular to the tube surface.

The liquids used in the investigation were distilled water and 99.9 percent pure benzene. Water masses used were 0.0506, 0.0992, 0.0516, 0.0308, 0.0151, and 0.0079 grams. Benzene masses used were 0.174, 0.0859, 0.0419,, 0.0155, 0.0094, and 0.0032 grams.

To aid the measuring of distances, a ten-foot scale was placed alongside the tube. Thus, a given distance could be indicated by a small wire bolted to the cradle and bent across the tube and measuring scale.

CHAPTER IV

EXPERIMENTAL PROCEDURE

The split tube was cleaned with a fine emery paper before heating. This was necessary because of the heat rings left on the inside of the tube after attaching the supports and thermocouples to the outside. Kimwipes wet with acetone were used to remove the residue left after using the emery paper, and for cleaning between runs.

After cleaning the tube for each run, the tube was leveled and then adjusted to the desired inclination. The inclinations used in the experiment were 0.362°, 0.905°, 1.809°, and 4.528° from the horizontal. First the cradle was leveled by sighting with a cathetometer at the top metal strip in the cradle supports. This required a trial-and-error procedure. After leveling the cradle, sightings were made at the bottom of the tube. The ends of the tube were first leveled, and then the middle supports. When the tube was level, the height of the bottom of the tube was recorded. Next, readings for the sight wires, located at each end of the tube in Figure 3, were made. This gives the distance a given sight wire is above or below the bottom of the tube. Then the tube could be inclined to the desired inclination by trial-and-error sightings of the sight wires. The distance between sight wires was 125.5 inches. The above procedure was repeated each time a change in inclination was made.

The equipment start-up procedure was to:

(1) Start the flow of cooling water in the water-cooled resistor

(2) Set power output controls at the minimum

(3) Start DC generator and run for ten minutes

(4) Turn electrode switch to the "on" position

(5) Increase power output (over a period of fifteen to twenty minutes) until desired tube temperature is reached.

The reverse of this procedure was followed when shutting equipment down.

A smooth golden brown oxide film formed on the tube after heating to 400°C and holding this temperature for about two hours. Further heating did not change the tube color. Normally, about twenty minutes were required to reach a steady-state temperature. Once steady state was reached, temperature readings were made at approximately fifteen minute intervals. The temperature of the tube was taken as being the average of all thermocouples, excluding the two end thermocouples. The end thermocouples were excluded because of the low temperature of the tube near the ends.

The tube surface temperatures for the water runs were nominally 315, 350, 400, and 500°C. The tube temperatures for the benzene runs were nominally 200, 300, 400, and 500°C.

The time for a drop to travel a given distance down the tube was measured. The distances normally timed for each droplet size were 14, 38, 62, 86, and 110 inches. However, the actual distances timed depended upon the time elapsed at that increment and upon the evaporation rate of the droplet. Usually, five runs were made for each combination of liquid, mass size, inclination, surface temperature, and distance.

The larger droplets were deposited by holding the needle tip in the top of the drop, depositing the complete liquid volume, and releasing the droplet from the needle tip by lifting the syringe. The volume deposited for the larger droplets was measured each time by referring to the calibration markings on the syringe. The smaller droplets were dropped from a needle tip which was held approximately three-eighths of an inch above the tube surface. The tip of the needle was always held perpendicular to the surface. Liquid temperature in the syringe was near normal room temperature.

The timer was started with a hand switch as soon as the droplet contacted the surface in the case of the small droplets or for the larger droplets as soon as the droplet was released from the tip. The timer was stopped when the droplet had traveled the desired distance. Sometimes a bad release would cause a side-to-side motion of the droplet as it moved down the tube. Timings for such cases were discarded.

CHAPTER V

DISCUSSION OF RESULTS

There are four major factors influencing the rate a Leidenfrost droplet moves down a hot surface. These factors are (1) droplet size, (2) surface temperature, (3) magnitude of the accelerating force acting on the droplet, and (4) physical properties of the liquid considered. The effect of these factors can be seen by referring to Figures 4 and 5, and to the distance-time curves in Appendix C.

The shape of a particular droplet mass is governed by the surface tension and, for larger masses, by the diameter of the tube. Water droplets of mass less than 0.02 grams are spherical. As the droplet size is increased, the shape of the drop becomes an oblate spheroid with the ratio of the minor axis to the major axis decreasing as droplet mass increases. Finally, for water masses of approximately 0.08 grams and larger, the minor axis of the spheroid becomes constant and the droplet begins to elongate down the inclined surface. For benzene the above changes in droplet shape occur at mass sizes slightly smaller than those for water. This is expected since the surface tension for benzene is less than that of water.

Drag coefficients for the case of terminal velocities were calculated using Equation (4) of Chapter II. A plot of drag

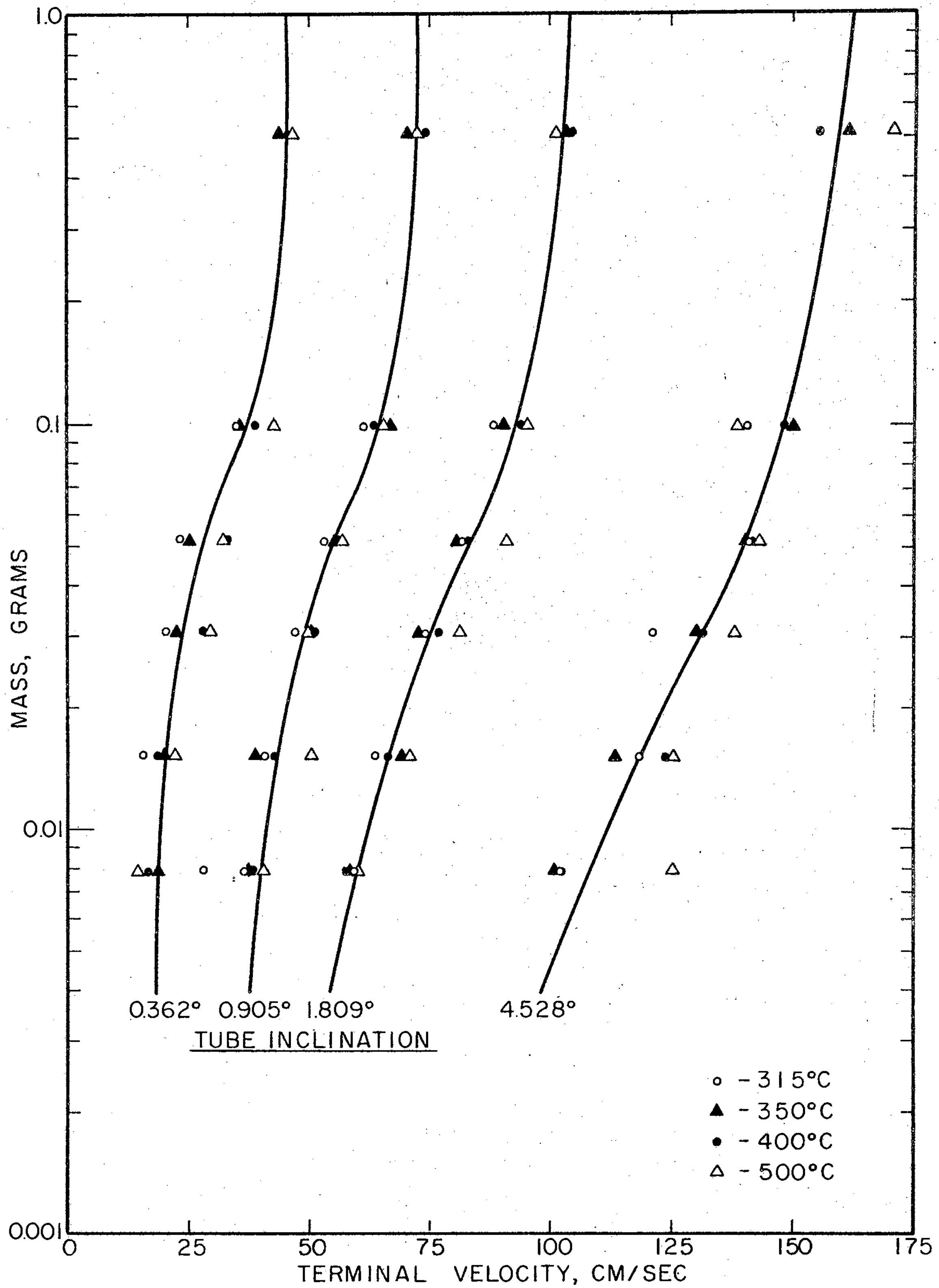

Figure 5. Terminal Velocity of Water Droplets

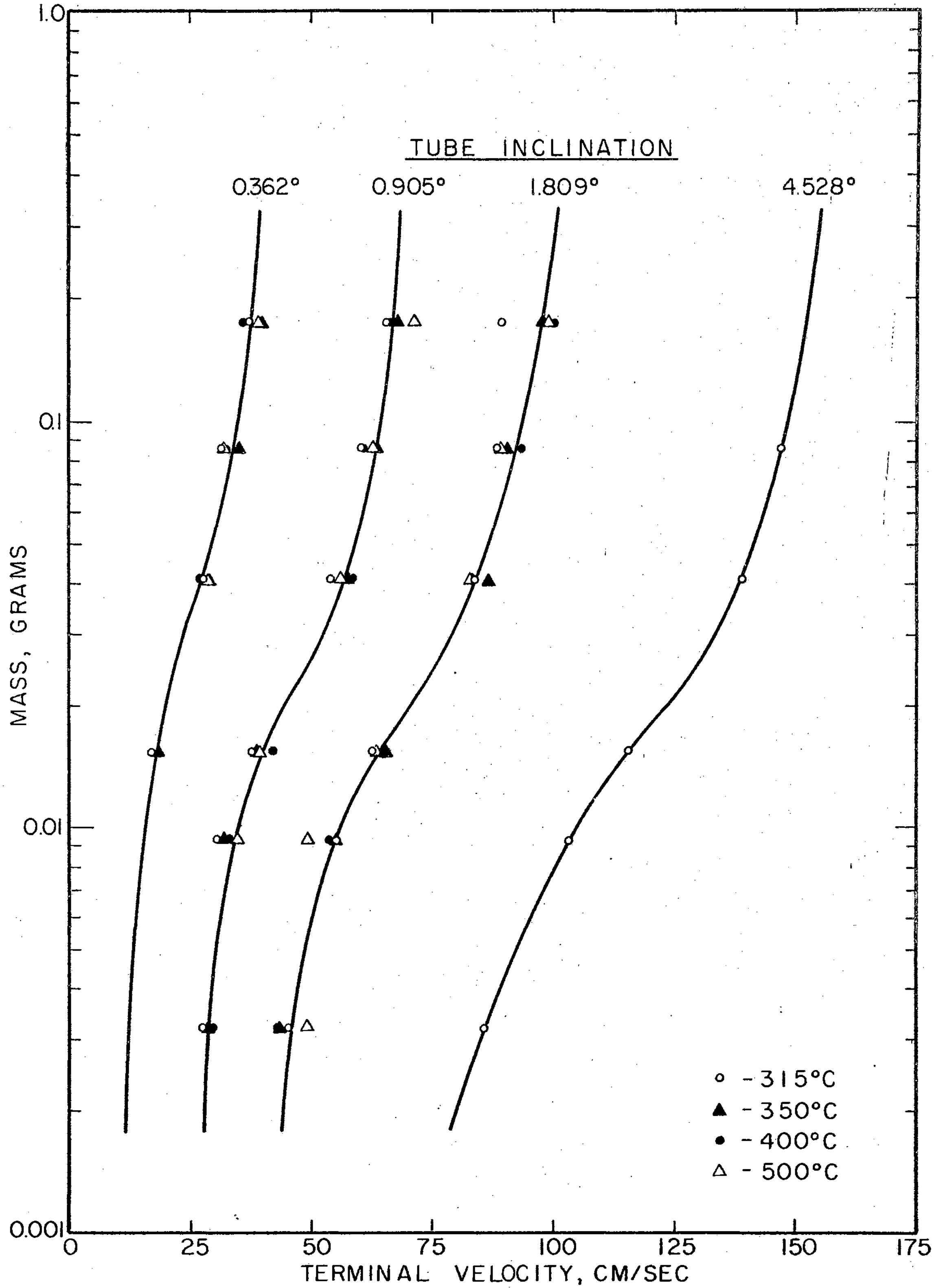

Figure 6. Terminal Velocity of Benzene Droplets

coefficient versus Reynolds number is used to present the calculated data. These plots for water and benzene are shown in Figures 7 and 8.

The Reynolds number is defined as:

$$N_{Re} = \frac{u\rho\delta}{\mu} \tag{1}$$

where

u = Terminal velocity

ρ = Density of the vapor

μ = Viscosity of the vapor

δ = Thickness of the vapor film supporting the droplet

The equation for calculating the effective vapor film thickness is theoretically derived by Baumeister (8) from the heat transfer to a stationary Leidenfrost droplet. The equation is:

$$\delta = \left[\frac{9k(T_p - T_s)\mu r}{8\rho\rho_L\lambda^*}\right]^{1/4} \tag{2}$$

where

k = Thermal conductivity of the vapor

r = Droplet radius

g = Acceleration of gravity

T_p = Temperature of the heated surface

T_s = Liquid saturation temperature

ρ_L = Liquid density

$\lambda^* = h_v + 7C_p(T_p - T_s)/20$

h_v = Latent heat of vaporization

C_p = Heat capacity of the vapor

All vapor properties are considered as being at the average temperature of $(T_p + T_s)/2$.

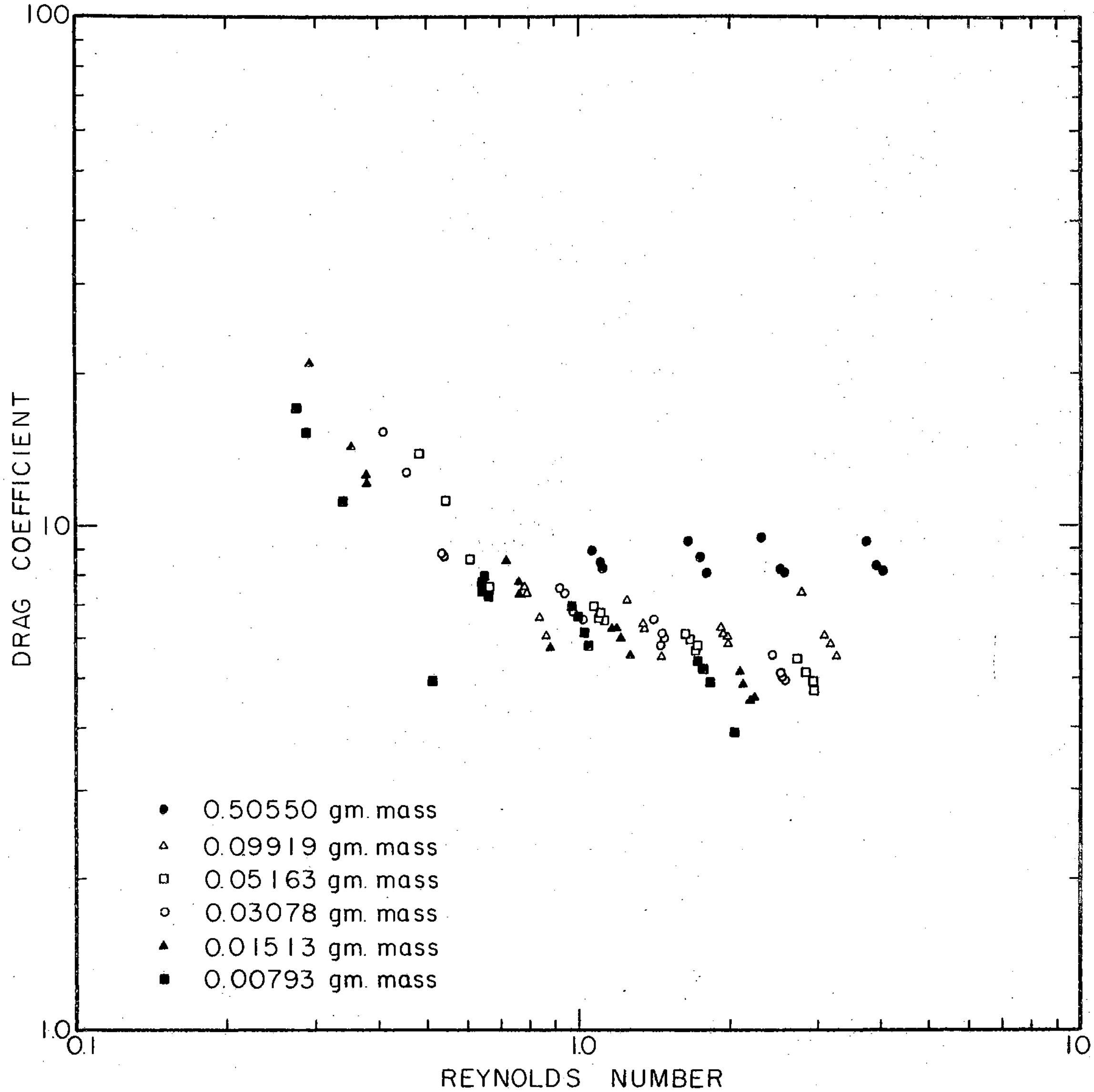

Figure 7. Drag Coefficients for Water Droplets

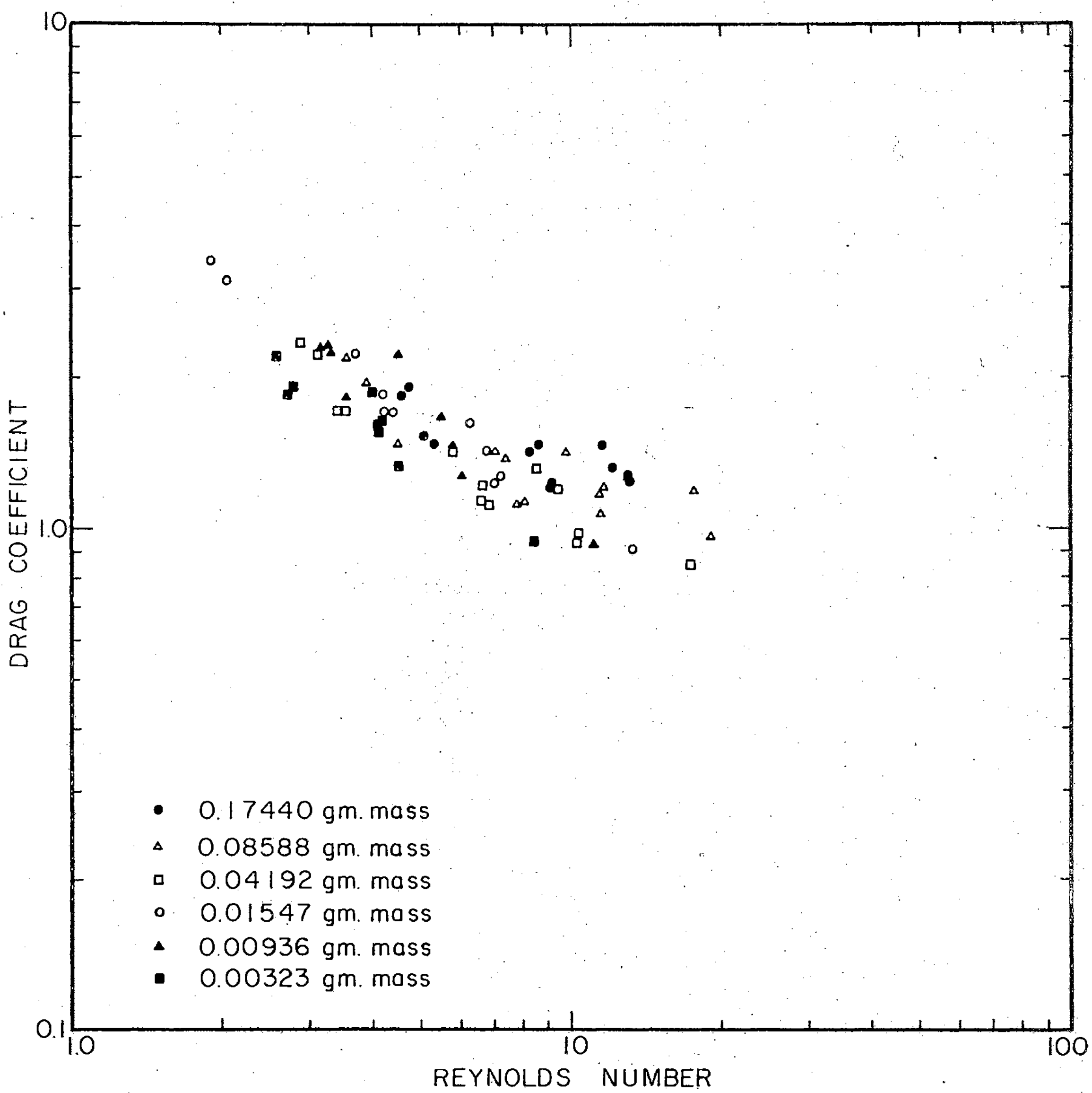

Figure 8. Drag Coefficients for Benzene Droplets

For the present work the drag coefficient may be represented by an empirical equation of the form:

$$C = (\text{constant})/N_{Re})^{n} \tag{3}$$

where n is the geometric slope of a straight line through the data in Figures 7 and 8. By inspection of straight lines drawn through the data for a given mass, n is seen to decrease as the droplet mass increases. This fact supports the previous discussion concerning droplet shape.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The following significant conclusions are supported by the previous discussion:

(1) The droplet velocity is primarily determined by the the external force acting upon the droplet and by droplet size and shape.

(2) The effect of surface temperature upon the motion of the droplet is comparatively minor once the droplet is in the film boiling regime.

The following recommendations are made after considering the results of this investigation.

(1) A study of the change in mass should be made with particular emphasis upon the mode of mass transfer.

(2) The effective thickness of the supporting vapor layer should be determined for a moving Leidenfrost droplet. This effective thickness could be determined by considering the change in mass of the droplet.

(3) Drag coefficients for the case of droplet acceleration should be determined.

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APPENDIX A

CALIBRATIONS

TABLE A1

CALIBRATION OF SYRINGE WITH WATER AT 24°C

Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent	Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent	Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent
0.5 ml	0.5060	+0.103	0.1 ml	0.10105	+1.287	0.05 ml	0.04999	-3.175
	0.5037	-0.358		0.09501	-4.214		0.05138	-0.484
	0.5065	+0.194		0.10036	+1.179		0.05128	-0.678
	0.5048	-0.144		0.09778	-1.421		0.05129	-0.658
	0.5026	-0.562		0.10020	+1.018		0.05201	+0.736
	0.5066	+0.220		0.09743	-1.774		0.05129	-0.658
	0.5079	+0.483		0.09729	-1.814		0.05009	-3.001
	0.5066	+0.097		0.10349	+4.355		0.05418	+4.898
	0.5065	+0.293		0.09894	-0.252		0.05272	+2.110
	0.5044	-0.220		0.10032	+1.139		0.05209	+0.890
	0.5055	0.267		0.09919	1.902		0.05163	1.729

TABLE A2

CALIBRATION OF SYRINGE WITH BENZENE AT 24°C

Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent	Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent	Nominal Liquid Volume	Liquid Mass gm	Deviation From Mean percent
0.2 ml	0.1725	-1.072	0.1 ml	0.08370	-2.866	0.05 ml	0.03815	-8.991
	0.1733	-0.636		0.08479	-1.601		0.04348	+3.721
	0.1738	-0.333		0.08469	-1.718		0.04275	+1.980
	0.1781	+2.148		0.08620	+0.035		0.04352	+3.816
	0.1748	+0.218		0.08842	+2.611		0.04321	+3.077
	0.1737	-0.390		0.08842	+2.611		0.04039	-3.649
	0.1718	-1.502		0.08596	-0.244		0.03978	-5.104
	0.1778	+1.973		0.08632	+0.174		0.04450	+6.153
	0.1753	+0.510		0.08455	-1.880		0.04244	+1.240
	0.1738	-0.929		0.08575	-0.487		0.04099	-2.218
	0.1744	0.971		0.08588	1.423		0.04192	3.994
0.02 ml	0.01540	- 0.452						
	0.01622	+ 4.848						
	0.01611	+ 4.137						
	0.01499	- 3.103						
	0.01544	- 0.194						
	0.01347	-12.928						
	0.01636	+ 5.753						
	0.01470	- 4.977						
	0.01457	- 5.818						
	0.01741	+18.358						
	0.01547	6.057						

TABLE A3

HYPODERMIC NEEDLE CALIBRATIONS FOR WATER AT 24°C

Needle Size gage	Drop Mass gm	Deviation From Mean percent	Needle Size gage	Drop Mass gm	Deviation From Mean percent	Needle Size gage	Drop Mass gm	Deviation From Mean percent
15	0.03015	-2.047	21	0.01502	+0.727	27	0.00828	+ 4.413
	0.03087	+0.292		0.01486	-1.784		0.00830	+ 4.666
	0.03133	+1.787		0.01553	+2.644		0.00801	+ 1.009
	0.03045	-1.072		0.01497	-1.058		0.00817	+ 3.026
	0.03136	+1.884		0.01600	+5.750		0.00822	+ 3.657
	0.03112	+1.105		0.01455	-3.833		0.00723	- 3.783
	0.03052	-0.845		0.01519	+0.396		0.00826	+ 4.161
	0.03024	-1.787		0.01585	+4.759		0.00802	+ 1.135
	0.03049	-0.942		0.01473	-2.644		0.00733	- 7.566
	0.03027	-1.657		0.01476	-2.445		0.00822	+ 3.657
	0.03167	+3.151		0.01514	+0.066		0.00828	+ 4.413
	0.03078	0.000		0.01516	+0.198		0.00820	+ 3.405
	0.02995	-2.696		0.01467	-3.040		0.00800	+ 0.883
	0.03235	+5.101		0.01500	+0.859		0.00672	-15.258
	0.03056	-0.715		0.01536	+1.520		0.00806	+ 1.639
	0.02944	-4.678		0.01549	+2.379		0.00812	+ 2.396
	0.03207	-2.307		0.01509	-0.264		0.00814	+ 2.648
	0.02995	-2.696		0.01489	-1.586		0.00840	+ 5.927
	0.03084	+0.195		0.01532	+1.256		0.00790	- 0.378
	0.03115	+1.202		0.01494	-1.256		0.00676	-14.754
	0.03078	1.808		0.01513	1.923		0.00793	4.439

TABLE A4

HYPODERMIC NEEDLE CALIBRATIONS FOR BENZENE AT 24°C

Needle Size gage	Drop Mass gm	Deviation From Mean percent	Needle Size gage	Drop Mass gm	Deviation From Mean percent
15	0.00917	-2.030	21	0.00407	+26.005
	0.00943	+0.748		0.00300	- 7.121
	0.00944	+0.855		0.00319	- 1.238
	0.00967	+3.312		0.00345	+ 6.811
	0.00980	+4.701		0.00347	-23.529
	0.00970	+3.632		0.00293	- 9.288
	0.00965	+2.098		0.00357	+10.526
	0.00919	-1.816		0.00377	+16.718
	0.01008	+7.692		0.00336	+ 4.025
	0.00932	-0.427		0.00331	+ 2.477
	0.00919	-1.816		0.00329	+ 1.857
	0.00954	+1.923		0.00312	- 2.786
	0.00898	-4.059		0.00322	- 0.309
	0.00900	-3.846		0.00283	-12.383
	0.00950	+1.709		0.00370	+14.551
	0.00888	-5.128		0.00323	0.000
	0.00890	-4.914		0.00319	- 1.238
	0.00936	3.643		0.00323	8.286

CALIBRATIONS OF THERMOCOUPLES

Eleven 20 BWG iron-constantan thermocouples were used to measure the outside wall temperature of the split tube. The iron-constantan combination was chosen because of the high e.m.f. output per degree of temperature rise.

Thermocouple calibrations were made by boiling various liquids in the tube and measuring the outside wall temperature. The liquid was held in the level tube by slipping a short length of rubber hose over each end of the tube, and then clamping the free end of the hose. The tube was filled with the test liquid, and was slowly heated until the liquid boiled. When boiling of the liquid was observed along the entire length of the tube, the thermocouple readings were made. Liquids used were distilled water, ethylene glycol, and tri-ethylene glycol. Results of the calibration are showm in Table A5.

The measured outside wall temperature in Table A5 is the average of nine thermocouples omitting the first thermocouple from each end of the tube. The inside wall temperature was taken as the boiling point of the liquid in the tube. A barometric pressure correction was made for the boiling point of water. A boiling point range of 2°C and 10°C was given for ethylene glycol and tri-ethylene glycol, respectively. In each case the lower temperature of the boiling point range was taken as the correct inside wall temperature.

The thermocouple calibration was not performed to obtain a temperature correction factor but rather to obtain the magnitude of the error and determine if this error could be tolerated. The maximum expected error is approximately 10°C at an outside wall temperature of 500°C. The expected error at 100°C is 1°C. These errors are acceptable.

TABLE A5

CALIBRATION OF THERMOCOUPLES

Measured Outside Wall Temperature, °C	Inside Wall Temperature °C	Method of Determining Inside Wall Temperature
22.4	22.2	Ambient temperature
99.7	99.3	B.P. of water
195.2	195.0	B.P. of ethylene glycol
275.7	280.0	B.P. of tri-ethylene glycol

APPENDIX B

RAW DATA

TABLE B1

WATER DISTANCE-TIME DATA, TUBE INCLINATION 0.362°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.00919			0.05163			0.03078		
Temp., °C	315			317			317		
% Dev.	2.00			1.94			1.93		
	38	4.56	2.16	38	4.80	3.33	38	5.63	3.22
	62	6.37	1.70	62	8.34	1.52	62	7.99	1.25
	86	7.94	1.40	86	10.87	0.29	86	11.20	1.34
	110	9.73	1.60	110	12.39	2.08	110	14.37	1.44
Mass, gm	0.01513			0.00793					
Temp., °C	316			316					
% Dev.	2.18			1.95					
	38	5.96	4.27	38	6.73	4.76			
	62	10.14	1.82	62	8.67	3.46			
	86	12.60	1.79	86	10.95	3.56			
	110	17.93	0.83						
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	349			345			345		
% Dev.	1.66			1.74			1.74		
	38	4.10	212	38	4.56	0.47	38	4.73	3.18
	62	5.67	0.69	62	6.50	2.73	62	7.27	1.47
	86	7.01	0.88	86	8.16	2.90	86	9.25	1.61
	110	8.17	1.07	110	9.52	1.52	110	11.77	1.18

TABLE B1 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	348			348			357		
% Dev.	1.75			1.72			1.72		
	38	5.30	1.30	38	5.90	4.34	26	4.42	8.11
	62	7.85	5.66	62	8.54	5.41	50	7.83	5.32
	86	10.73	1.58	86	11.34	4.79	74	10.69	6.94
	110	13.56	2.79	110	14.83	3.50			
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	404			400			399		
% Dev.	1.74			1.78			1.72		
	38	4.09	1.25	38	4.21	2.15	38	4.79	1.40
	62	5.54	0.76	62	6.11	2.07	62	6.70	1.76
	86	6.85	1.23	86	7.44	1.57	86	8.55	1.86
	110	7.98	0.34	110	8.84	1.92	110	10.28	1.89
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	398			399			400		
% Dev.	1.73			1.73			1.92		
	38	4.93	2.35	38	5.48	4.46	38	5.12	3.44
	62	7.36	1.63	62	8.53	2.53	62	8.95	1.74
	86	9.45	3.50	86	11.20	2.46	86	12.25	2.51
	110	11.35	1.85	110	14.90	1.93			

TABLE B1 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.5055			0.05163			0.03078		
Temp., °C	503			499			494		
% Dev.	1.57			1.62			1.44		
	38	3.91	1.45	38	4.22	1.38	38	4.47	3.46
	62	5.33	1.20	62	5.85	1.64	62	6.40	1.82
	86	6.67	0.50	86	7.14	1.64	86	8.08	1.81
	110	7.79	0.60	110	8.47	1.07	110	10.15	2.06
Mass, gm.	0.03078			0.01513			0.00793		
Temp., °C	493			496			494		
% Dev.	1.41			1.48			1.64		
	38	4.84	3.11	38	5.27	4.58	38	5.78	4.11
	62	7.10	2.20	62	8.24	3.05	62	8.08	6.32
	86	8.94	1.54	86	10.62	2.32	86	12.70	2.27
	110	11.05	1.38	110	13.54	7.39			

TABLE B2

WATER DISTANCE-TIME DATA, TUBE INCLINATION 0.905°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.09919			0.05163			0.03078		
Temp., °C	312			314			315		
% Dev.	1.50			1.57			1.67		
	38	3.03	1.03	38	3.16	2.99	38	3.34	2.70
	62	4.16	2.35	62	4.40	1.13	62	4.77	2.35
	86	5.14	1.99	86	5.55	0.66	86	6.00	0.67
	110	5.98	2.25	110	6.53	1.70	110	7.21	1.46
Mass, gm	0.01513			0.00793					
Temp., °C	315			316					
% Dev.	1.66			1.85					
	38	3.52	1.62	38	2.70	1.51			
	62	5.00	1.76	62	5.52	2.00			
	86	6.20	2.04	86	7.00	1.30			
	110	8.07	2.61						
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	346			352			353		
% Dev.	1.65			1.71			1.68		
	38	2.90	2.40	38	3.19	8.59	38	3.16	1.52
	62	3.91	2.48	62	4.26	0.66	62	4.42	1.79
	86	4.72	1.46	86	5.06	0.81	86	5.51	1.41
	110	55.52	0.67	110	5.94	1.12	110	6.46	2.23

TABLE B2 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	353			352			351		
% Dev.	1.63			1.67			1.58		
	38	3.45	0.95	38	3.40	2.87	38	3.76	2.23
	62	4.76	1.13	62	4.90	2.79	62	5.13	2.12
	86	5.97	0.99	86	6.35	1.20	86	6.99	0.76
	110	7.04	1.27	110	8.08	1.96			
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	396			396			398		
%Dev.	1.54			1.62			1.74		
	38	2.74	0.76	38	2.88	1.44	38	3.02	1.85
	62	3.76	1.64	62	4.01	1.14	62	4.25	1.88
	86	4.54	1.36	86	4.94	0.86	86	5.35	0.79
	110	5.18	0.65	110	5.74	1.28	110	6.31	1.28
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	394			394			396		
% Dev.	1.81			1.67			1.62		
	38	3.31	1.64	38	3.50	3.27	38	3.60	1.53
	62	4.68	2.05	62	5.10	1.26	62	5.07	3.77
	86	5.87	1.51	86	6.38	7.72	86	6.84	1.40
	110	6.84	2.15	110	7.74	3.71			

TABLE B2 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	499			496			495		
% Dev.	1.58			1.57			1.45		
	38	2.77	1.65	38	2.85	1.94	38	3.01	0.69
	62	3.75	2.03	62	3.85	1.60	62	4.06	1.18
	86	4.47	3.02	86	4.81	1.60	86	5.14	2.05
	110	5.32	0.98	110	5.74	1.28	110	6.20	1.20
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	495			494			494		
% Dev.	1.45			1.39			1.39		
	38	3.07	1.88	38	3.36	1.60	38	3.43	1.82
	62	4.44	2.31	62	4.98	2.10	62	5.08	2.10
	86	5.61	1.30	86	6.06	3.75	86	6.42	1.41
	110	6.65	1.12	110	6.81	1.50			

TABLE B3

WATER DISTANCE-TIME DATA, TUBE INCLINCATION 1.809°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.09919			0.05163			0.03078		
Temp., °C	313			313			317		
% Dev.	1.45			1.45			1.73		
	38	2.19	0.88	38	2.27	1.41	38	2.40	1.20
	62	2.98	1.13	62	3.12	0.62	62	3.33	0.91
	86	3.64	1.08	86	3.86	1.04	86	4.15	0.81
	110	4.26	0.81	110	4.84	0.87	110	4.86	1.48
Mass, gm	0.01513			0.00793					
Temp, °C	317			316					
% Dev.	1.73			1.61					
	38	2.43	1.35	38	2.63	2.34			
	62	3.47	2.88	62	3.72	1.66			
	86	4.45	1.22	86	4.68	2.05			
	110	5.29	2.01						
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	347			347			348		
% Dev.	1.77			1.67			1.58		
	38	2.10	4.34	38	2.14	2.02	38	2.17	2.10
	62	2.80	4.51	62	2.92	1.40	62	3.05	1.39
	86	3.39	1.25	86	3.52	0.89	86	3.78	1.16
	110	3.87	0.87	110	4.17	1.23	110	4.42	0.51

TABLE B3 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	348			348			348		
% Dev.	1.58			1.55			1.55		
	38	2.31	0.90	38	2.47	1.62	38	2.48	2.93
	62	3.25	1.72	62	3.39	2.22	62	3.53	1.40
	86	4.04	1.58	86	4.17	2.52	86	4.56	1.33
	110	4.86	0.76	110	5.15	1.48			
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	394			394			394		
% Dev.	1.70			1.70			1.62		
	38	2.03	2.44	38	2.12	2.00	38	2.21	1.23
	62	2.74	0.93	62	2.88	1.17	62	3.03	0.95
	86	3.29	1.60	86	3.56	0.74	86	3.70	0.95
	110	3.77	7.36	110	4.03	0.36	110	4.45	1.12
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	394			394			395		
% Dev.	1.62			1.66			1.59		
	38	2.35	0.89	38	2.41	1.16	38	2.51	2.01
	62	3.28	1.20	62	3.34	1.80	62	3.54	1.92
	86	3.99	0.80	86	4.33	0.96	86	4.62	1.11
	110	4.72	0.90	110	5.14	0.92			

TABLE B3 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	495			497			493		
% Dev.	1.54			1.66			1.57		
	38	1.96	4.11	38	2.12	2.37	38	2.16	1.34
	62	2.72	0.62	62	2.85	0.90	62	2.88	1.94
	86	3.28	1.07	86	3.48	1.17	86	3.57	1.26
	110	3.76	2.15	110	4.04	0.69	110	4.14	1.10
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	493			496			496		
% Dev.	1.57			1.61			1.61		
	38	2.30	1.22	38	2.32	1.80	38	2.40	0.96
	62	3.13	0.74	62	3.25	1.48	62	3.44	1.70
	86	3.80	1.43	86	4.11	1.62	86	4.44	1.50
	110	4.56	0.79	110	4.87	1.46			

TABLE B4

WATER DISTANCE-TIME DATA, TUBE INCLINATIONS 4.528°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.09919			0.05163			0.03078		
Temp., °C	312			312			314		
% Dev.	1.45			1.45			1.54		
	38	1.38	2.38	38	1.45	0.99	38	1.34	4.25
	62	1.82	1.71	62	1.87	2.32	62	1.95	1.39
	86	2.22	1.37	86	2.33	1.24	86	2.35	2.45
	110	2.69	2.53	110	2.73	0.67	110	2.87	1.84
Mass, gm	0.01513			0.00793					
Temp., °C	314			316					
% Dev.	1.54			1.60					
	38	1.48	1.24	38	1.49	0.96			
	62	2.04	1.68	62	2.16	1.00			
	86	2.54	1.64	86	2.68	0.78			
	110	3.02	1.06						
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	346			349			349		
% Dev.	1.57			1.61			1.70		
	38	1.28	1.56	38	1.32	0.79	38	1.39	1.61
	62	1.73	1.29	62	1.81	0.44	62	1.83	1.22
	86	2.05	2.71	86	2.17	1.29	86	2.27	1.45
	110	2.42	1.47	110	2.55	0.94	110	2.68	2.26

TABLE B4 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	349			347			347		
% Dev.	1.70			1.60			1.60		
	38	1.46	1.98	38	1.43	0.84	38	1.53	1.57
	62	1.97	1.83	62	2.01	1.59	62	2.08	1.54
	86	2.45	1.43	86	2.60	2.56	86	2.73	1.23
	110	2.85	1.21	110	3.01	0.96			
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	402			402			397		
% Dev.	1.68			1.68			1.56		
	38	1.21	2.20	38	1.33	3.68	38	1.37	3.33
	62	1.59	1.42	62	1.84	0.61	62	1.84	1.52
	86	2.05	4.02	86	2.18	0.85	86	2.25	1.24
	110	2.36	2.36	110	2.56	1.84	110	2.67	1.74
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	397			398			398		
% Dev.	1.56			1.67			1.67		
	38	1.41	1.99	38	1.44	1.72	38	1.42	3.33
	62	1.99	1.69	62	1.98	1.94	62	2.08	2.26
	86	2.35	1.66	86	2.40	2.03	86	2.61	1.14
	110	2.82	0.57	110	2.94	1.17			

TABLE B4 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.5055			0.09919			0.05163		
Temp., °C	495			488			499		
% Dev.	1.52			4.28			1.53		
	38	1.17	1.52	38	1.22	3.15	38	1.31	2.37
	62	1.66	2.15	62	1.78	0.81	62	1.81	1.01
	86	1.96	1.48	86	2.11	1.36	86	2.21	0.72
	110	2.22	1.40	110	2.56	1.22	110	2.59	1.48
Mass, gm	0.03078			0.01513			0.00793		
Temp., °C	499			499			499		
% Dev.	1.53			1.56			1.56		
	38	1.41	2.27	38	1.42	1.07	38	1.46	1.75
	62	1.89	1.48	62	1.98	2.02	62	1.99	0.96
	86	2.33	1.78	86	2.49	0.71	86	2.43	1.28
	110	2.72	0.68	110	2.86	1.45			

TABLE B5

BENZENE DISTANCE-TIME DATA, TUBE INCLINATION 0.362°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	204			204			207		
% Dev.	1.53			1.53			1.73		
	14	2.21	3.41	14	2.33	2.54	14	2.30	2.99
	38	4.85	1.02	38	4.83	0.71	38	4.97	0.87
	62	6.74	0.40	62	6.91	0.49	62	7.38	1.83
	86	8.22	0.67	86	8.54	0.28	86	8.99	1.06
	110	9.80	0.36	110	10.61	0.46	110	11.67	0.60
Mass, gm	0.01547								
Temp., °C	207								
% Dev.	1.89								
	14	2.43	2.70						
	38	6.35	3.80						
	62	9.58	1.86						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	296			296			296		
% Dev.	1.79			1.79			1.53		
	14	2.27	2.01	14	2.28	0.81	14	2.34	2.70
	38	4.49	1.27	38	4.77	0.97	38	4.69	1.43
	62	6.23	0.96	62	6.65	0.64	62	6.92	0.94
	86	7.76	0.74	86	8.24	1.42	86	8.84	0.72
	110	9.01	0.80	110	9.89	0.93	110	10.94	1.21

TABLE B5 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.01547								
Temp., °C	298								
% Dev.	1.78								
	14	2.59	2.14						
	38	5.83	6.81						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	396			396			393		
% Dev.	1.59			1.59			1.47		
	14	2.37	1.76	14	2.38	2.73	14	2.36	3.86
	38	4.65	1.10	38	4.79	0.85	38	5.11	2.08
	62	6.42	0.78	62	6.66	0.97	62	7.33	0.76
	86	7.94	0.78						
	110	9.60	1.18						
Mass, gm	0.01547								
Temp., °C	397								
% Dev.	1.55								
	14	2.68	2.66						

TABLE B5 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	498			498			498		
% Dev.	1.47			1.47			1.38		
	14	2.20	2.00	14	2.36	1.05	14	2.38	2.39
	38	4.39	1.93	38	4.68	1.06	38	5.02	1.16
	62	6.19	0.78	62	6.54	1.21	62	7.21	1.27
	86	7.65	1.20	86	8.42	1.02			
	110	8.99	0.96						
Mass, gm	0.01547								
Temp., °C	496								
% Dev.	1.46								
	14	2.41	0.99						

TABLE B6

BENZENE DISTANCE-TIME DATA, TUBE INCLINATION 0.905°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	205			205			206		
% Dev.	2.08			2.08			1.81		
	14	1.53	3.55	14	1.59	2.92	14	1.66	2.13
	38	2.94	1.47	38	2.98	0.91	38	3.08	1.12
	62	4.04	1.15	62	4.15	0.44	62	4.35	0.84
	86	4.94	1.91	83	5.15	0.33	86	5.40	0.93
	110	5.69	0.91	110	5.97	0.55	110	6.48	0.63
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	206			205			205		
% Dev.	1.81			1.88			1.81		
	14	1.70	4.06	14	1.81	1.94	14	1.96	1.84
	38	3.52	1.55	38	3.73	0.62	38	4.16	1.40
	62	4.90	1.31	62	5.48	0.86			
	86	6.59	0.53						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	299			299			298		
% Dev.	1.72			1.75			1.73		
	14	1.54	1.82	14	1.51	2.17	14	1.56	2.01
	38	2.93	0.46	38	2.88	2.78	38	2.99	0.91
	62	3.92	1.64	62	3.98	1.06	62	4.23	0.44
	86	4.73	0.21	86	4.92	0.39	86	5.24	0.76
	110	5.62	0.51	110	5.72	0.98	110	6.16	0.99

TABLE B6 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	298			299			299		
% Dev.	1.73			1.72			1.72		
	14	1.72	2.19	14	1.81	0.93	14	1.94	2.68
	38	3.34	1.44	38	3.74	1.86	38	4.06	1.38
	62	4.69	1.14	62	5.71	3.53			
	86	6.51	0.93						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	399			399			396		
% Dev.	1.55			1.55			1.59		
	14	1.54	3.09	14	1.53	2.30	14	1.51	1.12
	38	2.86	0.47	38	2.92	1.61	38	2.98	1.13
	62	3.88	2.01	62	4.01	0.66	62	4.09	0.96
	86	4.82	1.43	86	5.00	0.85	86	5.14	1.15
	110	5.55	0.76	110	5.89	0.31	110	6.10	1.57
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	396			396			396		
% Dev.	1.59			1.52			1.52		
	14	1.59	3.23	14	1.78	3.28	14	1.83	3.83
	38	3.21	1.30	38	3.52	1.23	38	4.00	3.75
	62	4.52	1.24	62	5.44	1.29			
	86	5.92	0.52						

TABLE B6 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	498			499			502		
% Dev.	1.45			1.60			1.37		
	14	1.51	2.50	14	1.51	4.13	14	1.49	1.72
	38	2.85	2.03	38	2.93	1.14	38	2.98	1.24
	62	3.80	0.58	62	4.01	0.61	62	4.06	0.59
	86	4.67	0.67	86	4.94	0.40	86	5.12	0.94
	110	5.38	0.08	110	5.79	1.50			
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	502			493			493		
% Dev.	1.37			1.33			1.33		
	14	1.67	3.44	14	1.80	2.22	14	1.86	2.63
	38	3.21	1.87	38	3.54	1.42			
	62	4.80	0.75						

TABLE B7

BENZENE DISTANCE-TIME DATA, TUBE INCLINATION 1.809°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	205			205			205		
% Dev.	1.76			1.76			1.96		
	14	1.09	3.06	14	1.09	4.06	14	1.10	2.12
	38	2.00	1.89	38	2.05	2.60	38	2.18	1.72
	62	2.80	1.35	62	2.89	0.31	62	3.04	1.32
	86	3.52	0.50	86	3.56	0.81	86	3.75	1.26
	110	4.02	0.44	110	4.10	0.60	110	4.34	0.35
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	205			207			205		
% Dev.	1.96			1.66			1.87		
	14	1.15	2.44	14	1.25	4.62	14	1.34	3.47
	38	2.31	1.11	38	2.48	0.61	38	2.72	0.47
	62	3.37	1.38	62	3.55	1.58	62	3.99	1.08
	86	4.13	1.16	86	4.52	1.44			
	110	5.06	1.28						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	294			294			301		
% Dev.	1.64			1.64			1.84		
	14	1.07	2.71	14	1.04	0.43	14	1.08	3.48
	38	2.04	0.61	38	2.03	0.98	38	2.17	1.81
	62	2.74	0.89	62	2.82	1.26	62	2.99	1.36
	86	3.73	0.46	86	3.45	0.32	86	3.59	1.07
	110	4.88	0.97	110	4.02	0.44	110	4.28	0.50

TABLE B7 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	301			298			297		
% Dev.	1.84			1.59			1.61		
	14	1.23	1.70	14	1.22	3.09	14	1.26	3.18
	38	2.28	0.91	38	2.48	0.58	38	2.66	1.59
	62	3.22	0.74	62	3.49	0.69			
	86	4.02	1.05	86	4.52	1.65			
	110	4.98	0.95						
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	395			395			398		
% Dev.	1.46			1.46			1.49		
	14	1.07	1.67	14	1.04	0.64	14	1.10	2.03
	38	2.03	1.42	38	2.08	0.66	38	2.12	2.00
	62	2.80	1.90	62	2.80	0.16	62	2.84	0.47
	86	3.31	0.81	86	3.38	0.86	86	3.58	0.74
	110	3.84	0.58	110	3.97	1.06	110	4.30	0.67
Mass, gm	0.01547			0.00936			0.00323		
Temp., °C	398			396			396		
% Dev.	1.49			1.60			1.53		
	14	1.17	3.00	14	1.24	1.86	14	1.22	1.51
	38	2.30	1.46	38	2.39	1.31	38	2.62	1.98
	62	3.20	1.00	62	3.47	1.18			
	86	3.96	1.72						

TABLE B7 (Continued)

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.1744			0.08588			0.04192		
Temp., °C	500			500			500		
% Dev.	1.40			1.40			1.60		
	14	1.17	4.36	14	1.09	1.02	14	1.09	1.43
	38	1.97	1.24	38	2.06	0.32	38	2.01	0.66
	62	2.83	2.90	62	2.78	0.64	62	2.93	0.68
	86	3.27	0.82	86	3.41	0.39	86	3.53	0.94
	110	3.81	0.35	110	4.11	1.03	110	4.23	0.71
Mass, gm.	0.01547			0.00936			0.00323		
Temp., °C	500			496			596		
% Dev.	1.60			1.25			1.29		
	14	1.16	0.58	14	1.06	2.73	14	1.39	1.96
	38	1.76	2.22	38	2.28	0.98	38	2.62	1.65
	62	3.24	0.57						
	86	3.93	0.40						

TABLE B8

BENZENE DISTANCE-TIME DATA, TUBE INCLINATION 4.528°

	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation	Distance inches	Average Time sec	Percent Time Deviation
Mass, gm	0.08588			0.04192			0.01547		
Temp., °C	206			207			207		
% Dev.	1.78			1.92			1.92		
	38	1.38	1.61	38	1.33	2.01	38	1.47	0.45
	62	1.86	1.08	62	1.89	1.64	62	2.03	0.98
	86	2.31	0.38	86	2.22	1.30	86	2.62	1.27
	110	2.59	0.69	110	2.66	0.50	110	3.01	0.52
Mass, gm	0.00936			0.00323			0.08588		
Temp., °C	205			205			296		
% Dev.	1.78			1.69			1.74		
	38	1.41	1.42	38	1.61	4.14	38	1.39	0.72
	62	2.07	1.50	62	2.28	2.30	62	1.90	1.58
	86	2.65	1.51	86	3.03	2.72	86	2.29	1.89
	110	3.17	1.75				110	2.62	0.40

APPENDIX C

DISTANCE-TIME CURVES

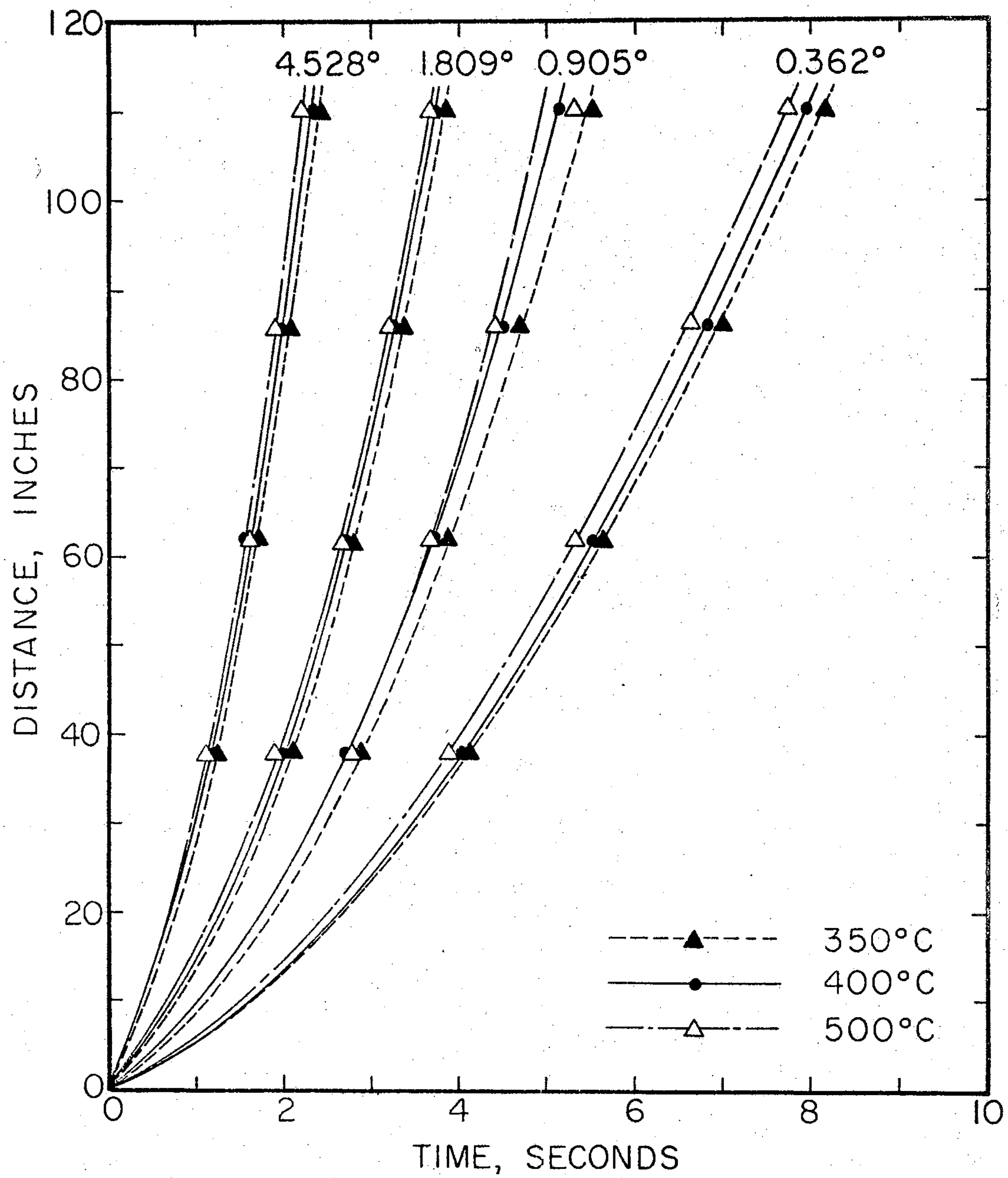

Figure 9. Distance-Time Curves for Water (0.506 gm).

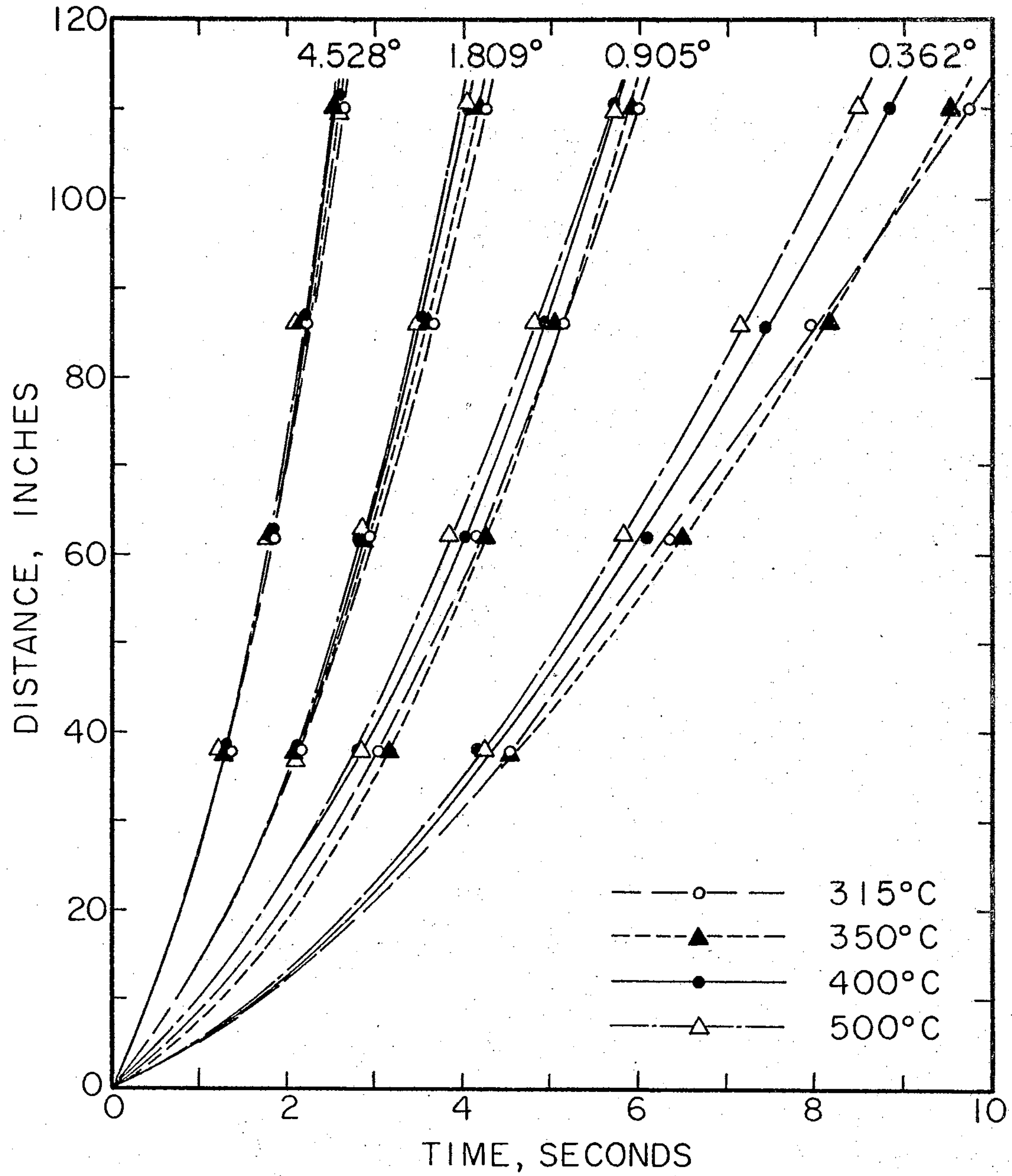

Figure 10. Distance-Time Curves for Water (0.0992 gm).

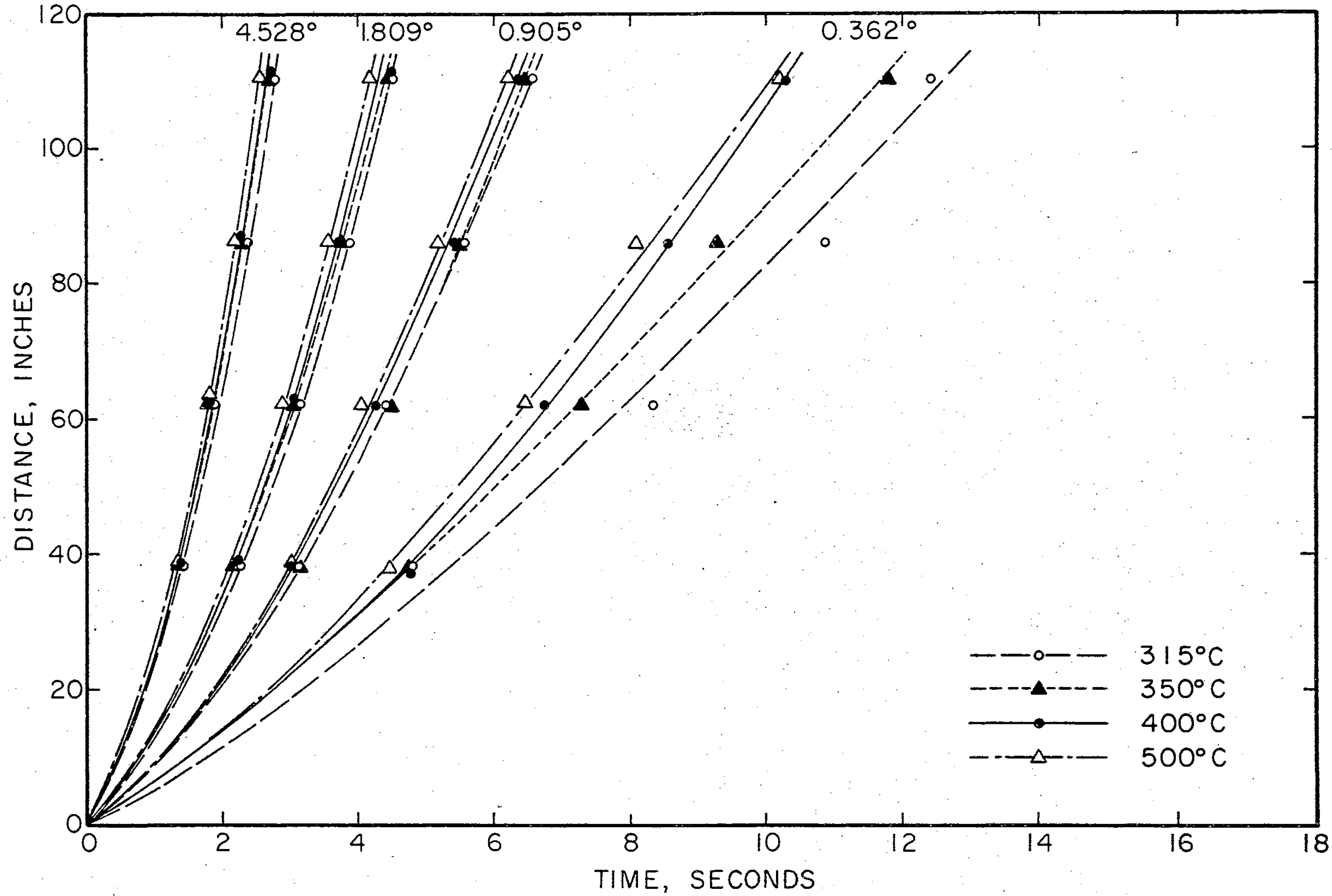

Figure 11. Distance-Time Curves for Water (0.0516 gm).

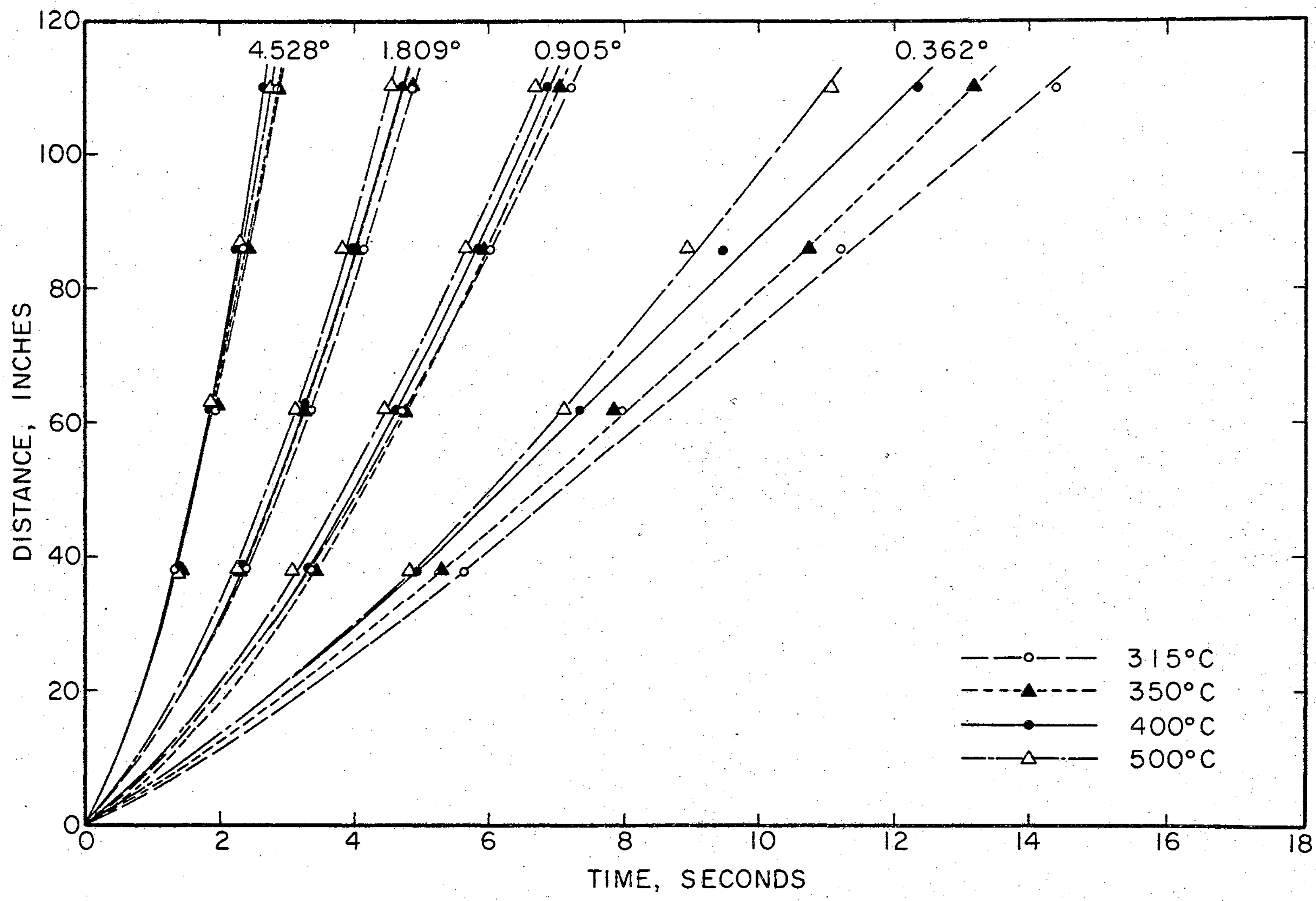

Figure 12. Distance-Time Curves for Water (0.0308 gm).

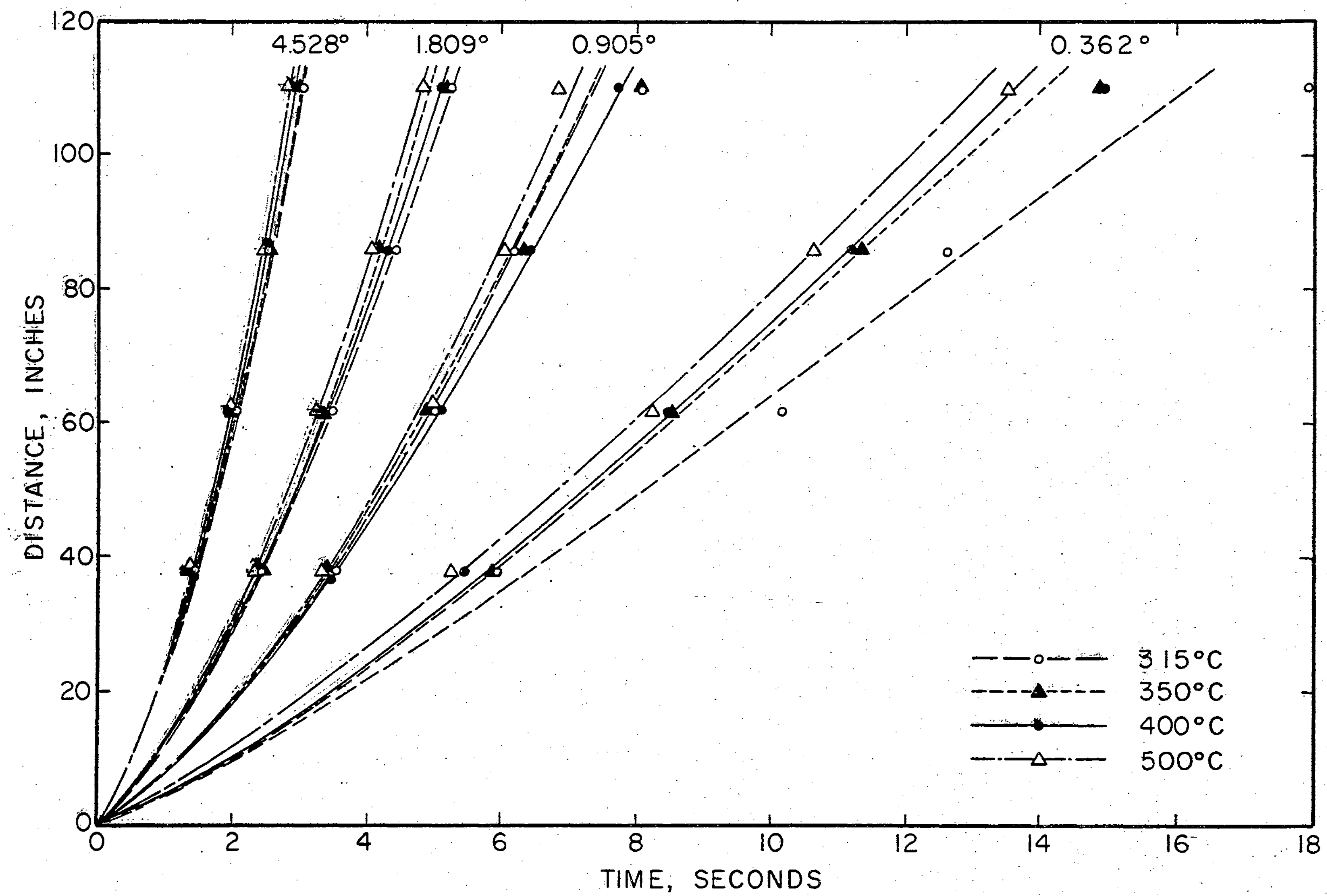

Figure 13. Distance-Time Curves for Water (0.0151 gm).

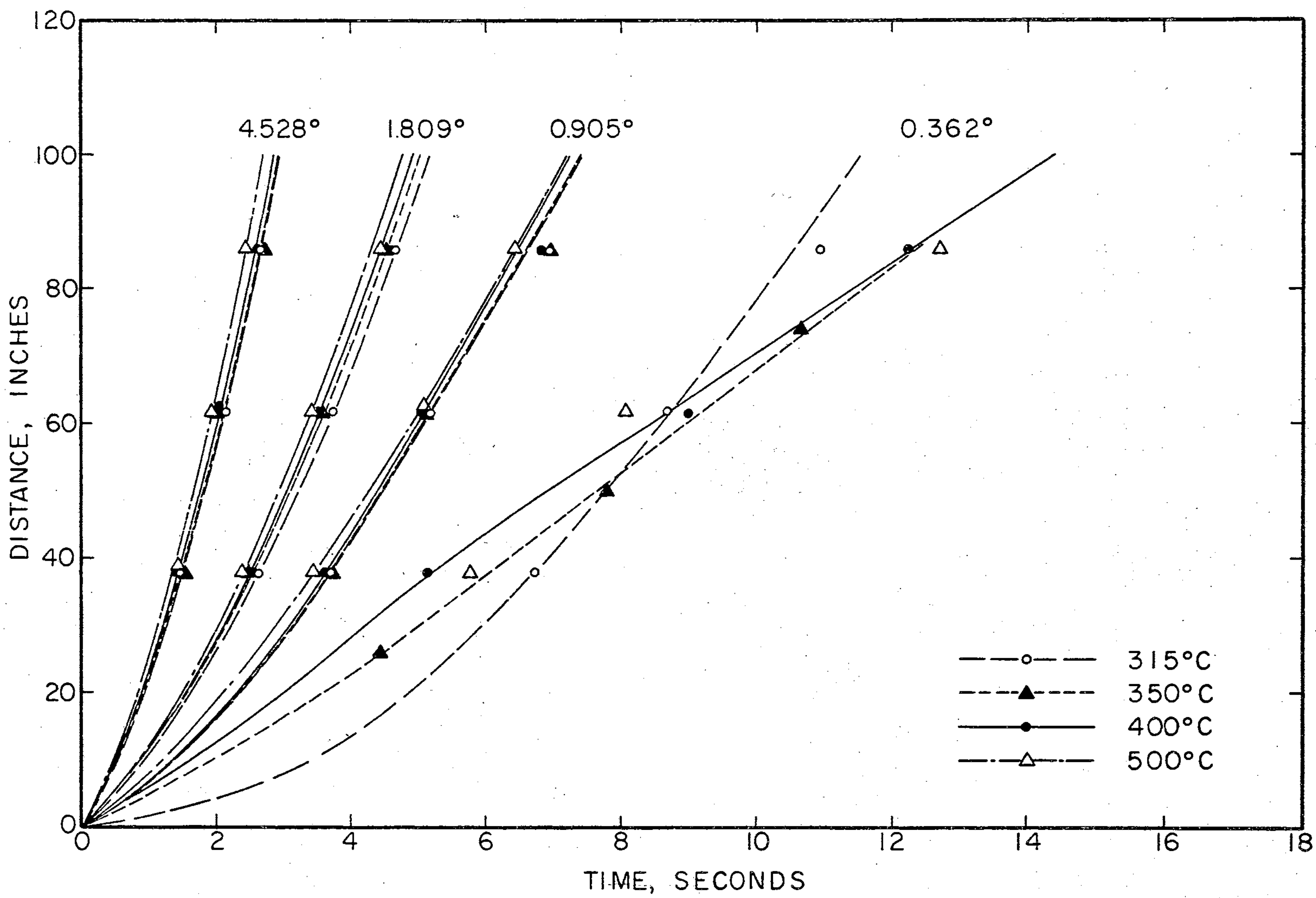

Figure 14. Distance-Time Curves for Water (0.0079 gm).

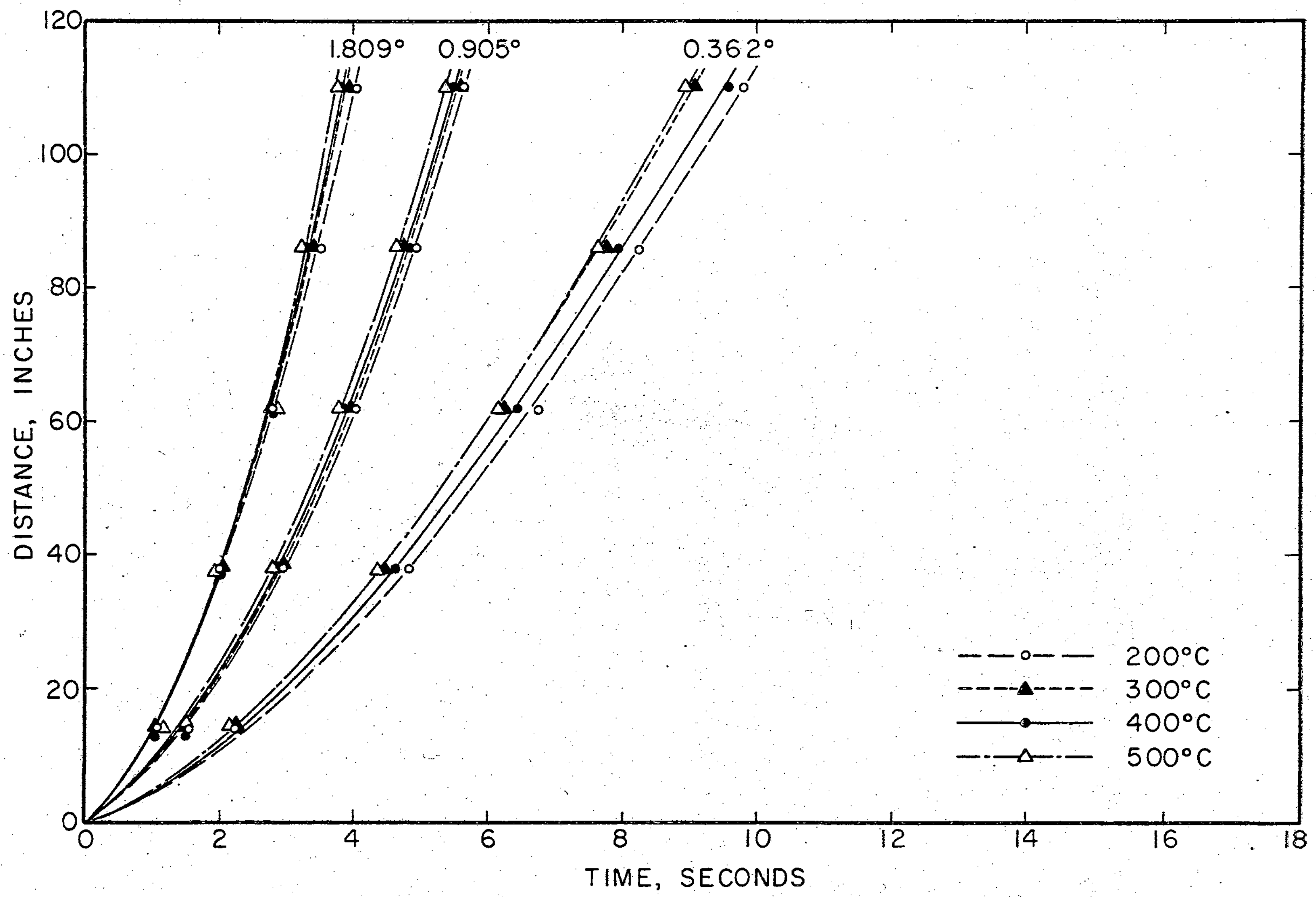

Figure 15. Distance-Time Curves for Benzene (0.174 gm).

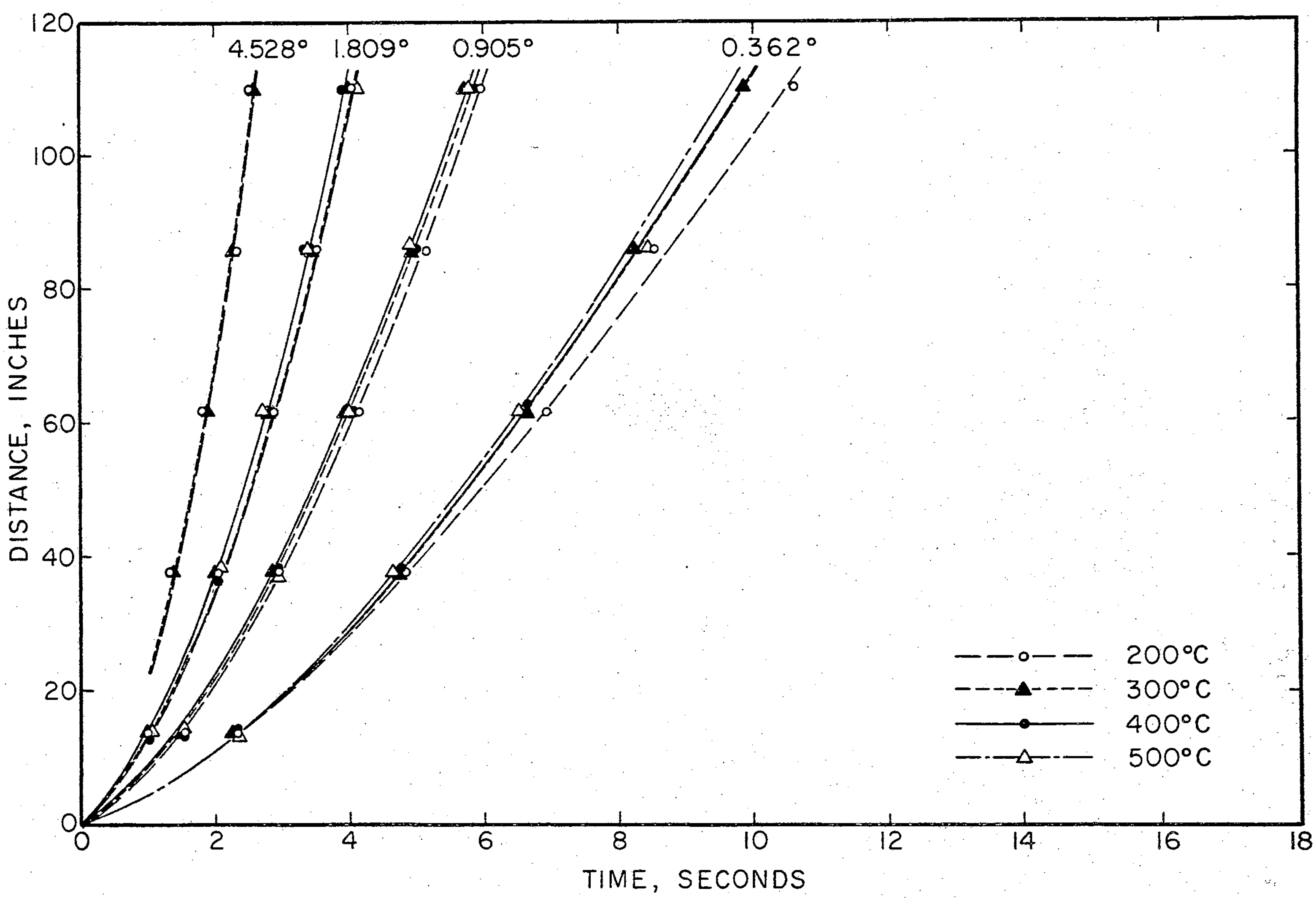

Figure 16. Distance-Time Curves for Benzene (0.0859 gm).

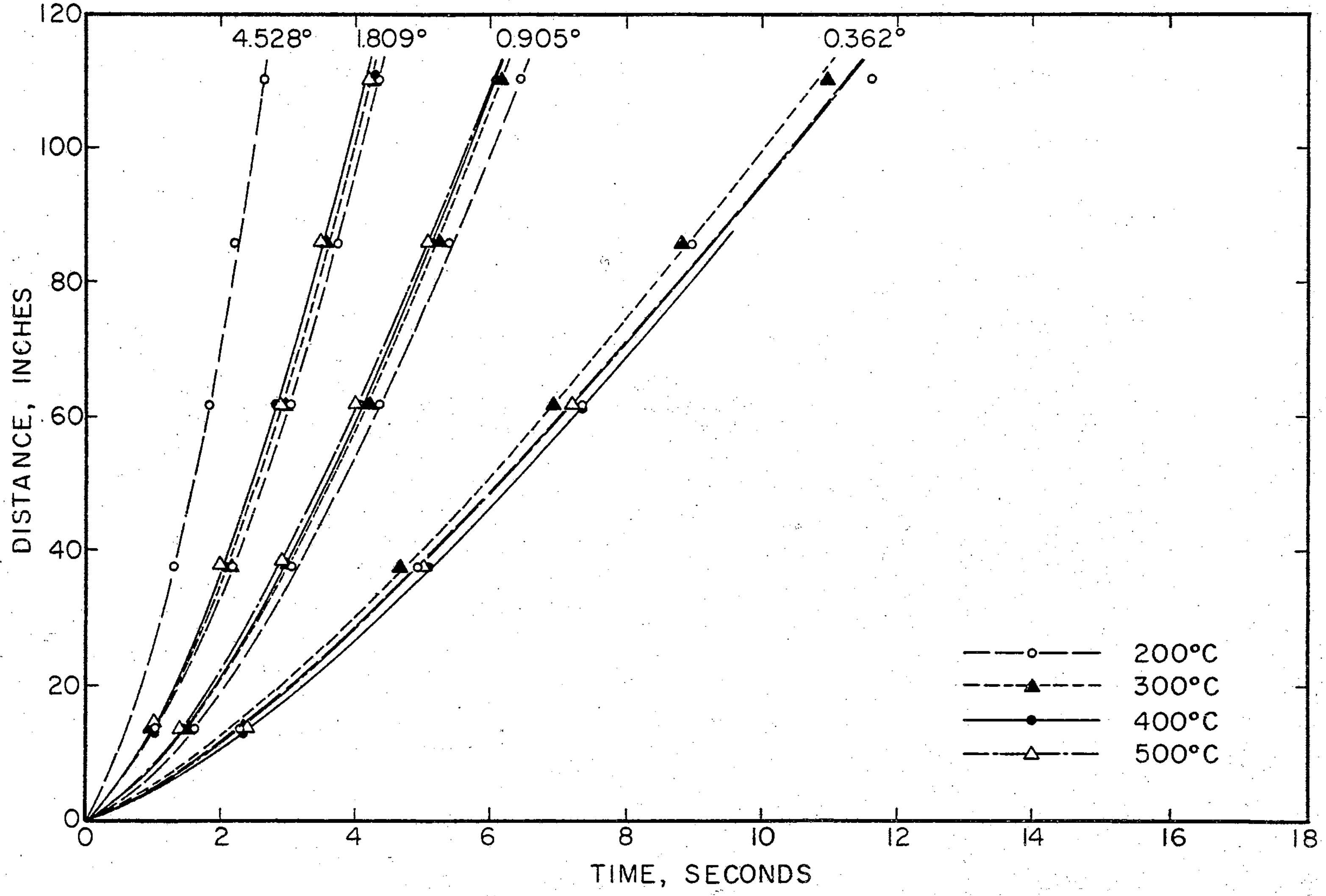

Figure 17. Distance-Time Curves for Benzene (0.0419 gm).

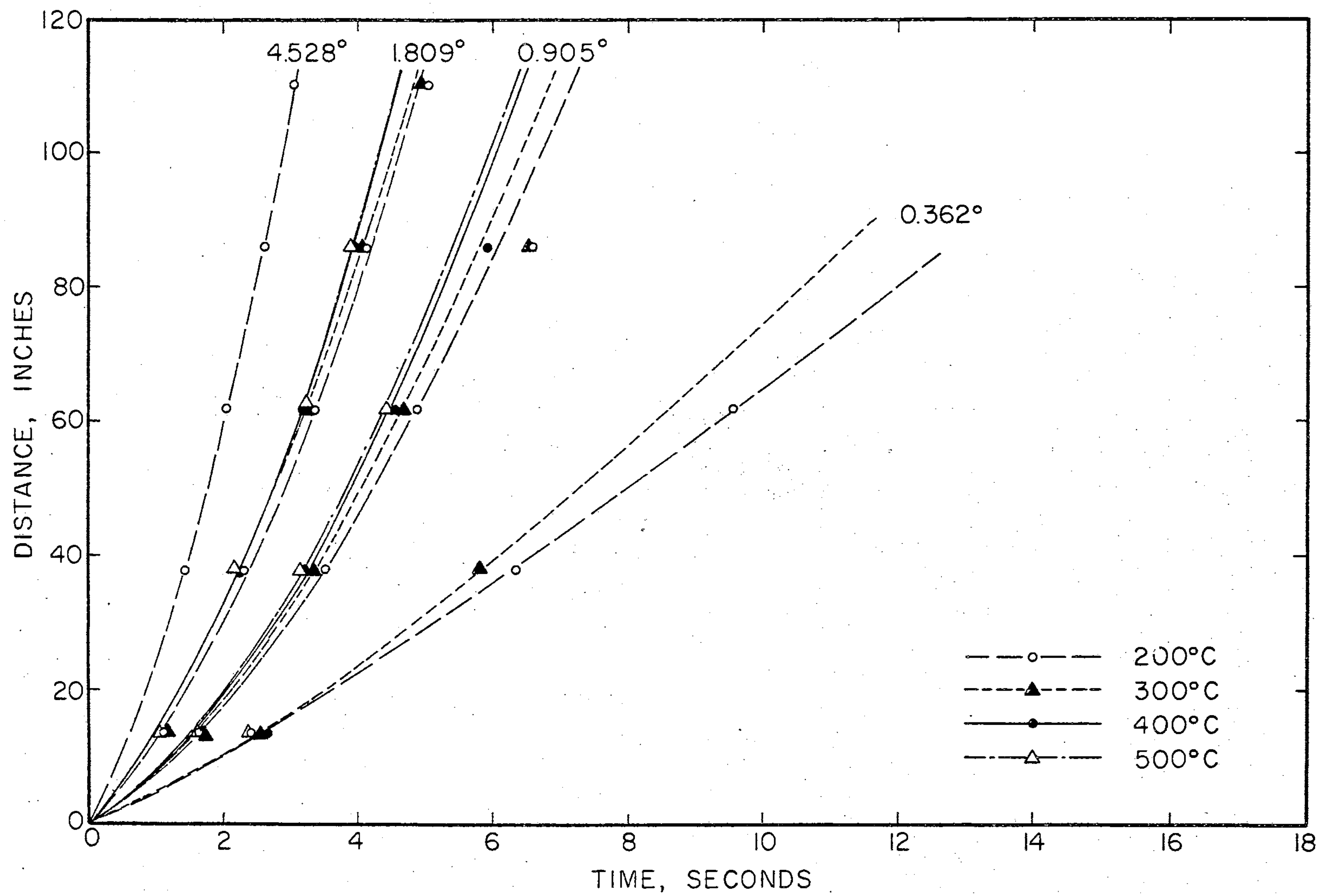

Figure 18. Distance-Time Curves for Benzene (0.0155 gm).

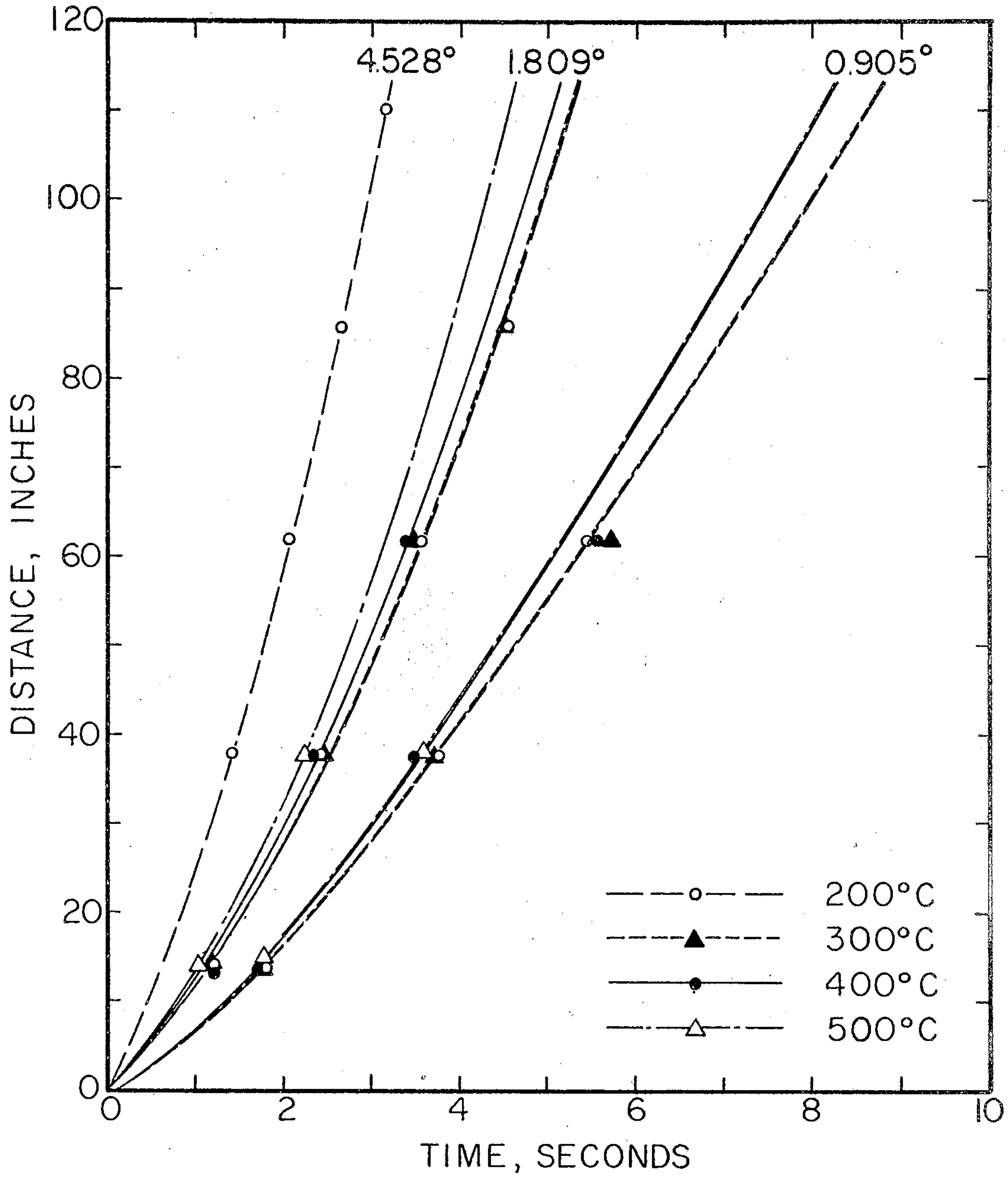

Figure 19. Distance-Time Curves for Benzene (0.0094 gm).

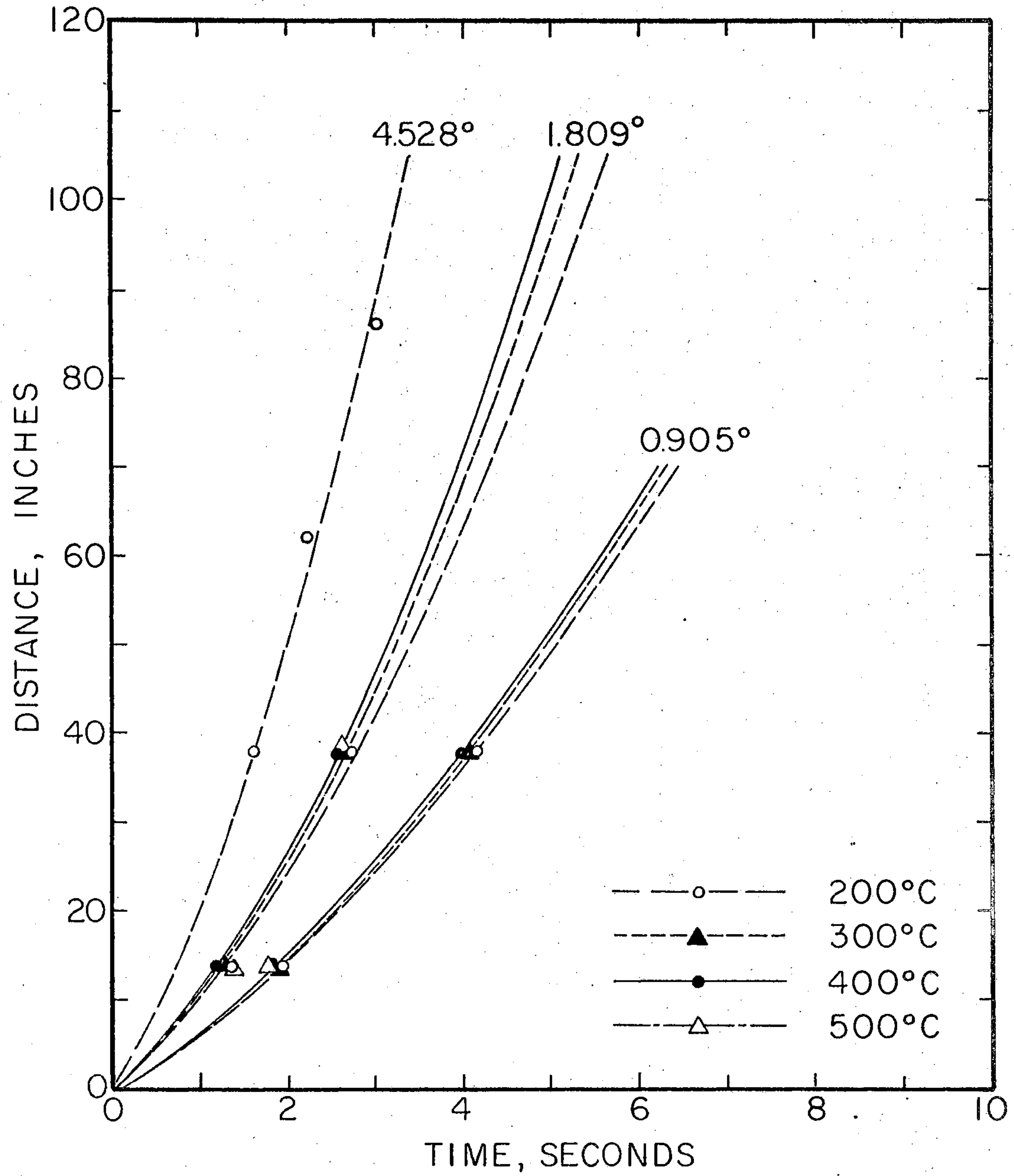

Figure 20. Distance-Time Curves for Benzene (0.0032 gm).

APPENDIX D

CALCULATED DATA

TABLE D1

EMPIRICAL CORRELATIONAL GROUPS FOR WATER

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
0.362	315	0.09919	35.7	8.01×10^{-3}	7.53	0.787
	317	0.05163	23.3	7.59×10^{-3}	13.98	0.487
	318	0.03078	20.6	7.27×10^{-3}	15.28	0.412
	316	0.01513	15.6	6.85×10^{-3}	21.08	0.294
	316	0.00793	28.8	6.49×10^{-3}	4.99	0.514
	349	0.50550	44.8	9.77×10^{-3}	8.47	1.118
	345	0.09919	36.6	8.53×10^{-3}	7.42	0.798
	345	0.05163	26.4	8.08×10^{-3}	11.30	0.546
	348	0.03078	23.0	7.74×10^{-3}	12.70	0.455
	348	0.01513	20.5	7.29×10^{-3}	12.64	0.382
	357	0.00793	19.4	6.91×10^{-3}	11.37	0.343
	404	0.50550	46.8	10.52×10^{-3}	8.17	1.133
	400	0.09919	39.8	9.18×10^{-3}	6.60	0.842
	399	0.05163	33.2	8.69×10^{-3}	7.50	0.666
	398	0.03078	28.5	8.32×10^{-3}	8.72	0.546
	399	0.01513	19.6	7.85×10^{-3}	14.49	0.355
	400	0.00793	17.1	7.44×10^{-3}	15.44	0.293
	503	0.50550	46.8	12.04×10^{-3}	8.95	1.069
	499	0.09919	43.3	10.52×10^{-3}	6.10	0.864
	494	0.05163	32.5	9.96×10^{-3}	8.60	0.614
	493	0.03078	29.7	9.54×10^{-3}	8.78	0.538
	496	0.01513	22.4	8.99×10^{-3}	12.22	0.382
	494	0.00793	17.0	8.52×10^{-3}	17.10	0.274

TABLE D1 (Continued

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
0.905	312	0.09919	61.7	8.01×10^{-3}	6.30	1.359
	314	0.05163	53.9	7.59×10^{-3}	6.56	1.124
	315	0.03078	47.4	7.27×10^{-3}	7.23	0.947
	315	0.01513	40.7	6.85×10^{-3}	7.74	0.767
	316	0.00793	36.9	6.49×10^{-3}	7.61	0.658
	346	0.50550	70.2	9.78×10^{-3}	8.63	1.752
	352	0.09919	67.2	8.53×10^{-3}	5.51	1.464
	353	0.05163	55.2	8.08×10^{-3}	6.46	1.141
	353	0.03078	50.8	7.74×10^{-3}	6.51	1.005
	352	0.01513	39.3	7.29×10^{-3}	8.58	0.733
	351	0.00793	37.5	6.91×10^{-3}	7.62	0.662
	396	0.50550	74.6	10.51×10^{-3}	8.03	1.808
	396	0.09919	63.8	9.18×10^{-3}	6.41	1.350
	398	0.05163	55.5	8.69×10^{-3}	6.74	1.116
	394	0.03078	51.6	8.33×10^{-3}	6.64	0.990
	394	0.01513	43.6	7.85×10^{-3}	7.34	0.789
	396	0.00793	37.6	7.44×10^{-3}	7.97	0.644
	499	0.50550	72.5	12.04×10^{-3}	9.32	1.656
	496	0.09919	63.3	10.52×10^{-3}	7.15	1.263
	495	0.05163	57.1	9.96×10^{-3}	6.96	1.079
	495	0.03078	51.0	9.54×10^{-3}	7.47	0.922
	494	0.01513	51.7	8.99×10^{-3}	5.72	0.882
	494	0.00793	40.7	8.52×10^{-3}	7.44	0.658

TABLE D1 (Continued)

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
1.809	313	0.09919	88.5	8.01×10^{-3}	6.13	1.949
	313	0.05163	82.2	7.59×10^{-3}	5.64	1.715
	317	0.03078	74.2	7.27×10^{-3}	5.91	1.482
	317	0.01513	63.5	6.85×10^{-3}	6.37	1.196
	316	0.00793	59.3	6.49×10^{-3}	5.88	1.059
	347	0.50550	102.7	9.78×10^{-3}	8.06	2.565
	347	0.09919	90.5	8.53×10^{-3}	6.06	1.974
	348	0.05163	81.1	8.08×10^{-3}	5.99	1.675
	348	0.03078	72.1	7.74×10^{-3}	6.58	1.425
	348	0.01513	69.0	7.29×10^{-3}	5.57	1.287
	348	0.00793	58.6	6.91×10^{-3}	6.23	1.035
	394	0.50550	104.7	10.51×10^{-3}	8.14	2.538
	394	0.09919	94.1	9.18×10^{-3}	5.89	1.992
	394	0.05163	82.2	8.69×10^{-3}	6.13	1.648
	394	0.03078	77.4	8.33×10^{-3}	5.90	1.486
	394	0.01513	66.2	7.85×10^{-3}	6.37	1.197
	395	0.00793	57.8	7.44×10^{-3}	6.74	0.990
	495	0.5055	101.4	12.04×10^{-3}	9.52	2.317
	497	0.09919	95.3	10.52×10^{-3}	6.31	1.901
	493	0.05163	91.5	9.96×10^{-3}	5.43	1.729
	493	0.03078	81.7	9.54×10^{-3}	5.81	1.478
	496	0.01513	71.4	8.99×10^{-3}	6.01	1.217
	496	0.00793	59.8	8.52×10^{-3}	6.90	0.967

TABLE D1 (Continued)

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
4.528	312	0.09919	140.6	$8.01x10^{-3}$	6.07	3.097
	312	0.05163	141.7	$7.59x10^{-3}$	4.74	2.956
	314	0.03078	121.2	$7.27x10^{-3}$	5.53	2.422
	314	0.01513	118.8	$6.85x10^{-3}$	4.55	2.236
	316	0.00793	102.4	$6.49x10^{-3}$	4.93	1.827
	346	0.50550	161.7	$9.78x10^{-3}$	8.13	4.037
	349	0.09919	150.0	$8.53x10^{-3}$	5.52	3.270
	349	0.05163	141.0	$8.08x10^{-3}$	4.96	2.912
	349	0.03078	130.5	$7.74x10^{-3}$	4.94	2.581
	347	0.01513	113.5	$7.29x10^{-3}$	5.16	2.115
	347	0.00793	101.0	$6.91x10^{-3}$	5.25	1.784
	402	0.50550	155.4	$10.51x10^{-3}$	9.23	3.768
	402	0.09919	149.3	$9.18x10^{-3}$	5.85	3.160
	397	0.05163	141.3	$8.69x10^{-3}$	5.09	2.831
	397	0.03078	131.6	$8.33x10^{-3}$	5.10	2.527
	398	0.01513	124.0	$7.85x10^{-3}$	4.53	2.244
	398	0.00793	101.8	$7.44x10^{-3}$	5.43	1.745
	495	0.50550	171.8	$12.04x10^{-3}$	8.29	3.926
	488	0.09919	138.8	$10.52x10^{-3}$	7.43	2.770
	499	0.05163	143.9	$9.96x10^{-3}$	5.49	2.719
	499	0.03078	138.9	$9.54x10^{-3}$	5.03	2.513
	499	0.01513	125.3	$8.99x10^{-3}$	4.87	2.138
	499	0.00793	125.1	$8.52x10^{-3}$	3.94	2.022

TABLE D2

EMPIRICAL CORRELATIONAL GROUPS FOR BENZENE

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
0.362	204	0.17440	38.3	$5.61x10^{-3}$	1.52	5.15
	204	0.08588	32.0	$5.29x10^{-3}$	1.63	4.17
	207	0.04192	27.8	$4.99x10^{-3}$	1.72	3.42
	207	0.01547	17.0	$4.59x10^{-3}$	3.40	1.92
	296	0.17440	40.1	$7.47x10^{-3}$	1.48	5.40
	296	0.08588	35.9	$7.04x10^{-3}$	1.47	4.56
	298	0.04192	29.5	$6.63x10^{-3}$	1.73	3.52
	298	0.01547	18.8	$6.10x10^{-3}$	3.13	2.07
	396	0.17440	37.2	$9.23x10^{-3}$	1.92	4.80
	396	0.08588	32.6	$8.71x10^{-3}$	1.98	3.96
	393	0.04192	27.5	$8.20x10^{-3}$	2.22	3.15
	498	0.17440	39.8	$10.73x10^{-3}$	1.84	4.63
	498	0.08588	32.6	$10.11x10^{-3}$	2.18	3.58
	498	0.04192	27.9	$9.53x10^{-3}$	2.36	2.88
0.905	205	0.17440	66.2	$5.61x10^{-3}$	1.20	9.15
	205	0.08588	60.9	$5.29x10^{-3}$	1.13	7.93
	206	0.04192	54.0	$4.98x10^{-3}$	1.14	6.63
	206	0.01547	37.9	$4.59x10^{-3}$	1.61	4.28
	205	0.00936	31.2	$4.40x10^{-3}$	1.82	3.59
	205	0.00323	27.6	$4.03x10^{-3}$	1.84	2.74

TABLE D2 (Continued)

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
0.905	299	0.17440	68.6	7.47×10^{-3}	1.27	9.24
	299	0.08588	64.1	7.04×10^{-3}	1.15	8.13
	298	0.04192	57.7	6.63×10^{-3}	1.13	6.90
	298	0.01547	38.6	6.10×10^{-3}	1.86	4.25
	299	0.00936	31.3	5.85×10^{-3}	2.31	3.30
	299	0.00323	28.8	5.36×10^{-3}	1.92	2.78
	399	0.17440	67.3	9.24×10^{-3}	1.47	8.68
	399	0.08588	61.5	8.71×10^{-3}	1.39	7.48
	396	0.04192	58.5	8.20×10^{-3}	1.22	6.70
	396	0.01547	42.5	7.55×10^{-3}	1.71	4.48
	396	0.00936	33.3	7.24×10^{-3}	2.27	3.36
	396	0.00323	28.1	6.62×10^{-3}	2.24	2.60
	498	0.17440	71.7	10.73×10^{-3}	1.42	8.35
	499	0.08588	63.9	10.11×10^{-3}	1.42	7.01
	502	0.04192	56.7	9.53×10^{-3}	1.42	5.88
	502	0.01547	39.0	8.77×10^{-3}	2.23	3.71
	493	0.00936	35.0	8.41×10^{-3}	2.26	3.19
1.809	205	0.17440	89.2	5.61×10^{-3}	1.33	12.32
	205	0.08588	88.6	5.29×10^{-3}	1.07	11.54
	205	0.04192	84.4	4.98×10^{-3}	0.94	10.35
	205	0.01547	62.8	4.58×10^{-3}	1.24	7.09
	207	0.00936	55.9	4.40×10^{-3}	1.28	6.05
	205	0.00323	45.9	4.03×10^{-3}	1.33	4.54

TABLE D2 (Continued)

Tube Inclination degrees	Tube Temperature °C	Drop Mass gm	Terminal Velocity cm/sec	Delta cm	Drag Coefficient	Reynolds Number
1.809	294	0.17440	98.3	7.47×10^{-3}	1.24	13.23
	294	0.08588	91.7	7.04×10^{-3}	1.22	11.66
	301	0.04192	87.4	6.63×10^{-3}	0.98	10.45
	301	0.01547	65.7	6.10×10^{-3}	1.28	7.23
	298	0.00936	55.7	5.85×10^{-3}	1.46	5.88
	297	0.00323	43.5	5.36×10^{-3}	1.68	4.20
	395	0.17440	101.9	9.24×10^{-3}	1.28	13.14
	395	0.08588	94.7	8.71×10^{-3}	1.18	11.51
	398	0.04192	83.5	8.20×10^{-3}	1.20	9.56
	398	0.01547	65.3	7.55×10^{-3}	1.44	6.88
	396	0.00936	54.8	7.24×10^{-3}	1.67	5.54
	396	0.00323	43.5	6.62×10^{-3}	1.87	4.02
	500	0.17440	99.9	10.73×10^{-3}	1.46	11.62
	500	0.08588	89.9	10.11×10^{-3}	1.43	9.87
	500	0.04192	83.2	9.53×10^{-3}	1.33	8.60
	500	0.01547	64.9	8.77×10^{-3}	1.61	6.17
	496	0.00936	49.9	8.41×10^{-3}	2.22	4.55
	496	0.00323	49.7	7.70×10^{-3}	1.58	4.14
4.528	206	0.08588	147.2	5.29×10^{-3}	0.97	19.17
	207	0.04192	139.8	4.98×10^{-3}	0.85	17.15
	207	0.01547	116.3	4.58×10^{-3}	0.91	13.13
	205	0.00936	103.5	4.40×10^{-3}	0.93	11.21
	205	0.00323	85.8	4.03×10^{-3}	0.95	8.50
	296	0.08588	147.9	8.71×10^{-3}	1.20	17.97

APPENDIX E

ERROR ANALYSIS

TABLE E1

MAXIMUM RELATIVE ERRORS

Variable Measured or Calculated	Magnitude of Variable at Condition of Maximum Relative Error	Maximum Relative Error of Variable, %
Tube Inclination	0.0362°	2.0
Droplet Mass	0.00323 gm.	8.3
Tube Temperature	500°C.	2.0
Distance	14 in.	0.4
Droplet Timings	5.0 sec.	3.0
Droplet Diameter	0.224 cm.	5.5
Terminal Velocity	30 cm/sec	5.7
Drag Coefficient	1.60	13.0

APPENDIX F

COMPUTER PROGRAMS

```
C     CONVECTIVE LEIDENFROST DATA ANALYSIS FOR WATER
C     DROP DIMENSION IN CM
C     DENSITY IN LB/FT**3
C     CONVECTIVE LEIDENFROST DATA ANALYSIS FOR WATER
C     DROP DIMENSION IN CM
C     DENSITY IN LB/FT**3
C     VISCOSITY IN LB/FT-SEC
C     DROP MASS IN GRAMS
C     FORCE ON DROPLET IN LBF/LBM
      DIMENSION TX(10),SX(10),XSP(10),XTC(10),D(10,10)
      DIMENSION RHOG(15),VISC(15),DM(10),R(6)
      DIMENSION XG(30),T(10),S(10),A(10)
      DATA TX(1),TX(2),TX(3),TX(4)/315.0,350.0,400.0,500.0    /
      DATA SX(1),SX(2),SX(3),SX(4)/0.460,0.465,0.475,0.485   /
      DATA XTC(1),XTC(2),XTC(3)/7.9E-05,8.2E-05,8.4E-05    /
      DATA  XTC(4)/9.2E-05    /
      DATA RHOG(10),RHOG(11),RHOG(12)/0.02860,0.02762,0.02629  /
      DATA RHOG(13),VISC(10),VISC(11)/0.02397,1.1196E-5,1.1632E-5 /
      DATA   VISC(12),VISC(13)/1.2277E-5,1.3601E-5/
      DATA DM(1),DM(2),DM(3)/0.50549,0.09919,0.05163/
      DATA DM(4),DM(5),DM(6)/0.03078,0.01513,0.00793/
      DATA XG(2),XG(5),XG(10)/2.0309E-01,5.0768E-01,1.01539    /
      DATA XG(25),RHOL/2.53854,55.809    /
   10 FORMAT (1X,1P6E15.4//)
   11 FORMAT (1X,1P6E15.4//)
   40 FORMAT (7I5)
   41 FORMAT (1X,7I5//)
   42 FORMAT ( 6F10.3)
   43 FORMAT (1X,6F10.3//)
  150 FORMAT (1X,1P6E15.4//)
      DO 4 I = 1,6
    4 R(I) = (0.75*DM(I)/(3.14159*453.59*RHOL))**0.333333
      WRITE (6,10) R
      DO 50 J = 1,6
      DO 30 I = 1,4
      N = 9 + I
      XSP(I) = 539.0 + 7.0*SX(I)*(TX(I) - 100.0)/20.0
   30 D(J,I) = (9.0*XTC(I)*(TX(I) - 100.0)*VISC(N)*R(J)*30.48/(8.0*32.17
     1*453.59*XSP(I)*RHOL*RHOG(N)))**0.25*30.48
      WRITE (6,11) (D(J,K), K = 1,4)
   50 AA = 0.0
    1 READ (5,40) NSETS,ITEMP,IDROP,IELEV,ITSTOP,IDIST,IFIT
      WRITE (6,41)NSETS,ITEMP,IDROP,IELEV,ITSTOP,IDIST,IFIT
      READ (5,42) (T(I),I = 1,NSETS)
      WRITE (6,43) (T(I),I = 1,NSETS)
      ZZ = IDIST
      S(1) = 38.0 - 12.0*ZZ
      DO 100 J = 2,NSETS
      I = J - 1
  100 S(J) = S(I) + 24.0
      NPTS = NSETS
      M = 2
      CALL CURFIT (M,NPTS,S,T,A)
C     M = NUMBER OF COEFFICIENTS
C     NPTS = NUMBER OF DATA POINTS
C     S = F(T)
C     A = COEFFICIENTS OF POLYNOMIAL
```

```
BBBB = A(2)/12.0
CD = 8.0*RHOL*XG(IELEV)*R(IDROP)/(3.0*RHOG(ITEMP)*BBBB**2.0)
JJ = ITEMP - 9
RN = BBBB*RHOG(ITEMP)*D(IDROP,JJ)/(VISC(ITEMP)*30.48)
WRITE (6,150) BBBB,CD,RN,D(IDROP,JJ)
GO TO 1
END
```

```
C     CONVECTIVE LEIDENFROST DATA ANALYSIS FOR BENZENE
C     DROP DIMENSION IN CM
C     DENSITY IN LB/FT**3
C     VISCOSITY IN LB/FT-SEC
C     DROP MASS IN GRAMS
C     FORCE ON DROPLET IN LBF/LBM
      DIMENSION TX(10),SX(10),XSP(10),XTC(10),D(10,10)
      DIMENSION RHOG(15),VISC(15),DM(10),R(6)
      DIMENSION XG(30),T(10),S(10),A(10)
      DATA TX(1),TX(2),TX(3),TX(4)/200.0,300.0,400.0,500.0   /
      DATA SX(1),SX(2),SX(3),SX(4)/0.35,0.405,0.42,0.465   /
      DATA XTC(1),XTC(2),XTC(3)/5.0E-05,6.6E-05,9.0E-05    /
      DATA  XTC(4)/1.1E-04    /
      DATA RHOG(10),RHOG(11),RHOG(12)/0.14675,0.13002,0.11676 /
      DATA RHOG(13),VISC(10),VISC(11)/0.10617,6.4200E-6,7.7616E-6 /
      DATA VISC(12),VISC(13)/9.0048E-6,1.0537E-5 /
      DATA DM(1),DM(2),DM(3)/0.17437,0.08588,0.04192 /
      DATA DM(4),DM(5),DM(6)/0.01547,0.00936,0.00323 /
      DATA XG(2),XG(5),XG(10)/2.0266E-01,5.0648E-01,1.01298  /
      DATA XG(25),RHOL/2.5324,51.046          /
   10 FORMAT (1X,1P6E15.4//)
   11 FORMAT (1X,1P6E15.4//)
   40 FORMAT (7I5)
   41 FORMAT (1X,7I5//)
   42 FORMAT ( 6F10.3)
   43 FORMAT (1X,6F10.3//)
  150 FORMAT (1X,1P6E15.4//)
      DO 4 I = 1,6
    4 R(I) = (0.75*DM(I)/(3.14159*453.59*RHOL))**0.333333
      WRITE (6,10) R
      DO 50 J = 1,6
      DO 30 I = 1,4
      N = 9 + I
      XSP(I) = 94.1 + 7.0*SX(I)*(TX(I) - 100.0)/20.0
   30 D(J,I) = (9.0*XTC(I)*(TX(I) - 100.0)*VISC(N)*R(J)*30.48/(8.0*32.17
     1*453.59*XSP(I)*RHOL*RHOG(N)))**0.25*30.48
      WRITE (6,11) (D(J,K), K = 1,4)
   50 AA = 0.0
    1 READ (5,40) NSETS,ITEMP,IDROP,IELEV,ITSTOP,IDIST,IFIT
      WRITE (6,41)NSETS,ITEMP,IDROP,IELEV,ITSTOP,IDIST,IFIT
      READ (5,42) (T(I),I = 1,NSETS)
      WRITE (6,43) (T(I),I = 1,NSETS)
      ZZ = IDIST
      NPTS = NSETS
      IF (IFIT) 5,5,15
   15 T(10) = T(1)
      S(1) = 38.0
      DO 110 J = 2,NSETS
      I = J - 1
      T(I) = T(J)
  110 S(J) = S(I) + 24.0
      NPTS = NSETS - 1
      GO TO 20
    5 S(1) = 14.0
```

```
      DO 112 J = 2,NSETS
      I = J - 1
  112 S(J) = S(I) + 24.0
   20 CONTINUE
      M = 2
      CALL CURFIT (M,NPTS,S,T,A)
C     M = NUMBER OF COEFFICIENTS
C     NPTS = NUMBER OF DATA POINTS
C     S = F(T)
C     A = COEFFICIENTS OF POLYNOMIAL
      BBBB = A(2)/12.0
      CD = 8.0*RHOL*XG(IELEV)*R(IDROP)/(3.0*RHOG(ITEMP)*BBBB**2.0)
      JJ = ITEMP - 9
      RN = BBBB*RHOG(ITEMP)*D(IDROP,JJ)/(VISC(ITEMP)*30.48)
      WRITE (6,150) BBBB,CD,RN,D(IDROP,JJ)
      GO TO 1
      END
```

```
C      CURVE FIT SUBROUTINE FOR DISTANCE-TIME DATA
       SUBROUTINE CURFIT( NOBS, NPTS, YA, XA, X)
       DIMENSION XA(26),YA(26),NC(7),A(7,8),X(7),XL(7,7),T(7,8),PID(12)
       DIMENSION RR(3), RS(3), RT(3)
       DATA        RR(3), RS(3), RT(3)/ 1H , 1H , 6H CALC-/
       DATA RR(1), RR(2),RS(1),RS(2)/6HTIME, ,6HSEC    ,6HDISTAN,6HACE   /
       DATA XPLUS,XTIMES,YPLUS,YTIMES/0.0,1.0,0.0,1.0/
       DATA NC(1),NC(2),NC(3),NC(4),NC(5),NC(6),NC(7)/0,1,2,3,4,5,6/
  165  FORMAT(16H COEFFICIENTS-  ,E15.8, 5H  ** , I2)
  195  FORMAT(30H STANDARD ERROR OF ESTIMATE = ,F10.5////)
  185  FORMAT (3X, 3(3A6, E15.8, 3X),3HDEL, E10.3)
C      Y=F(X)
C      NPTS=NUMBER OF DATA POINTS
C      NOBS=NUMBER OF COEFFICIENTS
C      NC=POWER OF T
C      X = COEFFICIENTS OF POLYNOMIAL
       RT(1)= RS(1)
       RT(2)= RS(2)
       DO 40 I=1,NPTS
       YA(I)= YA(I)*YTIMES+YPLUS
       XA(I)= XA(I)*XTIMES+ XPLUS
   40  CONTINUE
       DO 60 I=1,NOBS
       DO 55 J=I,NOBS
       XB=0.0
       DO 50 K=1,NPTS
       A(J,I)=(XA(K)**NC(I))*(XA(K)**NC(J))+XB
   50  XB=A(J,I)
       IF(J.EQ.I)GO TO 55
   51  A(I,J)=A(J,I)
   55  CONTINUE
   60  CONTINUE
       KEY=NOBS+1
       DO 70 I=1,NOBS
       A(I,KEY)=0.0
       DO 65 J=1,NPTS
   65  A(I,KEY)=A(I,KEY)+YA(J)*XA(J)**NC(I)
   70  CONTINUE
       NVAR=NOBS
       NP=NVAR+1
       DO 75 I=1,NVAR
       T(I,I)=1.0
   75  XL(I,1)=A(I,1)
       DO 80 I=1,NP
   80  T(1,I)=A(1,I)/A(1,1)
       I=1
   85  I=I+1
       DO 95 J=I,NVAR
       XL(J,I)=A(J,I)
       M=I-1
       DO 90 L=1,M
   90  XL(J,I)=XL(J,I)-XL(J,L)*(T(L,I))
   95  CONTINUE
       IM=I+1
```

```
      DO 105 J=IM,NP
      T(I,J)=A(I,J)/XL(I,I)
      N1=I-1
      DO 100 L=1,N1
  100 T(I,J)=T(I,J)-XL(I,L)*(T(L,J))/XL(I,I)
  105 CONTINUE
      IF(NVAR.GT.I)GO TO 85
  110 X(NVAR)=T(NVAR,NP)
      IZZ=NVAR-1
      DO 120 I=1,IZZ
      K=NVAR-I
      X(K)=T(K,NP)
      L=K+1
      DO 120 J=L,NVAR
  120 X(K)=X(K)-X(J)*T(K,J)
  155 DO 160 I=1,NOBS
  160 WRITE(6,165)X(I)   , NC(I)
  170 DELII=0.0
      BA=0.0
      DO 190 I=1,NPTS
      BB=0.0
      YCALC=0.0
      DO 175 J=1,NOBS
      BB=BB+1.0
  175 YCALC=X(J)*XA(I)**NC(J)+YCALC
      DEL=YA(I)-YCALC
      DELI=DEL**2
      DELII=DELII+DELI
      BA=BA+1.0
  180 WRITE (6, 185) RR, XA(I), RS, YA(I), RT, YCALC,DEL
  190 CONTINUE
      ERROR = (DELII/(BA - 1.0))**0.5
      WRITE(6,195)ERROR
      RETURN
      END
```

PROGRAM NOMENCLATURE

IDIST	Denotes distances deviating from normal distance increments
IDROP	Indicates size of droplet considered
IELEV	Tube inclination considered
IFIT	Denotes points to be used in curve fit
ITEMP	Surface temperature considered
ITSTOP	Odd temperature
M	Number of coefficients in polynomial
NPTS	Number of points to be curve fitted
NSETS	Number of experimental points on distance-time curve
A	Coefficients of polynomial
CD	Drag coefficient
C	Effective thickness of supporting vapor film, cm
DM	Droplet mass, gm
R	Droplet radius, cm
RHOG	Density of vapor, lb/ft^3
RHOL	Density of liquid, lb/ft^3
RN	Reynolds number
S	Distance of droplet travel, in
SX	Heat capacity of vapor, cal/gm
T	Time of droplet travel, sec
TX	Surface temperature, °C
VISC	Viscosity of vapor, lb/ft-sec

XG	Force on droplet, ft/sec^2
ESP	Heat transferred to droplet, cal/gm
XTC	Thermal conductivity of vapor, cal/cm-sec-°C.

VITA

LESLIE GERALD RESTER

Candidate for the Degree of

Master of Science

Thesis: A STUDY OF THE CONVECTIVE LEIDENFROST PHENOMENON

Major Field: Chemical Engineering

Biographical:

Personal Data: Born in Poplarville, Mississippi, February 16, 1945, the son of Heber S. and Maris Rogers Rester.

Education: Attended elementary and high school in Poplarville, Mississippi; graduated from Poplarville High School in 1962; attended Pearl River Junior College for one year and then transferred to Mississippi State University in September, 1963; received a Bachelor of Science degree in Chemical Engineering in May, 1966; completed requirements for Master of Science degree at Oklahoma State University in May, 1968. Membership in scholarly or professional societies includes Phi Theta Kappa, Omega Chi Epsilon, American Institute of Chemical Engineers, and National Society of Professional Engineers.

Professional Experience: Summer employment in Technical Service, Masonite Corporation, Laurel, Mississippi, in 1964; summer of 1965, employed as Engineering Trainee, Offshore District Office, Production Department of Humble Oil and Refining Company at Grande Isle, Louisiana; spring of 1966, part-time Production Technician with American Potash and Chemical Company, Hamilton, Mississippi; summer of 1966, employed in Process Division of Central Engineering, Phillips Petroleum Company, Bartlesville, Oklahoma. Presently employed by Enjay Chemical Company, Baton Rouge, Louisiana.