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Correlation of Curtis and Gullett equation for viscosity of non-Newtonian suspensions and Franks and Rinaldi equation for heat transfer coefficients

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CORRELATION OF CURTIS AND GULLETT EQUATION FOR VISCOSITY OF NON-NEWTONIAN SUSPENSIONS AND FRANKS AND RINALDI EQUATION FOR HEAT TRANSFER COEFFICIENTS.

A THESIS

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ABSTRACT

Curtis and Gullett (7) developed an equation correlating the effect of velocity, concentration and particle size on apparent viscosity of non-Newtonian water slurries.

$$\frac{\mu}{\mu_w} = 1.02\left(AK/GC\right)^{.105}$$

The object of this paper was to determine the validity of using the viscosity, as determined by the Curtis-Gullett (7) equation, in predicting the heat transfer coefficient of non-Newtonian fluids, where the suspending medium is something other than pure water. The authors used various concentrations of sugar solutions as the dispersion medium, for the slurries.

A dimensionless equation resembling the Dittus-Boelter equation with modified exponents and additional dimensionless groups has been developed by J.J. Salamone (14):

$$\frac{hD}{K_f} = .131\left(\frac{DV_b\rho_b}{\mu_b}\right)^{.62}\left(\frac{C_s}{C_f}\right)^{.35}\left(\frac{C_f\mu_b}{K_f}\right)^{.72}\left(\frac{D}{D_s}\right)^{.05}\left(\frac{K_s}{K_f}\right)^{.05}$$

Franks and Rinaldi (8) found the magnitude of the exponents to be as follows:

$$\frac{hD}{K_f} = .0138\left(\frac{DV_b\rho_b}{\mu_b}\right)^{.8}\left(\frac{C_s}{C_f}\right)^{.42}\left(\frac{C_f\mu_b}{K_f}\right)^{.79}\left(\frac{D}{D_s}\right)^{.106}\left(\frac{K_s}{K_f}\right)^{.05}$$

Experimentally determined heat transfer coefficients deviated from the values calculated by the Franks and Rinaldi (8) equation by 16%.

This is what was expected, since the Curtis and Gullett (7) equation is accurate to 14.4%, the authors of this paper feel this equation may be used to obtain the viscosity of a slurry in predicting the magnitude of the heat transfer coefficient.

The authors feel that a sufficient amount of experimental data has been obtained in determining the validity of the Franks and Rinaldi(8) equation for predicting heat transfer coefficients of non-newtonian fluids, but additional work of a statistical nature is recommended in re-evaluating the exponents of the Franks and Rinaldi(8) equation in the light of all available data. Closer agreement between experimental and calculated values for heat transfer coefficients would result.

INTRODUCTION

The purpose of this investigation was to undertake an experimental study in evaluating the validity of using the viscosity, as determined by the Curtis and Gullett (7) equation for slurries, in predicting the heat transfer coefficient of non-Newtonian fluids, where the suspending media is something other than water.

The Curtis and Gullett (7) equation is an expression of the apparent viscosity of non-Newtonian suspensions in terms of variables concerning the characteristics of the suspended solid and the suspension itself.

Presently, workers in the field of design of heat transfer equipment using suspensions must empirically determine apparent viscosity for the specific material involved. These empirical determinations require pilot plant equipment usually utilizing pipe-line viscometer and the measurement of the pressure drop in the line in order to calculate a viscosity value. It is of considerable practical value to be able to express apparent viscosity in terms of readily known characteristics of a suspension.

The Curtis and Gullett (7) equation is an equation which was developed, using data for water slurries.

This paper attempts to establish the applicability of this equation for suspensions using various concentrations of sugar solutions as the dispersion media.

The apparent viscosity thus obtained, was then employed in the Franks and Rinaldi (8) equation to calculate the heat transfer coefficient.

These results were then compared with experimently determined values for heat transfer coefficients and the extent of deviation was found to be 16%.

The authors investigated the turbulent range of Reynolds numbers, 50,000 to 200,000.

THEORY

In developing the empirical relationship of Nusselt number, Reynolds number, Prandtl number, and the groups relating the physical properties of the individual components of the slurry, it was assumed that the film coefficient was a function of the following:

D = Pipe Diameter

X = Weight Fraction

K = Thermal conductivity of the dispersion

K_f = Medium

D_s = Average particle diameter

C_s = Specific heat of particle

C_f = Specific heat of dispersion medium

ρ = Density of solid

ρ = Density of dispersion medium

u_b = Apparent bulk viscosity of the suspension

V = Velocity, based on bulk density

Weight fraction, density of the solid and dispersion medium may be represented in the form of a bulk density. Then assuming spherical shaped particles, and the equation to be of an exponential type, the following expression may be written:

$$h = Z(D^a, V_B^b, \rho_B^e, \mu_B^f, K_f^g, C_f^i, C_s^j, D_s^r, K_s^n)$$

Previous investigators have shown by dimensional analysis and experimental data, the following equation as an expression of the above variables:

$$\frac{hD}{K_f} = .0138\left(\frac{DV_b\rho_b}{\mu_b}\right)^{.8}\left(\frac{C_f\mu_b}{K_f}\right)^{.79}\left(\frac{D}{D_s}\right)^{.106}\left(\frac{C_s}{C_f}\right)^{.42}\left(\frac{K_s}{K_f}\right)^{.05}$$

As may be seen from the above equation, the specific heat of the solid and of the fluid, along with the effect of the Reynolds number are of major importance. The group $(D/D_s)^{.106}$ becomes significant when very small particles are used as the suspended solid.

The bulk viscosity of the suspension was evaluated by an equation developed by Curtis and Gullett (7) for non-Newtonian suspensions

$$\frac{\mu}{\mu_w} = 1.02\left(\frac{AK}{GC}\right)^{.105}$$

Where A = surface area of particles, sq. ft./cu. ft. of suspension.

K = Thermal conductivity of suspended solid.

G = Mess velocity, Lbs./sec.-ft.^{2}

C = Specific heat of fluid BTU/(Lb.)(^{o}F).

It has been found that liquids generally are Newtonian or non-Newtonian. For Newtonian fluids, the ratio between shearing stress and rate of shearing strain is the same for all rates of shearing strain.

Where discrete particles of solid material are dispersed in a liquid, the viscosity of the continous phase is critically affected in that the viscosity is non-Newtonian and is considered an apparent viscosity of the mixture. The size and shape of the particles are of importance in heat transfer equipment because the effectiveness of heat transfer within a suspension will assume greater proportions as the surface area increases due to decrease of particle diameter.

The equation developed by Curtis and Gullett correlates the effect of velocity, concentration and particle size on apparent viscosity of non-Newtonian water slurries. This equation was found to be accurate to 14.4%.

In industrial operations slurries are often encountered where the dispersion medium is not water, but, a fluid with greater viscosity. The specific heat and viscosity of the more common liquids have been determined and data is available.

If the density of the slurry is known, the weight fraction of solids may be obtained from a previously prepared graph of density versus weight % solids. The volume fraction solids in slurry and surface area of particles may then be calculated as follows:

$$\text{Volume Fraction } \phi = \frac{\text{(Weight \% Solids)(Slurry Density)}}{\text{Solid Particle Density}}$$

Surface area of particles = A

$$\text{Volume per solid particles} = \frac{D^3}{6} \text{ ft}^3$$

$$N = \frac{\text{Number of solid particles}}{\text{ft}^3 \text{ slurry}} = \frac{6\phi}{D^3}$$

$$A = \text{Surface of solid particles} = \frac{6\phi}{D}$$

In this investigation, the viscosities calculated by the Curtis-Gullett equation, were found to be essentially constant from a Reynolds number of 40,000 to 200,000.

The magnitude of the viscosity for the suspension was always greater than for the dispersion medium.

REVIEW OF PERTINENT WORK

A relatively meager amount of data on heat transfer to suspensions can be found in the literature. Previous investigators have dealt with water slurries, with little reference to slurries with other suspending media.

Film coefficient heat transfer characteristics of chalk-water slurries were obtained by Bonilla et al (4). The data was obtained for concentrations up to 21%. Correlation with the Dittus-Boelter equation showed a deviation within 10%.

Orr and Dallavalle (12) investigated various suspensions of powdered solids in ethylene glycol. The data correlated fairly well using the Dittus-Boelter equation as modified by Sieder and Tate (15).

Film coefficients of heat transfer for fluids containing no solids but of the non-Newtonian classification were correlated by Chu et al (6) using a viscosity correction factor added to the Nusselt and Prandtl number relation.

J.J. Salamone (14) investigated a variety of particles suspended in water. A new equation was derived by dimensional analysis and experimental data used to calculate the constant and exponents of the dimensionless ratios representing individual properties of the components of the suspension. Viscosity, velocity, and density were measured as bulk properties at the conditions of heat transfer.

Binder and Pollara (3) constructed similar equipment as used by J.J. Salamone with added improvements. The lower turbulent region of Reynolds number 10,000 to 70,000 was investigated in order to obtain better accuracy in the constant and the exponents of the dimensionless groups.

Franks and Rinaldi (7) checked the magnitude of the constant and exponents of Salamone's equation. The data was obtained at the values of Reynolds number from 50,000 to 200,000. Viscosities were determined by a pipe-line viscosimeter.

Previous investigators of non-Newtonian fluids have determined apparent viscosity from pipe-line viscometers using pressure drop data.

Bonilla (4) found a correlation between the viscosity of the slurry and water using the Hatschek equation:

$$u_b = u_w (1-\phi)^{0.33}$$

where u_b and u_w are the viscosities of the slurry and water respectively and ϕ is the volume fraction of the solid in suspensions.

Orr and Dalla Valle (12) found the viscosity determinations with a saybolt type viscosimeter gave results with agued closely with viscosity calculated from the equation:

$$u_b = u_w \left(1^{-\phi} - \phi^1\right)^{1.8}$$

The terms u_b, u_w, and ϕ are as described above and ϕ^1 is the fraction of the solid in a sedimented bed.

Curtis and Gullet (7), through the use of dimensional and graphical analysis, developed an equation, $u/u_w = 1.02\ (AK/GC)^{.105}$, which correlated the effect of velocity, concentration and particle size on apparent viscosity of non-Newtonian slurries. The calculated viscosity was compared with experimental values. The average deviation was found to be 14.4%.

Krieger and Elrod suggested (21) a method for obtaining the shearing stress-velocity gradient curves for non-Newtonian liquids from a rotating cylinder instrument.

Since sugar solution suspensions of solid powders such as chalk, behave as pseudo plastic non-Newtonian fluids, the apparent viscosity decreases with increasing rate of flow.

Data on heat transfer to fluidized systems indicated a substantial increase in the film coefficient of heat transfer for the gas-solid system compared to that of the gas alone(14). Recent investigators (14), (8), have found that the presence of a suspended solid increases the film coefficient of heat transfer of a liquid flowing inside a pipe.

The authors of this paper have found that the film coefficient of heat transfer for sugar solution slurries increases with increase in suspended solids.

DESCRIPTION OF APPARATUS

A schematic diagram of the apparatus which is similiar to that constructed by Bonilla (4) and Salamone (14) and assembled by Franks and Rinaldi (8) was used in obtaining the data for this investigation as shown in figure 3.

The slurry was prepared and stored in a 55 gallon drum provided with a "Lightning" motor-driven agitator. An Allis-Chalmers pump of adequate capacity transported the slurry from the storage tank, through a by-pass, and then through the system back to the tank.

All lines in contact with the slurry were 85-15 brass.

The heat transfer section contained a ½ inch wrought iron pipe which in turn was surrounded by a 2½ inch wrought iron pipe. Steam was circulated through the annular space between the ½ inch wrought iron pipe and the 2½ inch wrought iron pipe. The 2½ inch iron pipe serving as a guard heater.

Heating of the slurry was accomplished in the ½ inch pipe by steam flowing in the inner annulus counter-current to experimental solution over a length of 8 ft. Provision was made for collecting and weighing the condensate obtained from the inner annulus. The 12 ft. length of the inner ½ inch pipe provided for a calming

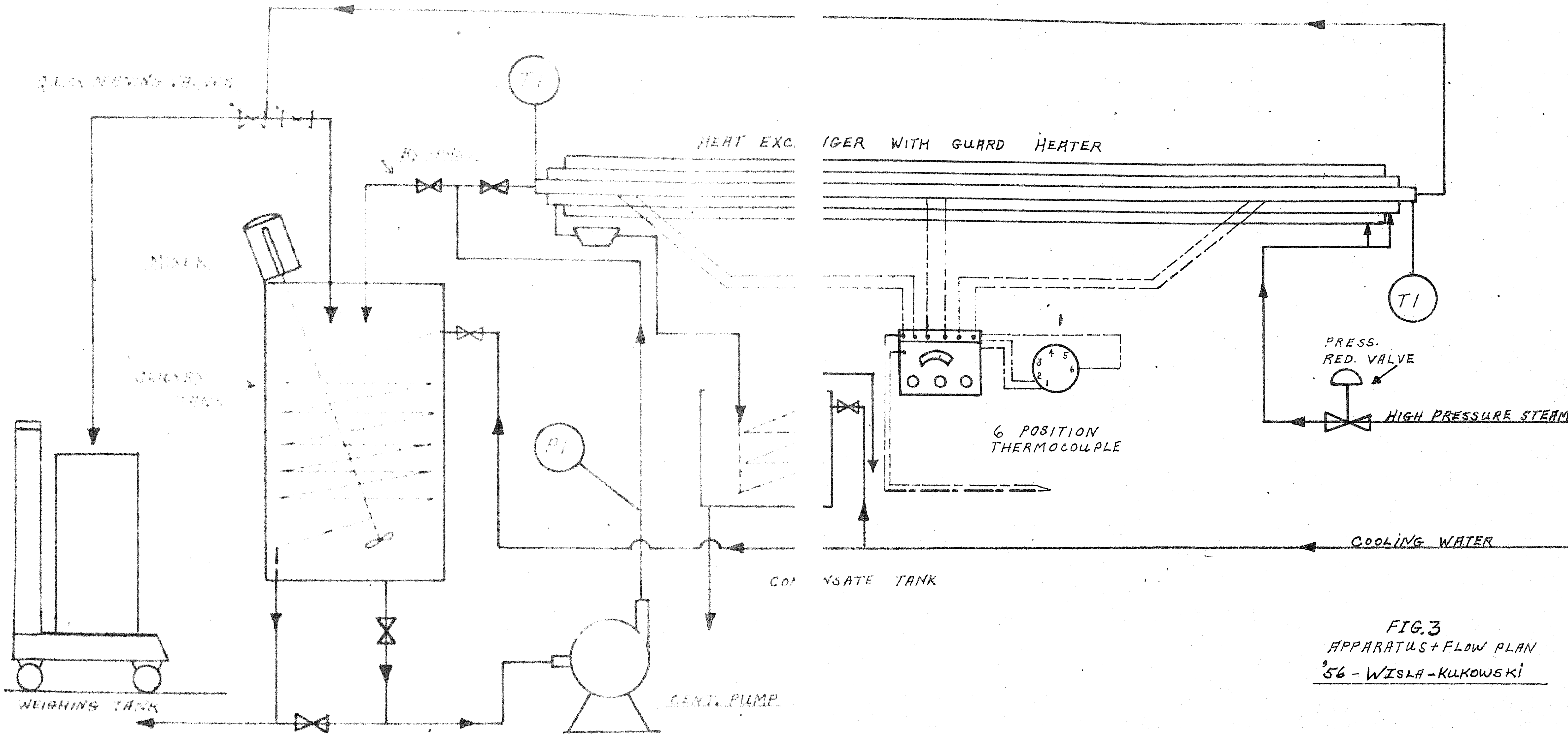

FIG. 3
APPARATUS + FLOW PLAN
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section of approximately 2 ft. at each end. Each end was connected to a 1 inch tee containing a thermometer well in which oil was used as a heat transfer medium. The thermometers were used to measure the inlet and outlet temperature of the slurry.

Six thermo-couples in the ½ inch brass pipe measured the inner wall temperature.

The heating section was completely insulated with 85% magnesia pipe insulation and aluminum foil. The cooler was a double pipe type heat exchanger consisting of 1 inch brass I.P.S. pipe inside a 2 inch standard iron pipe. Cold water was circulated counter-currently to the slurry through the annular space.

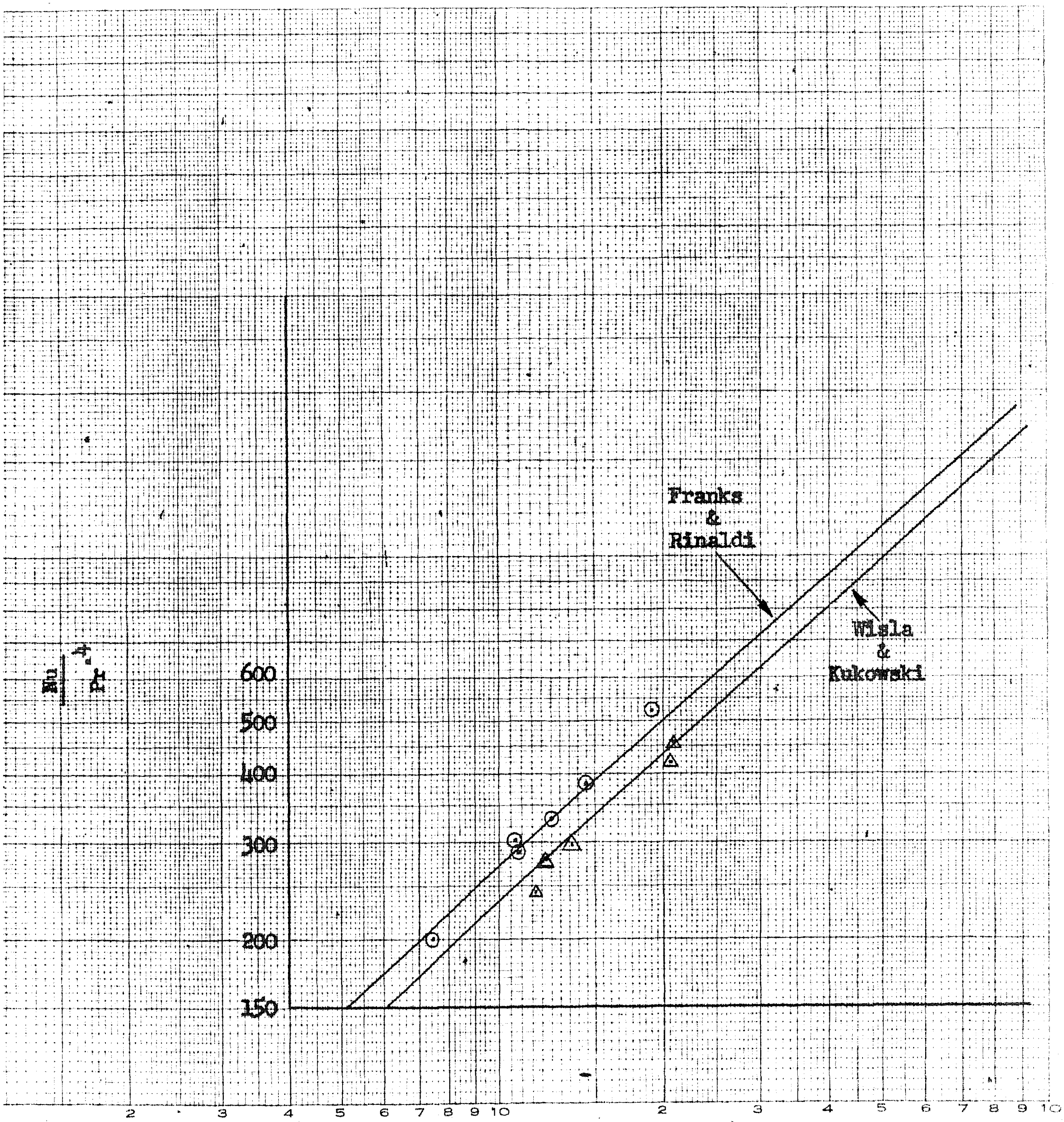
The pipe returning to the slurry tank was provided with a set of quick opening valves to conveniently allow diverting the slurry into a weighing tank for flow rate measurements. A cooling coil in the slurry tank maintained isothermal conditions in the tank.

The solids used for the slurries are described in table 1.

TABLE 1

PHYSICAL PROPERTIES OF MATERIALS AND SUPPLIERS

MATERIAL	SUPPLIER	DENSITY @20°C	SPEC. HEAT @20°C	THERM. CONDUCTIVITY	AVER. PARTICLE SIZE
		gm/cc	BTU/LB-°F	BTU / HR-°F-FT	Microns
ATOMITE	Thompson, Weinman & Co., Montclair, N.J.	2.71 (Company)	0.209 (Perry)	0.40 (Perry)	2.5 (Company)
SNOWFLAKE WHITE	Thompson, Weinman & Co., Montclair, N.J.	2.71 (Company)	0.209 (Perry)	0.40 (Perry)	6.0 (Company)
DURAMITE	Thompson, Weinman & Co., Montclair, N.J.	2.71 (Company)	0.209 (Perry)	0.40 (Perry)	14.0 (Company)
SUGAR	H. KARLIN, Newark, N.J.				



Reynolds no. - Scale reading x 10^4

Fig. 1

Heat transfer data for H_2O

EXPERIMENTAL PROCEDURE

The fifty gallon drum was filled with approximately two hundred pounds of water.

Valves on the discharge of the pump were closed and power to the pump turned on. The valve on the recirculating line was then opened to the desired position.

Steam was admitted to the system through a hand valve and constant pressure valve. All cooling water valves were opened; these included, cooling water for the fifty gallon drum and the condensate from the steam trap.

When the temperature of the water flowing in and out of the heat section, was constant, readings were taken of the thermocouples, inlet and outlet water temperature, water rate in pounds collected per interval of time and the condensate rate. Average time allowed for equilibrium was approximately thirty minutes.

From the observed heat transfer data a plot of $Nu/Pr^{.4}$ versus Reynolds number was constructed to determine whether excessive oxidation of the walls of the exchanger had taken place. See figure (1).

After completing the test runs with water, the drum was then emptied and the water replaced by a sugar solution of desired concentration containing a known weight of solids. The agitator was then set in motion. The equipment was allowed to come to equilibrium as was evidenced by the constant temperature readings of the slurry at the inlet and outlet of the slurry heat exchanger.

The readings observed and recorded were the following:

1. Thermocouple readings in millivolts, a total of six readings averaged; the average millivolt reading was converted to degrees F. and corrected to indicate the film coefficient temperature.

2. The water temperature inlet and outlet from the heat section.

3. Steam pressure.

4. Steam rate as determined by weighing condensate collected over a measured period of time.

5. Slurry flow rate as determined by weighing a sample over a measured period of time. The method used to collect the slurry was by diverting the flow with quick opening valves having alleged similar pressure drop characteristics.

6. Density of the suspension was obtained by weighing in a calibrated volumetric flask.

The density obtained in step (6) above was used to determine the weight fraction of the solid in the slurry from previously constructed density versus weight fraction

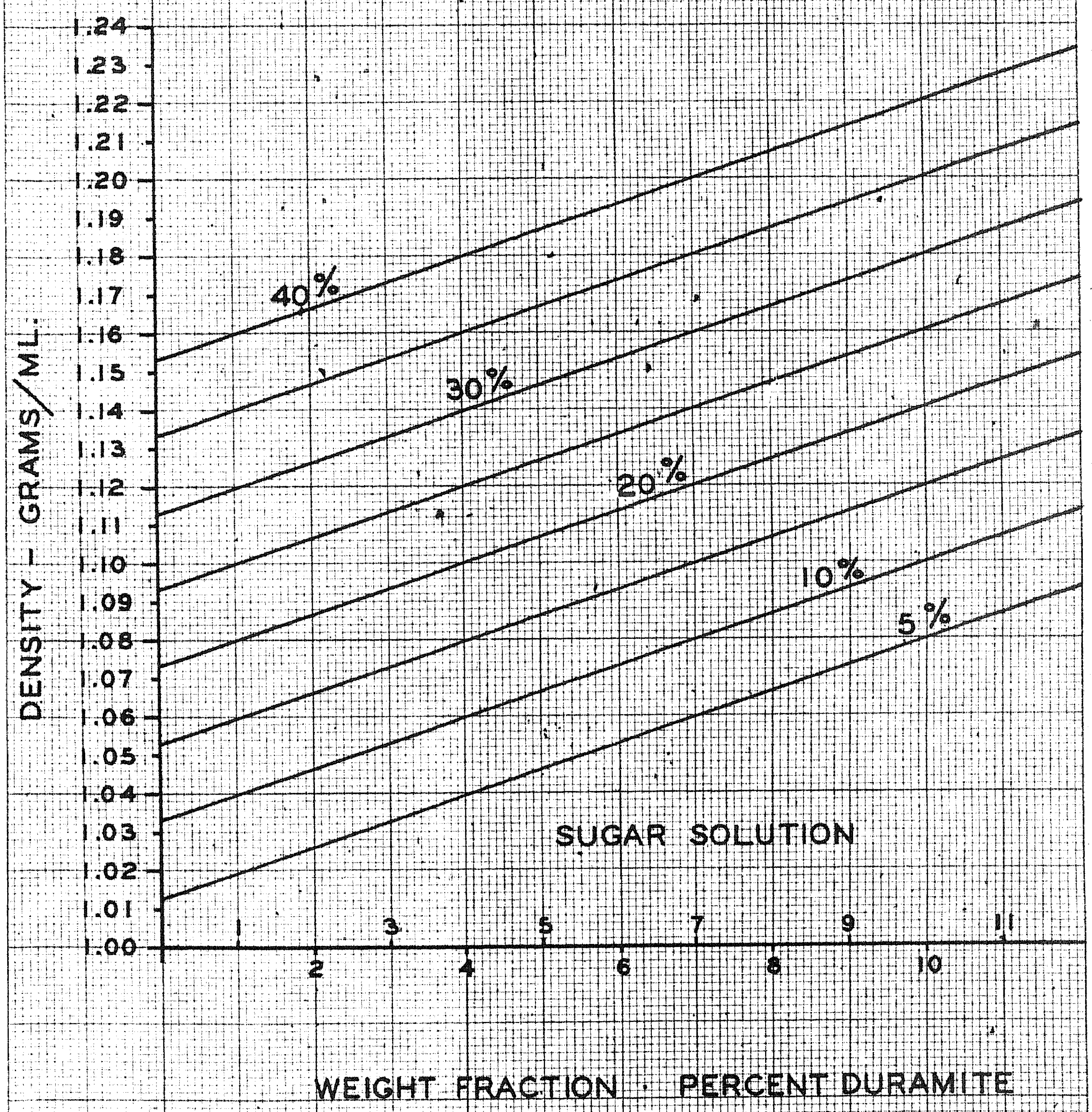

1.24
1.23
1.22
1.21
1.20
1.19
1.18
1.17
1.16
1.15
1.14
1.13
1.12
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
DENSITY - GRAMS/ML.
40%
30%
20%
10%
5%
SUGAR SOLUTION
1
2
3
4
5
6
7
8
9
10
11
WEIGHT FRACTION PERCENT DURAMITE

FIG. 2

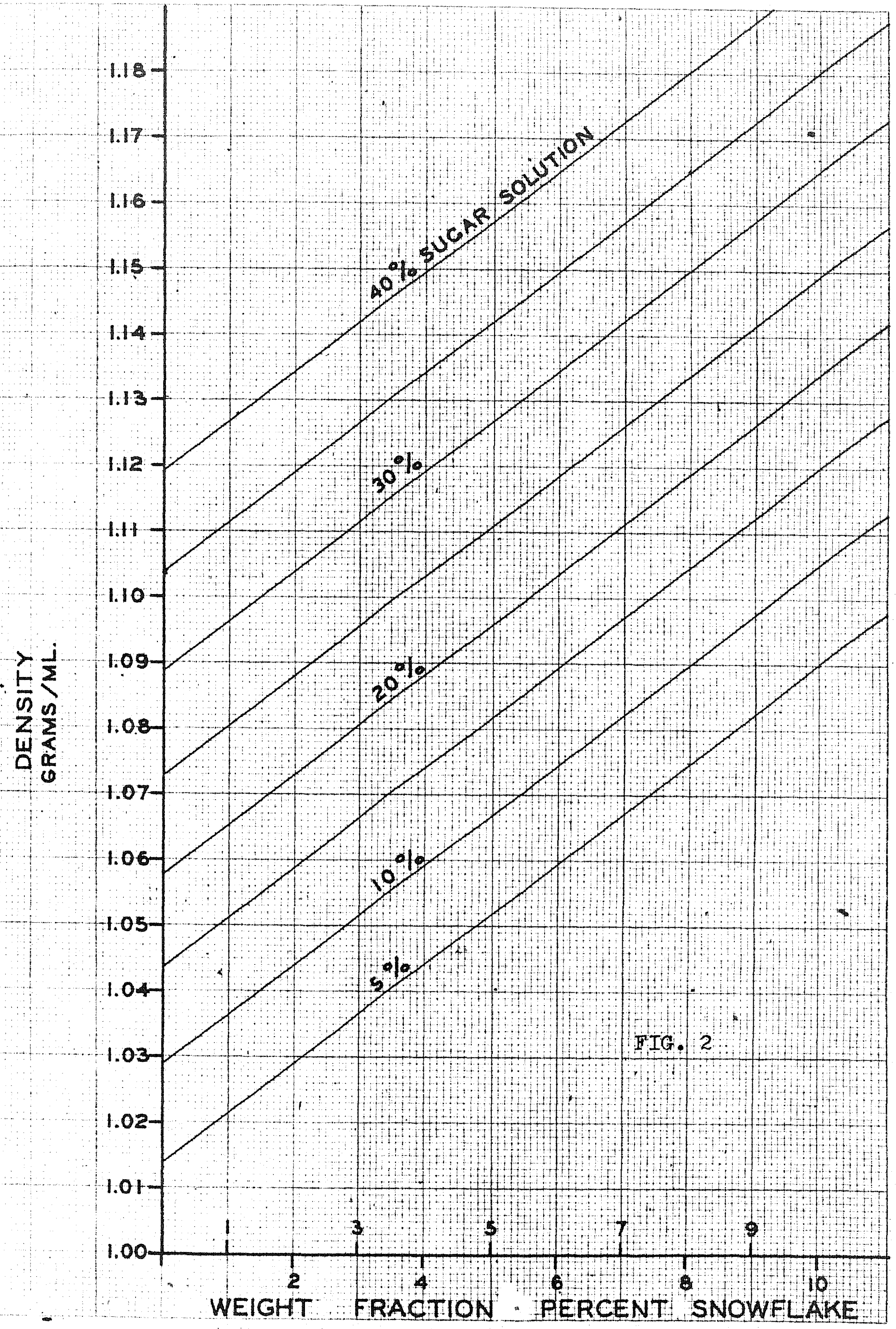
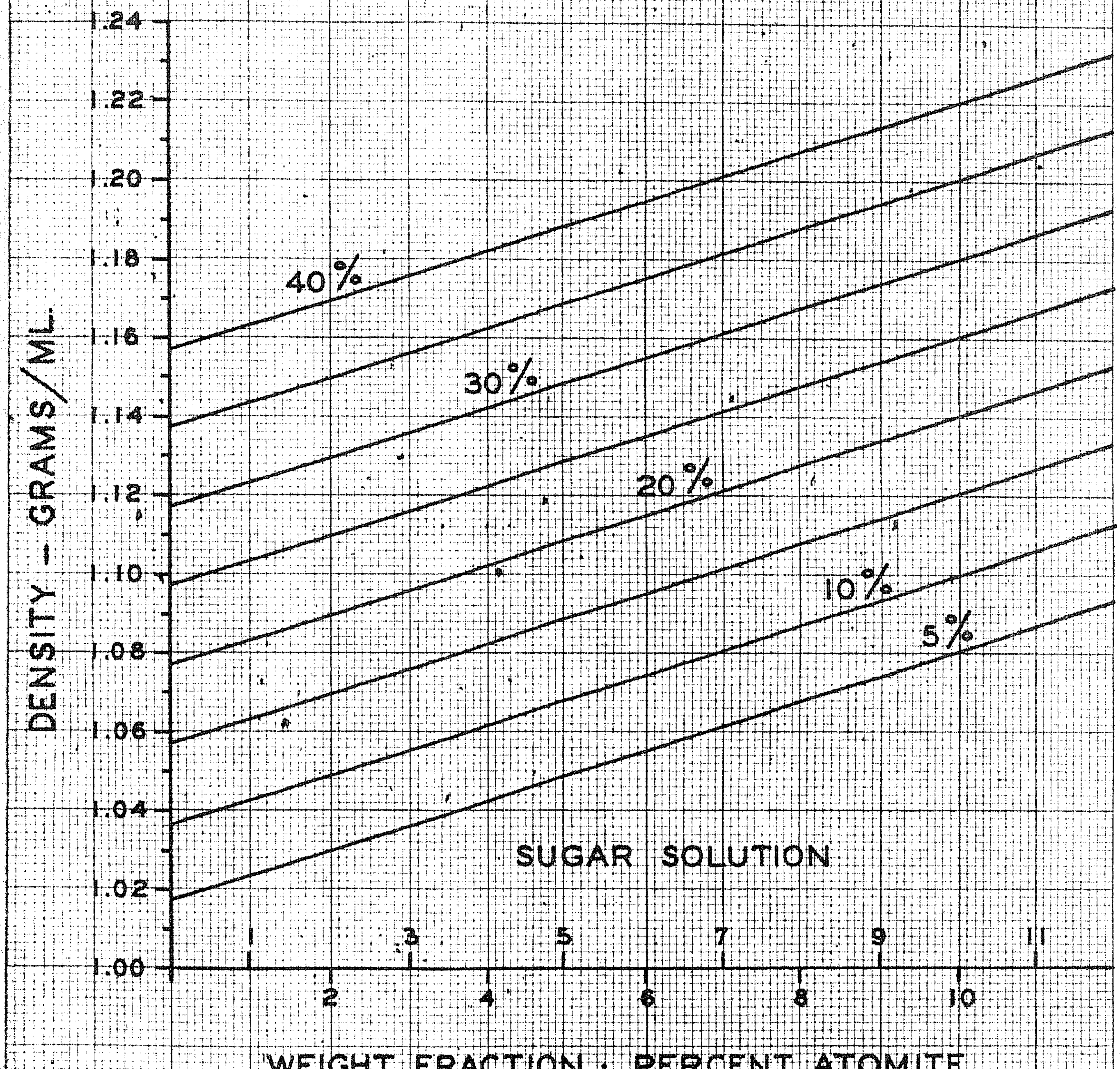

40% SUGAR SOLUTION
30%
20%
10%
5%
DENSITY GRAMS/ML.
1.00
1.01
1.02
1.03
1.04
1.05
1.06
1.07
1.08
1.09
1.10
1.11
1.12
1.13
1.14
1.15
1.16
1.17
1.18
1
2
3
4
5
6
7
8
9
10
WEIGHT FRACTION · PERCENT SNOWFLAKE

FIG. 2



1.24
1.22
1.20
1.18
1.16
1.14
1.12
1.10
1.08
1.06
1.04
1.02
1.00
DENSITY - GRAMS/ML.
40%
30%
20%
10%
5%
SUGAR SOLUTION
1
3
5
7
9
11
2
4
6
8
10
WEIGHT FRACTION - PERCENT ATOMITE

FIG. 2

curves, Fig. 2.

The weight fraction data was obtained as follows: A flask whose weight and volume were known was filled with water and weighed. After the water had been emptied from the flask, the weight of the various sugar solutions were similarly obtained. A small quanity of dry solids was introduced into the flask and weighed. The flask containing the weighed sample of solids was then filled with the desired sugar solution to the known volume mark and weighed again. By subtracting the weight of the flask from all of the observed weight readings, the density of the solid plus sugar solution was obtained when divided by the weight of the sugar solution having the same volume. Thus, the density of the solid plus liquid was known; the weight fraction was equal to the known weight of solid added, divided by the weight of sugar solution plus solid.

TABLE NO. II

THERMAL CONDUCTIVITY OF SUGAR SOLUTIONS*

KILO-CALORIE/(°C)(HR.)(METER)

TEMP.	0°	10°	20°	30°	40°	50°	60°	70°	80°
0%	0.486	0.501	0.515	0.528	0.540	0.551	0.561	0.570	0.578
10%	0.460	474	487	500	511	522	531	540	547
20%	0.434	447	460	471	482	492	501	509	516
30%	0.407	420	431	442	452	461	470	477	484
40%	0.381	393	404	413	423	432	440	446	452
50%	0.355	366	376	386	394	402	410	416	422
60%	0.329	339	348	357	360	373	379	386	391

CONVERSION FACTOR FOR UNITS:

$$\frac{\text{KILO-CALORIES}}{(^\circ\text{C})(\text{HR.})(\text{METERS})} = \frac{3.968}{(1.8)(3.281)} = \frac{\text{BTU}}{(^\circ\text{F})(\text{HR.})(\text{FT.})}$$

* CHEMIE ING. TECH., Vol. 21, 1949, p.340-341

TABLE NO. 3

OBSERVED AND CALCULATED DATA FOR WATER

RUN NO.	WATER TIME (SEC.)	WEIGHT WATER COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	WATER TEMP. °F IN	OUT	STEA	LET RESSURE SIG)	COND'S'TE TEMP. °C	COND'S'TE TIME (SEC.)	WATER HEAT $\frac{BTU}{HR.} \times 10^3$	$\frac{Nu}{Pr^{.4}}$	EXP. FILM COEFF. BTU/HR.-FT.^{2}-°F
1	61.0	76.0	3.42	3.25	3.35	4.35	4.59	4.52	117.0	157.0		1	38.0	240	179.6	243	2810
2	45.0	92.5	3.74	3.54	3.56	4.33	4.56	4.49	156.8	178.0		7	35.0	165	163.0	422	5060
3	33.0	53.5	3.48	3.33	3.36	4.06	4.28	4.23	157.0	182.8		8	33.0	192	150.5	670	8060
4	32.0	41.0	3.30	3.17	3.19	3.87	4.12	4.06	168.0	177.7		3	30.0	172	100.0	300	2200
5	30.0	68.5	3.69	3.52	3.48	4.32	4.50	4.43	180.6	202.0		.5	33.0	137	176.1	591	5870
6	30.0	56.0	4.35	4.18	4.17	5.00	5.22	5.16	174.2	200.0		4	33.0	44	173.0	461	4620
7	28.0	55.5	3.62	3.62	3.64	4.44	4.66	4.55	168.6	190.0		5	37.0	259	153.0	474	2640
8	26.0	57.0	3.46	3.28	3.32	4.06	4.24	4.21	157.4	177.7		0	32.0	120	176.0	280	4800

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	STEAM	ET ESSURE IG)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 7%																	
1	42.0	50.0	3.83	3.75	3.90	4.50	4.60	4.60	68.6	87.2			22	3 - 15	90	35.0	10 - 7
2	54.0	75.0	3.85	3.75	3.91	4.50	4.60	4.60	71.0	87.3			22	4 - 0	90	35.0	10 - 7
3	42.0	79.5	4.05	3.90	4.10	4.68	4.80	4.80	77.7	91.8			24	4 - 9	90	35.0	10 - 7
4	31.8	76.5	3.85	3.70	3.85	4.51	4.55	4.55	78.4	90.7			25	6 - 9	120	35.0	10 - 7
5	32.0	77.0	4.04	3.92	4.05	4.72	4.88	4.84	80.4	92.9			27	7 - 3	120	35.0	10 - 1
6	35.5	77.0	4.03	3.94	4.05	4.72	4.79	4.80	78.2	91.2			25	6 - 9	120	35.0	10 - 1
7	41.0	76.5	4.09	3.94	4.13	4.78	4.85	4.85	76.6	91.5		5	24	7 - 15	150	35.0	10 - 1
8	53.0	77.0	3.94	3.80	4.00	4.60	4.74	4.74	74.8	92.4			23	4 - 11	90	35.0	10 - 2
9	78.0	75.5	3.93	3.80	4.01	4.52	4.62	4.62	66.8	68.5			20	3 - 10	90	35.0	10 - 1
10	32.4	77.0	4.00	3.85	4.05	4.72	4.85	4.85	79.5	93.3			32	5 - 3	90	35.0	10 - 2
11	37.8	77.0	3.89	3.73	3.98	4.60	4.70	4.70	77.0	91.2			29	5 - 0	90	35.0	10 - 2
12	46.8	76.0	4.02	3.90	4.15	4.75	4.88	4.85	74.4	92.0			28	4 - 14	90	35.0	10 - 3
13	63.0	76.5	3.91	3.75	4.03	4.56	4.64	4.61	67.3	87.0		8	25	2 - 9	60	35.0	10 - 4
14	23.0	52.5	3.76	3.62	3.84	4.49	4.62	4.58	72.3	85.2			30	3 - 5	61	35.0	9 - 10
15	26.0	51.5	3.80	3.65	3.88	4.56	4.64	4.58	71.4	85.5			29	3 - 4	60	35.0	9 - 10
16	32.0	51.75	3.97	3.83	4.10	4.80	4.91	4.91	73.6	90.9			26	3 - 4	60	35.0	9- 10
17	41.0	55.0	4.00	3.84	4.15	4.77	4.91	4.91	71.3	91.0			24	4 - 1	80	35.0	9 - 10
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 7%																	
18	118.0	40.5	3.89	3.74	3.93	4.65	4.80	4.77	57.2	83.8			32	7 - 0	159	35.0	9 - 12
19	45.0	56.0	3.68	3.56	3.68	4.38	4.52	4.46	61.3	80.9			32	5 - 8	123	35.0	9 - 12
20	37.0	53.0	3.74	3.61	3.67	4.48	4.58	4.54	66.8	83.0			33	8 - 0	159	35.0	9 - 11
21	33.0	61.0	3.91	3.74	3.80	4.67	4.85	4.80	71.0	86.5			34	6 - 13	120	35.0	9 - 11
22	31.0	69.5	3.91	3.73	3.85	4.65	4.83	4.82	72.5	86.7			35	13 - 11	235	35.0	9 - 11
23	32.0	76.0	3.90	3.75	3.84	4.63	4.81	4.76	73.8	86.0			36	7 - 10	128	35.0	9 - 11
24	85.0	48.75	3.70	3.62	3.87	4.42	4.63	4.51	56.8	81.6			30	3 - 14	92	35.0	9 - 14
25	75.0	75.0	3.52	3.38	3.64	4.26	4.37	4.37	59.0	81.6			30	3 - 15	88	35.0	9 - 14
26	52.0	118.5	3.97	3.80	3.93	4.78	4.90	4.89	73.9	88.9			37	6 - 0	90	35.0	9 - 15
27	66.0	73.0	3.73	3.64	3.86	4.40	4.50	4.50	66.0	86.7			25	4 - 5	100	35.0	10 - 1
28	35.0	72.0	3.80	3.61	3.85	4.45	4.55	4.55	76.6	90.9			29	6 - 6	110	35.0	10 - 1
29	31.0	74.0	3.80	3.64	3.80	4.47	4.61	4.59	78.3	91.4			30	6 - 2	100	35.0	10 - 2
30	61.0	72.5	3.70	3.59	3.87	4.36	4.50	4.50	67.3	87.9			25	5 - 11	120	35.0	10 - 5
31	37.5	73.0	4.15	4.05	4.16	4.85	4.95	4.95	78.3	93.6			26	6 - 3	110	35.0	10 - 5
32	32.0	77.5	3.95	3.80	4.00	4.67	4.78	4.78	80.3	93.7			28	6 - 0	100	35.0	10 - 7

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	STEA	ET RESSURE SIG)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 5%																	
33	21.0	51.0	4.05	4.05	4.15	4.80	4.83	4.83	81.7	93.5		)	22	5 - 9	123	35.0	10 - 0
34	32.8	52.0	4.05	4.03	4.20	4.82	4.87	4.87	75.6	91.9		3	24	7 - 7	145	35.0	10 - 0
35	35.5	51.0	4.06	4.00	4.25	4.85	4.88	4.87	74.2	91.9		4	26	3 - 8	85	35.0	10 - 1/2
36	27.3	52.0	4.05	4.00	4.16	4.80	4.85	4.85	77.5	92.5		)	27	2 - 13	75	35.0	10 - 1/2
37	23.5	51.5	4.10	4.07	4.21	4.85	4.89	4.88	80.0	93.5		3	28	4 - 11	100	35.0	10 - 1/2

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	INLET S M PRESSURE (PSIG)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%																
38	62.0	51.0	3.88	3.88	4.14	4.62	4.70	4.70	59.4	86.4	7.8	23.0	3 - 9	80	35.0	10 - 4
39	39.0	51.0	3.85	3.85	4.08	4.67	4.76	4.76	64.2	85.7	8.7	25.0	6 - 2	120	35.0	10 - 4
40	32.0	53.0	4.06	4.15	4.33	5.02	5.12	5.05	68.7	88.5	13.0	28.0	10 - 6	184	35.0	10 - 5
41	30.0	54.0	4.09	4.11	4.30	4.97	5.07	5.05	71.3	90.2	13.5	25.0	5 - 5	90	35.0	10 - 5
42	22.0	51.75	3.99	4.04	4.20	4.90	4.99	4.99	74.3	89.3	11.9	26.0	4 - 8	70	35.0	10 - 5
43	52.0	51.0	4.06	4.10	4.36	4.85	4.92	4.92	64.0	90.3	13.6	19.0	4 - 1	90	35.0	10 - 9
44	36.0	49.0	4.11	4.16	4.37	4.96	5.07	5.07	68.3	90.2	13.1	23.0	3 - 9	80	35.0	10 - 10
45	29.0	50.0	3.98	4.04	4.22	4.83	4.92	4.92	70.5	88.5	11.3	25.0	5 - 11	100	35.0	10 - 10
46	61.0	53.0	3.78	3.70	4.05	4.55	4.65	4.65	57.7	81.3	5.5	19.0	5 - 12	135	35.0	10 - 7
47	53.0	49.25	3.86	3.71	4.06	4.54	4.59	4.59	57.6	81.4	5.5	19.0	2 - 8	60	35.0	10 - 8
48	37.0	51.5	3.97	3.85	4.15	4.76	4.84	4.84	65.9	86.4	9.6	23.0	4 - 9	90	35.0	10 - 8
49	32.0	50.0	3.81	3.70	4.05	4.64	4.75	4.75	66.9	86.2	9.0	23.0	5 - 7	105	35.0	10 - 8
50	27.0	51.75	4.07	3.94	4.27	4.94	5.03	5.00	72.1	89.8	12.6	24.0	7 - 14	135	35.0	10 - 8
51	117.0	50.0	4.45	4.37	4.67	5.00	5.06	4.04	49.0	86.3	13.4	14.5	2 - 6	75	35.0	10 - 11
52	48.0	56.5	4.05	3.95	4.30	4.87	4.95	4.95	63.7	88.3	12.0	19.0	3 - 7	70	35.0	10 - 11
53	32.0	52.5	4.10	4.01	4.36	4.94	5.04	5.03	70.9	90.6	12.5	22.0	4 - 0	75	35.0	10 - 11
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%																
54	43.0	49.0	4.08	3.96	4.27	3.80	4.91	4.91	67.6	88.7	9.5	18.0	5 - 2	120	35.0	12 - 10
55	41.0	54.75	4.09	3.98	4.24	4.82	4.88	4.88	69.7	88.9	9.3	18.0	4 - 3	90	35.0	12 - 11
56	28.0	49.0	4.24	4.15	4.36	5.00	5.10	5.08	77.0	92.8	13.0	19.0	4 - 10	90	35.0	12 - 11
57	27.0	62.0	4.33	4.16	4.34	5.00	5.10	5.05	87.6	94.5	13.0	19.0	4 - 0	75	35.0	12 - 11
58	36.0	49.0	4.26	4.15	4.42	4.96	5.08	5.04	73.8	92.8	12.6	18.0	2 - 13	60	35.0	12 - 11
59	63.0	55.5	4.12	4.08	4.33	4.90	5.01	5.01	61.8	88.6	11.5	24.0	10 - 1	210	35.0	12 - 11
60	38.0	57.0	4.06	3.94	4.23	4.87	4.98	4.96	66.6	87.3	11.0	28.0	4 - 11	90	35.0	12 - 11
61	33.0	52.0	4.14	4.06	4.34	4.97	5.08	5.06	72.2	91.1	13.0	28.0	4 - 13	90	35.0	12 - 12
62	21.0	56.0	4.05	4.00	4.21	4.94	5.04	5.05	76.4	91.1	12.7	33.0	5 - 4	90	35.0	12 - 12
63	25.0	56.0	3.70	3.68	3.74	4.36	4.44	4.44	69.5	81.6	2.5	28.0	3 - 9	75	35.0	12 - 14
64	28.0	58.0	4.05	4.06	4.13	4.79	4.86	4.82	77.4	88.9	9.5	26.0	5 - 4	105	35.0	12 - 14
65	29.0	49.0	4.05	4.11	4.17	4.77	4.87	4.86	71.3	88.1	9.5	23.0	4 - 9	90	35.0	12 - 15
66	36.0	50.0	4.09	4.19	4.26	4.84	4.90	4.90	68.3	89.1	10.0	22.0	6 - 5	120	35.0	12 - 15
67	78.0	49.0	3.85	3.77	4.09	4.49	4.54	4.54	46.4	76.8	3.8	16.0	2 - 15	90	35.0	12 - 14
68	54.0	52.0	3.84	3.78	4.10	4.50	4.66	4.66	56.4	80.4	5.5	18.0	3 - 11	90	35.0	12 - 15
69	350	52.0	3.80	3.68	4.01	4.50	4.63	4.59	64.0	82.4	5.5	25.0	3 - 7	75	35.0	12 - 16
70	30.00	50.5	3.72	3.68	3.94	4.51	4.55	4.55	65.4	82.4	5.5	23.0	2 - 15	60	35.0	12 - 16

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	STEAM	ET ESSURE IG)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%																	
71	35.0	48.5	3.71	3.61	3.90	4.43	4.54	4.54	62.8	80.9		5	23.0	3 - 15	90	35.0	10 - 2 1/2
72	30.0	53.0	3.71	3.58	3.89	4.48	4.57	4.54	65.2	81.8			23.0	3 - 8	120	35.0	10 - 2 1/2
73	29.0	53.0	3.95	3.95	4.14	4.81	4.93	4.87	70.7	87.2			24.0	3 - 4	60	35.0	10 - 2 1/2
74	26.0	52.5	4.02	3.87	4.13	4.82	4.94	4.86	72.7	87.7			25.0	6 - 12	120	35.0	10 - 4
75	26.0	54.75	3.90	3.79	4.06	4.72	4.83	4.80	72.8	87.5			24.0	6 - 6	120	35.0	10 - 6
76	26.0	50.5	4.11	3.97	4.25	4.93	5.05	5.03	73.3	89.8			25.0	6 - 6	100	35.0	10 - 6
77	30.0	51.0	4.12	4.00	4.25	4.95	5.02	5.02	70.6	88.8			23.0	3 - 3	60	35.0	10 - 6
78	37.0	48.5	3.67	3.60	3.94	4.47	4.57	4.57	66.3	88.2			20.0	2 - 0	60	35.0	10 - 7
79	61.0	76.0	3.76	3.66	3.95	4.46	4.59	4.59	62.4	83.5			24.0	2 - 9	60	35.0	10 - 11
80	35.0	48.0	3.95	3.88	4.14	4.76	4.86	4.86	67.0	88.4			23.0	5 - 1	100	35.0	10 - 11
81	30.0	56.25	3.98	3.87	4.15	4.83	4.85	4.86	69.8	86.8			24.0	8 - 9	160	35.0	10 - 12
82	22.5	48.5	3.91	3.85	4.09	4.74	4.83	4.83	70.7	86.7			27.0	2 - 10	45	35.0	10 - 14
83	45.0	50.0	3.89	3.99	4.11	4.62	4.68	4.68	60.8	83.7			21.0	3 - 8	75	35.0	10 - 2
84	34.0	49.5	3.89	3.97	4.10	4.62	4.68	4.68	65.5	84.7			23.0	3 - 11	75	35.0	10 - 2
85	26.5	49.75	3.95	4.04	4.13	4.74	4.82	4.78	70.0	86.4			25.0	4 - 15	90	35.0	10 - 2
86	22.0	51.5	3.94	3.95	4.07	4.77	4.84	4.78	72.5	86.7			29.0	6 - 7	105	35.0	10 -2

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	STEAM [illegible]SSURE ([illegible])	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%																
87	104.2	50.75	4.16	4.08	4.25	4.56	4.70	4.70	45.4	76.8	6	12.0	2 - 8	95	35.0	10 - 6 1/2
88	45.0	51.25	3.85	3.88	4.16	4.69	4.74	4.74	59.8	82.0	8	17.0	4 - 14	115	35.0	10 - 6 1/2
89	32.5	51.25	3.90	3.84	4.09	4.65	4.72	4.72	66.0	83.9	7	19.0	5 - 14	110	35.0	10 - 7
90	27.0	51.25	3.79	3.70	3.95	4.54	4.61	4.60	69.5	85.1	7	20.0	4 - 8	90	35.0	10 - 7
91	21.0	52.0	3.95	3.86	4.07	4.65	4.73	4.73	73.3	86.5	7	21.0	10 - 14	210	35.0	10 - 7
92	20.0	51.5	3.97	3.86	4.08	4.70	4.78	4.75	76.3	89.2	10	22.0	3 - 7	60	35.0	10 - 9 1/2
93	48.0	48.0	3.94	3.85	4.13	4.53	4.64	4.64	56.6	79.1	5	28.0	3 - 7	90	35.0	10 - 9 1/2
94	28.0	48.25	3.82	3.75	3.98	4.53	4.67	4.64	64.8	81.5	5	32.0	5 - 0	110	35.0	10 - 9 1/2
95	52.0	48.5	4.02	3.95	4.25	4.70	4.75	4.75	56.0	81.1	8	17.0	1 - 10	45	35.0	10 - 15
96	34.0	48.5	3.97	3.90	4.16	4.68	4.74	4.75	64.0	83.3	7	18.0	3 - 10	85	35.0	10 - 15
97	32.0	50.0	4.03	3.96	4.25	4.77	4.85	4.85	67.3	85.9	9	19.0	3 - 8	75	35.0	10 - 15
98	28.0	52.0	3.99	3.89	4.19	4.75	4.83	4.80	70.1	86.1	8	20.0	7 - 4	150	35.0	10 - 15
99	25.0	51.2	4.00	3.89	4.15	4.75	4.82	4.82	64.5	89.6	11	21.5	5 - 6	105	35.0	10 - 15
100	49.0	61.0	3.93	3.87	4.15	4.47	4.54	4.54	49.8	76.0	4	14.0	1 - 15	60	35.0	11 - 1
101	35.0	49.0	3.83	3.74	4.03	4.50	4.57	4.57	59.5	79.2	5	19.0	2 - 11	60	35.0	11 - 1
102	38.0	51.5	4.08	4.30	4.01	4.83	4.90	4.90	65.1	85.4	9	16.0	3 - 6	102	35.0	11 - 1
103	36.0	50.0	4.10	4.04	4.33	4.85	4.90	4.92	67.8	87.3	8	16.0	6 - 9	90	35.0	11 - 1
104	26.0	50.25	4.01	3.94	4.17	4.75	4.81	4.81	71.6	87.2	8	18.0	5 - 5	110	35.0	11 - 1
105	21.8	51.75	4.15	4.08	4.30	4.90	4.99	4.99	77.8	91.8	12	19.0	4 - 2	90	35.0	11 - 1
106	37.0	49.0	3.94	4.04	4.09	4.60	4.69	4.66	60.1	79.3	6	25.0	4 - 1	90	35.0	10 -11
107	28.0	53.0	3.96	4.06	4.12	4.66	4.72	4.72	68.3	83.4	7	24.0	4 - 8	90	35.0	10 - 11
108	25.0	50.75	3.95	4.02	4.08	4.59	4.64	4.64	69.9	83.6	6	23.0	6 - 12	135	35.0	10 - 11 1/2
109	22.5	52.0	3.96	3.94	3.98	4.53	4.56	4.56	70.0	82.8	5	26.0	5 - 6	105	35.0	10 - 11
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%																
110	43.8	51.25	4.21	4.23	4.38	4.90	4.98	4.98	62.8	84.3	11.	19.0	2 - 10	60	35.0	11 - 0
111	32.2	51.25	4.16	4.24	4.35	4.92	5.02	4.96	68.0	86.0	11	20.0	4 - 4	90	35.0	11 - 1
112	26.0	49.5	4.04	4.04	4.16	4.79	4.85	4.85	71.9	87.7	11	22.0	3 - 3	75	35.0	11 - 2
113	23.4	51.5	3.87	3.90	4.02	4.64	4.73	4.73	75.7	90.4	14	24.0	3 - 9	76	35.0	11 - 2
114	20.8	51.25	4.37	4.37	4.46	5.04	5.10	5.10	77.3	90.9	14	26.0	3 - 6	60	35.0	11 - 2
115	19.5	51.25	4.39	4.45	4.51	5.20	5.26	5.26	80.8	93.7	16	24.0	6 - 0	105	35.0	11 - 3
116	36.0	51.5	4.43	4.53	4.62	5.20	5.36	5.36	69.2	89.8	16	20.0	6 - 6	90	35.0	11 - 4 1/2
117	28.4	51.5	4.34	4.45	4.52	5.11	5.19	5.18	73.5	91.2	16	22.0	6 - 0	60	35.0	11 - 4
118	26.5	53.0	4.40	4.50	4.59	5.19	5.26	5.26	75.5	91.9	16	22.5	3 - 0	60	35.0	11 - 4
119	35.0	51.5	4.15	4.22	4.30	4.84	4.94	4.94	67.9	86.4	11	21.0	2 - 10	60	35.0	11 - 1
120	29.4	51.75	4.11	4.23	4.25	4.82	4.85	4.85	70.6	86.5	9	19.0	4 - 5	90	35.0	11 - 1
121	25.0	50.0	4.11	4.19	4.22	4.79	4.87	4.82	73.0	87.0	9	21.0	4 - 7	90	35.0	11 - 1

SNOWFLAKE RUNS CONTINUED ON FOLLOWING PAGE

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	IN… STEAM P… SURE (P…)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%																
122	34.2	51.25	4.20	4.31	4.35	4.85	4.90	4.90	70.8	87.5	10	14.0	2 - 12	60	35.0	10 - 12
123	26.0	51.25	4.37	4.44	4.49	5.04	5.12	5.09	78.2	92.6	12	16.0	3 - 0	60	35.0	10 - 12
124	23.3	51.5	4.40	4.43	4.56	5.03	5.10	5.06	80.0	93.1	13	16.0	6 - 2	120	35.0	10 - 12
125	21.3	51.25	4.21	4.24	4.30	4.85	4.90	4.86	81.8	94.0	13	16.0	3 - 6	65	35.0	10 - 12
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%																
126	45.4	52.75	3.90	3.88	4.11	4.59	4.63	4.63	59.8	80.1	6	16.0	3 - 8	85	35.0	10 - 10
127	33.6	51.75	3.83	3.77	4.06	4.51	4.63	4.63	65.8	82.4	6	17.0	3 - 8	80	35.0	10 - 10
128	27.2	52.0	3.91	3.87	4.05	4.59	4.66	4.66	69.8	84.5	6	18.0	5 - 8	120	35.0	10 - 10
129	24.0	51.0	4.05	3.96	4.19	4.74	4.85	4.83	73.6	87.3	9	20.0	8 - 13	180	35.0	10 - 10
130	21.0	52.0	4.14	4.10	4.26	4.90	4.99	4.99	77.3	90.3	12	21.0	7 - 0	130	35.0	10 - 10
131	35.0	51.0	4.20	4.14	4.35	4.89	4.99	4.99	68.2	86.7	11	17.0	3 - 4	70	35.0	10 - 14
132	27.4	51.0	4.21	4.14	4.35	4.96	5.03	5.03	72.2	88.5	11	20.0	4 - 15	100	35.0	10 - 14
133	23.0	50.0	3.98	3.92	4.11	4.70	4.78	4.78	75.1	89.0	11	19.0	3 - 12	71	35.0	10 - 14
134	20.8	51.75	4.19	4.19	4.35	4.91	5.00	5.00	76.9	89.8	11	20.0	4 - 14	90	35.0	10 -14
135	45.5	51.25	3.79	3.79	4.02	4.48	4.54	4.54	57.4	78.1	6	18.0	2 - 5	60	35.0	10 - 8
136	35.0	51.25	3.61	3.61	3.83	4.35	4.43	4.43	62.3	80.4	6	19.0	2 - 10	60	35.0	10 - 8
137	27.0	51.5	3.75	3.76	3.94	4.50	4.57	4.57	66.5	81.7	7	20.5	2 - 8	65	35.0	10 - 8
138	43.3	51.0	4.32	4.39	4.45	4.04	5.09	5.09	65.7	87.9	14	19.0	4 - 8	75	35.0	10 - 12
139	45.2	51.0	4.34	4.46	4.56	5.00	5.10	5.06	65.4	88.6	14	17.0	2 - 6	60	35.0	10 - 13
140	33.5	51.1	4.27	4.37	4.45	4.95	5.05	5.05	71.7	90.5	14	18.0	5 - 8	125	35.0	10 - 12 1/2
141	27.3	51.75	4.21	4.30	4.39	4.93	4.99	4.97	75.6	91.6	13	20.0	4 - 10	91	35.0	10 - 13

TABLE NO. 4

OBSERVED DATA FOR SUSPENSIONS

RUN NO.	SLURRY TIME (SEC.)	WEIGHT SLURRY COLLECTED (LBS.)	THERMOCOUPLE READINGS (M. V.) 1	2	3	4	5	6	SLURRY TEMP. °C IN	OUT	STEA	LET RESSURE SIG)	COND'S'TE TEMP. °C	COND'S'TE WEIGHT LBS.-OZ.	COND'S'TE TIME (SEC.)	SLURRY DENSITY TEMP. °C	SLURRY WEIGHT LBS.-OZ.
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%																	
142	45.0	51.0	4.12	4.04	4.38	4.74	4.77	4.77	62.8	82.8		.75	18.0	5 - 9	135	35	11 - 8
143	31.5	51.75	4.36	4.26	4.50	5.00	5.06	5.06	70.1	86.3		.3	21.0	3 - 2	65	35	11 - 8
144	23.5	50.0	4.27	4.21	4.43	4.99	5.03	5.03	75.4	88.5		.0	22.0	4 - 10	90	35	11 - 9
145	35.5	51.75	4.35	4.26	4.50	4.97	5.05	5.05	69.6	88.1		.6	21.0	3 - 10	75	35	11 - 11
146	24.5	52.0	4.18	4.06	4.35	4.90	4.94	4.94	76.0	90.1		.1	22.0	6 - 5	120	35	11 - 11
147	22.0	56.5	4.11	4.11	4.22	4.85	4.92	4.92	76.0	88.0		.1	26.0	3 - 3	60	35	11 - 10
148	25.0	49.0	3.94	3.94	4.11	4.63	4.66	4.65	72.2	86.25		.0	23.0	3 - 1	60	35	11 - 10
149	33.1	51.0	4.20	4.20	4.35	4.85	4.90	4.90	66.1	83.1		.0	22.0	2 - 12	60	35	11 - 10
150	33.0	49.5	4.16	4.16	4.29	4.80	4.81	4.81	67.7	84.5		.0	22.0	1 - 14	30	35	11 - 12
151	19.3	51.0	4.15	4.16	4.25	4.85	4.85	4.87	76.7	88.5		.0	21.0	1 - 14	30	35	11 - 12
152	31.0	51.5	4.04	3.93	4.12	4.61	4.66	4.66	63.9	79.7		.4	21.0	3 - 13	90	35	11 - 7
153	25.5	51.5	4.04	3.93	4.13	4.66	4.70	4.70	67.1	80.7		.6	21.0	2 - 13	60	35	11 - 7
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%																	
154	19.8	51.5	3.92	3.85	4.01	4.60	4.65	4.65	71.3	82.3		.0	26.0	3 - 1	60	35	11 - 7.5
155	26.8	51.5	3.93	3.84	4.01	4.54	4.58	4.58	64.7	78.5		.0	24.0	4 - 14	105	35	11 - 7.5
156	46.6	53.0	4.03	3.96	4.16	4.55	4.59	4.59	55.4	74.3		.0	21.0	5 - 10	150	35	11 - 7.5
157	20.0	52.6	3.86	3.77	4.00	4.51	4.58	4.58	69.8	80.8		.1	25.0	5 - 2	110	35	11 - 11
158	25.0	51.25	3.71	3.60	3.81	4.30	4.37	4.37	65.7	79.2		.0	24.0	2 - 13	60	35	11 - 11
159	48.8	51.5	4.07	3.96	4.18	4.53	4.58	4.58	51.9	71.6		.6	17.0	2 - 2	60	35	11 - 11
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%																	
160	21.0	51.75	4.0	3.94	4.07	4.65	4.73	4.73	72.0	83.7		.1	21.0	2 - 14	60	35	11 - 8
161	25.0	52.25	4.05	3.95	4.13	4.64	4.70	4.70	67.4	81.1		.9	21.0	2 - 12	60	35	11 - 8
162	44.0	51.5	4.16	4.09	4.28	4.65	4.72	4.72	55.9	75.3		.9	17.0	2 - 5	60	35	11 - 8
163	20.0	53.25	4.20	4.10	4.26	4.84	4.88	4.88	73.8	86.2		.0	23.0	3 - 3	60	35	11 - 12.5
164	29.5	51.75	4.2	4.14	4.30	4.80	4.82	4.82	65.1	81.3		.4	21.0	3	60	35	11 - 12.5

EXPERIMENTAL RESULTS

In general, the apparatus as used by these investigators was found to be adequate for the work undertaken. Since it was the same apparatus used by Franks and Rinaldi(8) the same shortcomings were evidenced, especially in keeping the flow rate constant to the exchanger.

No attempt was made to modify the equipment other than using a rubber hose in place of the quick opening valves used for diverting the flow of slurry from slurry tank to weighing drum.

Keeping the flow rate constant was still more difficult at low rates of flow, and at very low rates almost impossible. This explains the scarcity of data below 30,000 Reynolds number. The runs shown below 30,000 Reynolds number exhibited the widest deviation from experimental results at 40% sugar concentration. This is probably due to particle fall-out from the slurry at low flow rates.

The method for obtaining data was as indicated in the section marked 'Experimental Procedure', that is, both heat transfer data and viscosity data were taken simultaneously for each run.

Very accurate temperature control for the density of the slurries was not practiced, since in preparing the density versus weight fraction curves the slurry temperature was room temperature or approximately 35°C. The experimental slurry was cooled to approximately 35°C, weighed and density calculated. Greater accuracy between experimental and calculated 'h' would be obtained if temperature corrections made, since the viscosity exerts the greatest influence on the 'h' values.

Reference to Table VI, 'Correlated Results', shows that the greatest percent deviation of the calculated values for 'h' from the experimental values of 'h' appears in runs 1 to 37 and 142 to 164.

The large deviation in these runs is due to low flow rates where particle fall-out becomes increasingly significant. These particles tend to coat out on the tube surface invalidating any thermal analogies which are drawn concerning a heat transfer mechanism such as used here.

In considering the viscosity values for these runs (1 to 37 and 142 to 164) there appears to be a limiting value for apparent viscosity. The maximum apparent viscosity for runs 1 to 37 is 1.5#/ft. hr. and the minimum value for runs 142 to 164 is 4.0#/ft. hr.

The deviations of calculated film coefficients from experimental ones for the remainder of the data appear to give satisfactory results, the average deviation of these runs being in the range of 16.0%.

It appears, therefore that the Curtis-Gullet correlation for viscosity is applicable for slurries with viscosities of 1.5#/ft. hr. to 4.0#/ft. hr.

Larger deviations of 20-25% are probably due to particle fall-out as described before, due to high concentration of slurry. These deviations have been recorded as + or - depending on how they fell in reference to the experimental value of film coefficient.

Curtis and Gullet(7) and Franks and Rinaldi(8) and Salamone(14) have presented a discussion of probable error using experimental techniques of this nature.

Since Curtis and Gullet(7) cite the accuracy of their equation to be 14.4%, an experimental error of 16% between the limiting viscosities is applicable to this report.

TABLE NO. 5

CALCULATED RESULTS FOR SUSPENSIONS

RUN NO.	DENSITY LBS./FT.^{3}	WEIGHT SOLIDS %	MEAN SP. HEAT BTU/LBS.°F	FLOW RATE LBS./HR.	APPARENT VISCOSITY LBS./FT.-HR.	SLU[illegible] HEA[illegible] BTU/[illegible] x [illegible]	HEAT SECTION REYNOLDS NO. x 10^3	EXP. FILM COEFF. *
1	66.14	5.2	0.8944	4284	1.157	128.	91.1	3635
2	66.14	5.2	0.8944	5004	1.11	131.	111.0	4045
3	66.14	5.2	0.8944	6804	0.991	154.	165.8	5710
4	66.14	5.2	0.8944	8676	0.911	172	165.7	5705
5	67.85	8.4	0.8575	8676	1.037	167	205.5	7440
6	67.85	8.4	0.8575	7812	1.075	157	178.9	5670
7	67.85	8.4	0.8575	6732	1.108	154	149.8	4900
8	67.85	8.4	0.8575	5220	1.137	142	132.0	6090
9	67.85	8.4	0.8575	3492	0.98	91	90.8	3500
10	68.35	9.55	0.8494	8568	0.98	181	181.9	6400
11	68.35	9.55	0.8494	7344	1.11	159	163.0	7670
12	68.18	10.55	0.8342	5832	1.099	153	130.4	4800
13	69.20	11.55	0.8301	4356	1.31	131	81.9	3295
14	64.98	3.85	0.925	8208	0.98	175	206.5	6440
15	64.98	3.85	0.925	7128	0.921	170	190.5	5450
16	64.98	3.85	0.925	5832	0.936	167	153.6	5225
17	64.98	3.85	0.925	4824	0.989	157	120.0	4370
18	65.77	4.86	0.9102	1236	1.508	53	20.2	905
19	65.77	4.86	0.9102	4482	1.289	143	85.7	3164
20	65.77	4.86	0.9102	5155	1.213	136	104.74	3515
21	65.77	4.86	0.9102	6653	1.154	168	142.1	4652
22	65.77	4.86	0.9102	8071	1.077	187	184.7	5719
23	65.77	4.86	0.9102	8550	1.071	170	196.8	5183
24	66.58	6.56	0.8977	2065	1.477	82	34.4	1491
25	66.58	6.56	0.8977	3600	1.394	131	63.6	3473
26	66.96	7.35	0.8943	8204	1.124	198	79.64	6374
27	67.52	7.90	0.8746	3982	1.288	129	76.2	4164
28	67.52	7.90	0.8746	6113	1.143	153	131.8	9319
29	67.83	8.30	0.8717	8593	0.057	176	200.5	5200
30	69.14	10.60	0.8423	4280	1.356	133	71.1	5281
31	71.76	11.3	0.8374	6239	1.133	149	135.6	4490
32	71.76	11.30	0.8374	5134	1.218	139	103.4	4930
33	65.3	3.54	0.9389	8740	1.174	174	205.5	7600
34	65.3	3.54	0.9389	5705	1.228	157	114.6	4720
35	66.2	5.38	0.8874	5170	1.25	146	103.2	4015
36	66.2	5.38	0.8874	6860	1.263	164	139.4	5540
37	66.2	5.38	0.8874	7880	1.244	170	167.5	7000

* BTU/HR.-FT.^{2}-°F

TABLE NO. 5

CALCULATED RESULTS FOR SUSPENSIONS

RUN NO.	DENSITY LBS./FT.^{3}	WEIGHT SOLIDS %	MEAN SP. HEAT BTU/LBS.°F	FLOW RATE LBS./HR.	APPARENT VISCOSITY LBS./FT.-HR.	SLUE HEA BTU/ x 1	HEAT SECTION REYNOLDS NO. x 10^3	EXP. FILM COEFF. *
38	68.65	4.0	0.8355	2963	1.804	120.	40.5	2270
39	68.65	4.0	0.8355	4710	1.668	152.	69.6	2900
40	69.00	4.8	0.828	5960	1.55	176.	94.6	3320
41	69.00	4.8	0.828	6480	1.486	182.	107.3	4155
42	69.00	4.8	0.828	8460	1.417	189.	147.5	4920
43	70.75	8.8	0.799	3560	1.81	134.	48.6	2561
44	71.00	9.65	0.793	4900	1.683	153.	71.7	2920
45	71.00	9.65	0.793	6200	1.645	159.	92.9	3565
46	69.80	6.6	0.807	3130	1.989	107.	38.8	1775
47	70.20	7.65	0.807	3345	2.00	112.	41.25	1870
48	70.20	7.65	0.807	5015	1.885	147.	65.65	3670
49	70.20	7.65	0.807	5630	1.705	158.	81.5	3900
50	70.20	7.65	0.807	6900	1.552	177.	109.7	4210
51	71.45	10.6	0.785	1538	2.985	81.	12.7	778
52	71.45	10.6	0.785	4235	1.814	147.	57.4	2965
53	71.45	10.6	0.785	5900	1.62	164.	89.7	3555
54	67.9	3.8	0.835	4104	1.717	134.	59.1	2740
55	68.1	4.3	0.832	4810	1.826	139.	64.9	2269
56	68.1	4.3	0.832	6300	1.525	147.	101.6	3450
57	68.1	4.3	0.832	8270	1.43	148.	142.7	4160
58	68.1	4.3	0.832	4900	1.60	140.	75.5	3145
59	68.1	4.3	0.832	3175	1.908	128.	41.1	1693
60	68.1	4.3	0.832	5400	1.776	170.	75.0	3255
61	68.8	5.7	0.823	5675	1.675	158.	83.6	3390
62	68.8	5.7	0.823	9600	1.534	209.	154.4	5850
63	69.6	7.2	0.813	8070	1.83	143.	108.5	3985
64	69.6	7.2	0.813	7460	1.615	125.	113.6	3062
65	70.0	8.25	0.806	6080	1.765	148.	85.0	3315
66	70.0	8.25	0.806	5000	1.925	150.	64.1	3040
67	70.0	7.20	0.813	2263	2.57	100.	21.7	1283
68	70.1	8.25	0.806	3470	2.255	120.	38.4	1950
69	70.2	8.60	0.804	5345	1.984	142.	66.2	3035
70	70.2	8.60	0.804	6060	1.804	154.	82.6	3665
71	68.6	3.3	0.8385	4990	2.065	136.	59.55	2760
72	68.65	3.6	0.8366	6360	1.944	158.	80.7	3850
73	68.7	3.8	0.8353	6580	1.799	163.	90.1	3730
74	69.2	4.9	0.8281	7265	1.796	162.	99.6	3945

* BTU/HR.-FT.^{2}-°F

TABLE NO. 5

CALCULATED RESULTS FOR SUSPENSIONS

RUN NO.	DENSITY LBS./FT.^{3}	WEIGHT SOLIDS %	MEAN SP. HEAT BTU/LBS.°F	FLOW RATE LBS./HR.	APPARENT VISCOSITY LBS./FT.-HR.	SLURR HEAT BTU/H x 10^3	HEAT SECTION REYNOLDS NO. x 10^3	EXP. FILM COEFF. *
75	69.4	7.15	0.8135	7580	1.866	163.6	100.0	4520
76	69.4	7.15	0.8135	7000	1.876	169.5	92.0	3970
77	69.4	7.15	0.8135	6125	1.805	163.6	79.3	3400
78	69.4	7.15	0.8135	4720	2.098	151.6	55.7	5375
79	69.5	10.5	0.7915	4490	2.332	135.2	47.45	3100
80	69.5	10.5	0.7915	4940	2.18	150.9	55.80	3390
81	69.6	11.4	0.7858	6760	2.00	163.0	83.40	3670
82	69.65	13.7	0.7718	7760	2.075	172.9	92.2	3955
83	67.8	1.5	0.8510	4000	1.942	140.4	50.75	2555
84	67.8	1.5	0.8510	5245	1.752	154.5	73.8	3250
85	67.8	1.5	0.8510	6750	1.65	169.7	100.9	3900
86	67.8	1.5	0.8510	8420	1.556	183.4	133.3	4750
87	71.06	4.2	0.7677	1753	3.64	76.0	11.9	924
88	71.06	4.2	0.7677	4068	2.809	125.0	35.8	1885
89	71.55	6.0	0.7677	5652	2.609	139.7	53.5	2530
90	71.55	6.0	0.7612	6804	2.259	145.4	74.3	4060
91	71.55	6.0	0.7612	8892	2.189	160.7	100.2	4385
92	71.55	6.0	0.7612	9252	2.305	163.6	98.9	5535
93	72.4	7.0	0.7475	3600	2.935	108.0	30.3	2162
94	72.4	7.0	0.7475	6192	3.695	138.0	56.7	2780
95	73.1	8.7	0.7378	3360	3.14	110.9	26.3	1555
96	73.1	8.7	0.7378	5135	2.78	130.0	45.5	2795
97	73.1	8.7	0.7378	5630	2.40	137.9	57.9	2680
98	73.1	8.7	0.7378	6685	2.355	140.4	69.8	2240
99	73.1	8.7	0.7378	7420	2.33	245.0	78.5	1410
100	74.0	10.6	0.7266	4490	3.55	151.5	31.2	2108
101	74.0	10.6	0.7266	5040	3.03	128.4	41.1	2271
102	74.0	10.6	0.7266	4880	2.81	191.1	42.9	3400
103	74.0	10.6	0.7266	5000	2.485	125.9	49.6	2290
104	74.0	10.6	0.7266	6965	2.39	140.4	72.0	3250
105	74.0	10.6	0.7266	8540	2.13	154.5	99.0	4110
106	72.84	8.04	0.7415	4766	2.835	122.1	41.5	1890
107	72.85	8.04	0.7415	6815	2.569	137.4	65.5	2700
108	73.05	8.53	0.7387	7308	2.505	133.2	71.9	2815
109	72.85	8.04	0.7415	8320	2.51	14.1	81.6	3345
110	70.82	6.0	0.7536	4212	2.976	122.84	34.9	1764
111	71.26	6.9	0.7484	5731	2.702	138.96	52.3	2315

* BTU/HR.-FT.^{2}-°F

TABLE NO. 5

CALCULATED RESULTS FOR SUSPENSIONS

RUN NO.	DENSITY LBS./FT.^{3}	WEIGHT SOLIDS %	MEAN SP. HEAT BTU/LBS.°F	FLOW RATE LBS./HR.	APPARENT VISCOSITY LBS./FT.-HR.	SLURRY HEAT BTU/HR. x 10^3	HEAT SECTION REYNOLDS NO. x 10^3	EXP. FILM COEFF. *
112	71.64	7.66	0.7440	6854	2.532	144.8	66.7	3267
113	71.64	7.66	0.7440	7924	2.343	156.2	83.35	5146
114	71.64	7.66	0.7440	8870	2.451	161.7	89.2	3340
115	72.07	8.56	0.7388	9461	2.155	162.2	108.2	3770
116	72.63	9.72	0.7321	5152	2.750	139.9	46.2	2120
117	72.45	9.32	0.7344	6527	2.554	152.9	63.0	2759
118	72.45	9.32	0.7344	7200	2.436	156.0	72.8	2800
119	71.26	6.9	0.7484	5296	2.749	132.0	47.5	2284
120	71.26	6.9	0.7484	6336	2.650	135.6	60.3	2610
121	71.26	6.9	0.7484	7200	2.528	135.8	70.2	2839
122	69.14	2.49	0.7744	5396	2.563	125.7	56.5	2203
123	69.14	2.49	0.7744	7096	2.201	142.3	86.5	2913
124	69.14	2.49	0.7744	7956	2.132	145.3	100.1	3484
125	69.14	2.49	0.7744	8886	2.064	147.5	112.5	4693
126	71.1	3.5	0.7681	4187	2.749	117.4	32.5	1903
127	71.4	3.5	0.7681	5570	2.943	127.6	46.5	2664
128	71.4	3.5	0.7681	6885	2.697	140.2	62.9	3269
129	71.4	3.5	0.7681	7650	2.464	145.1	76.5	3426
130	71.1	3.3	0.7693	8910	2.277	160.7	96.7	4057
131	72.7	7.58	0.7445	5249	2.613	130.4	49.5	2222
132	72.7	7.58	0.7445	6703	2.562	146.5	64.5	2832
133	72.7	7.58	0.7445	7823	2.525	145.9	76.4	4212
134	72.7	7.58	0.7445	8964	2.491	155.1	88.7	3553
135	71.64	4.90	0.7615	4054	2.546	115.1	39.2	1848
136	71.64	4.90	0.7615	5270	2.512	130.8	51.8	2993
137	71.64	4.90	0.7615	6865	2.442	143.2	69.3	3228
138	73.26	8.96	0.7379	4241	2.742	125.2	38.1	1860
139	73.63	8.90	0.7310	4421	3.154	135.21	34.5	2030
140	73.44	9.41	0.7339	5490	2.783	136.2	50.0	2525
141	73.63	9.90	0.7310	7186	2.596	151.3	68.2	3463
142	74.2	5.03	0.718	4080	4.208	105.4	24.0	1594
143	74.2	5.03	0.718	5925	3.695	124.0	39.6	1918
144	74.35	6.21	0.713	7660	3.415	128.7	43.8	2441
145	75.4	7.09	0.709	5250	3.81	124.0	34.0	2012
146	75.4	7.09	0.709	7640	3.39	143.6	55.5	3440
147	75.7	8.6	0.702	9250	3.17	140.4	71.9	3150
148	75.7	8.6	0.702	7055	3.42	125.3	50.8	3065

* BTU/HR.-FT.^{2}-°F

TABLE NO. 5

CALCULATED RESULTS FOR SUSPENSIONS

RUN NO.	DENSITY LBS./FT.^{3}	WEIGHT SOLIDS %	MEAN SP. HEAT BTU/LBS.°F	FLOW RATE LBS./HR.	APPARENT VISCOSITY LBS./FT.-HR.	SLU HEA BTU x	HEAT SECTION REYNOLDS NO. x 10^3	EXP. FILM COEFF. *
149	75.7	8.6	0.702	5550	4.12	119	33.2	1794
150	76.65	11.0	0.693	5400	3.94	113	33.5	1897
151	76.65	11.2	0.693	9510	3.145	140	73.6	3152
152	74.34	1.26	0.7268	5980	4.908	170	30.03	3018
153	74.34	1.26	0.7268	7270	4.590	129	39.05	3294
154	74.76	2.0	0.7253	9364	3.57	134	64.6	3002
155	74.76	2.0	0.7253	6919	4.12	124	41.3	2204
156	74.76	2.0	0.7253	4093	4.90	101	20.6	1291
157	76.0	5.9	0.7047	9468	4.115	132	56.7	2903
158	76.0	5.9	0.7047	7380	4.46	126	40.7	3000
159	76.0	5.9	0.7047	3798	5.94	94	15.8	1094
160	74.01	3.26	0.719	8870	5.929	134	36.9	2914
161	74.01	3.26	0.719	7524	5.014	133	37.0	2412
162	74.01	3.26	0.719	4212	4.976	105	20.9	1281
163	75.94	6.37	0.698	9587	5.426	149	43.5	3080
164	75.94	6.37	0.698	6314	6.570	128	23.7	1949

* BTU/HR.-FT.^{2}-°F

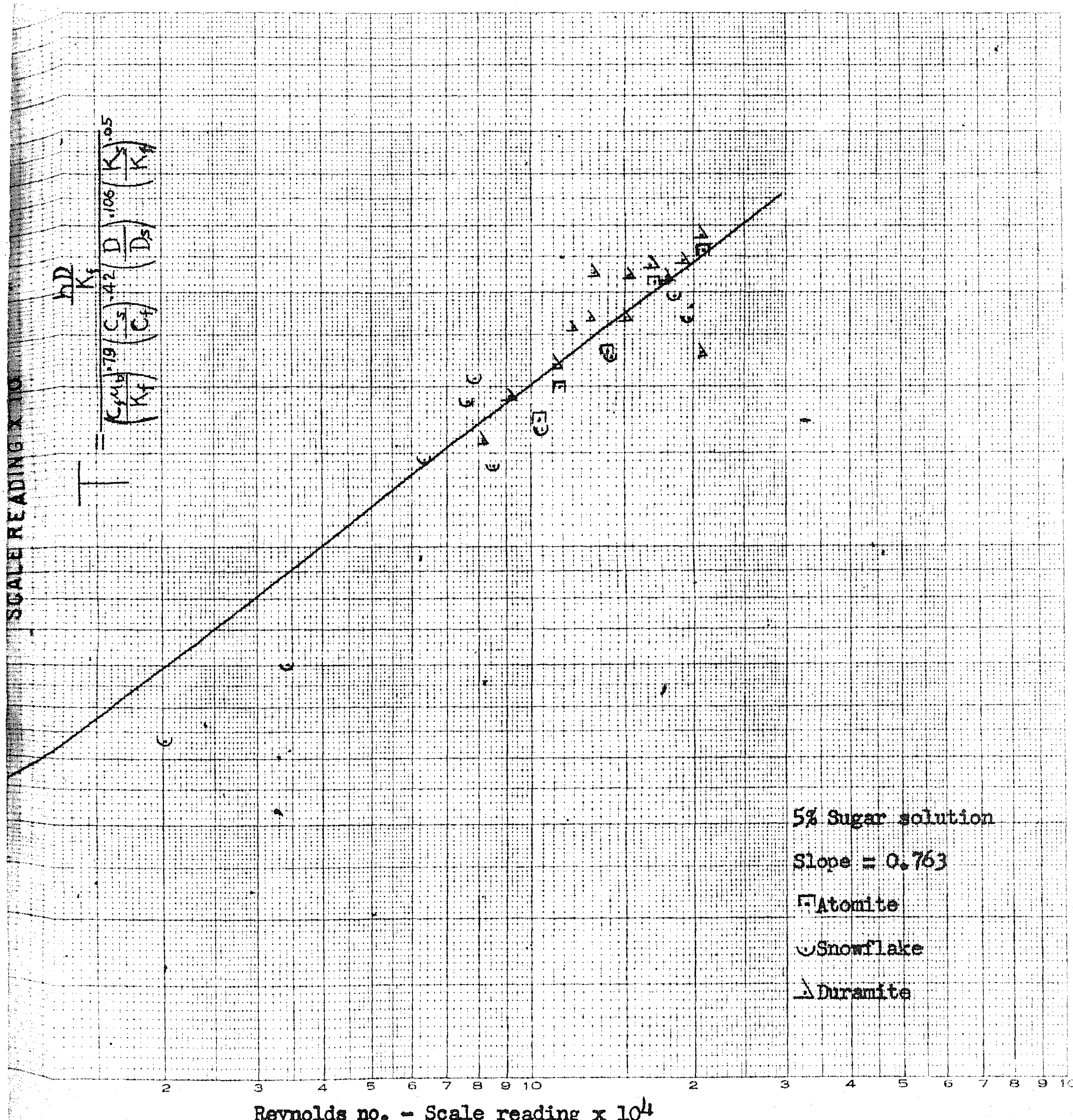
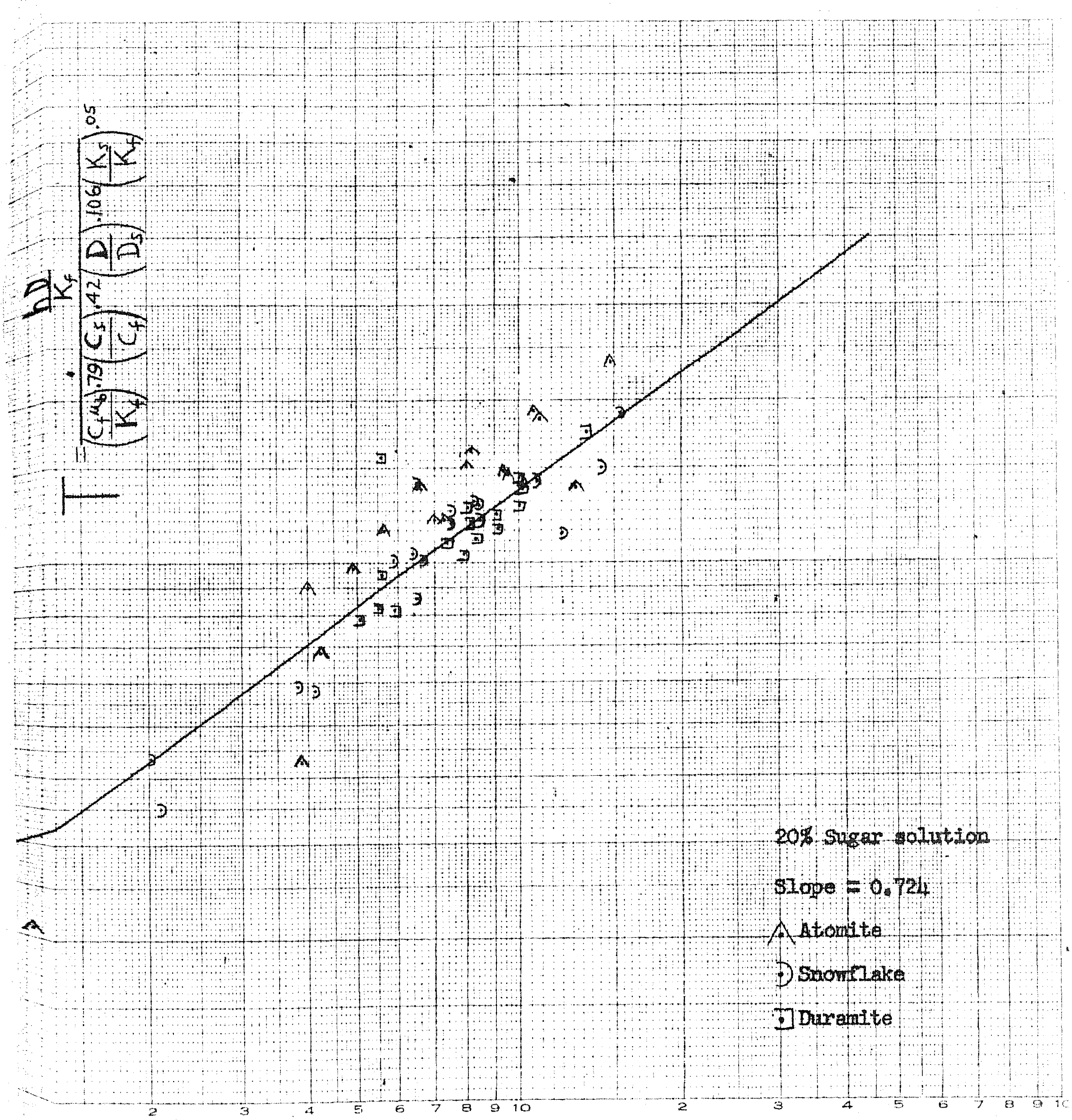


Fig. 4

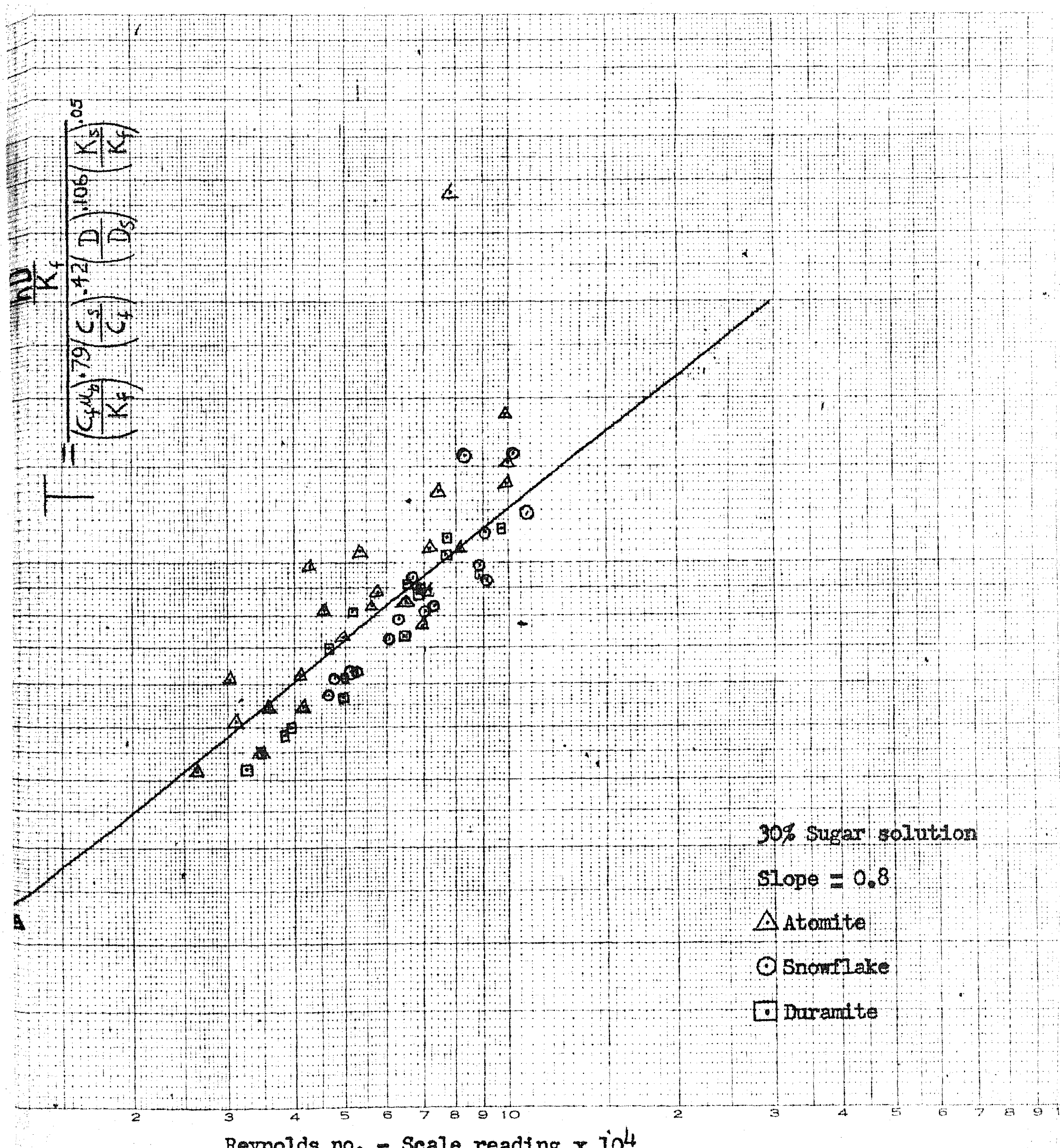
Correlation of heat transfer data by equation of Franks & Rinaldi



Reynolds no. - Scale reading x 10^4

Fig. 5

Correlation of heat transfer data by equation of Franks & Rinaldi



ig. 6

<u>Correlation of heat transfer data by equation of Franks & Rinaldi</u>

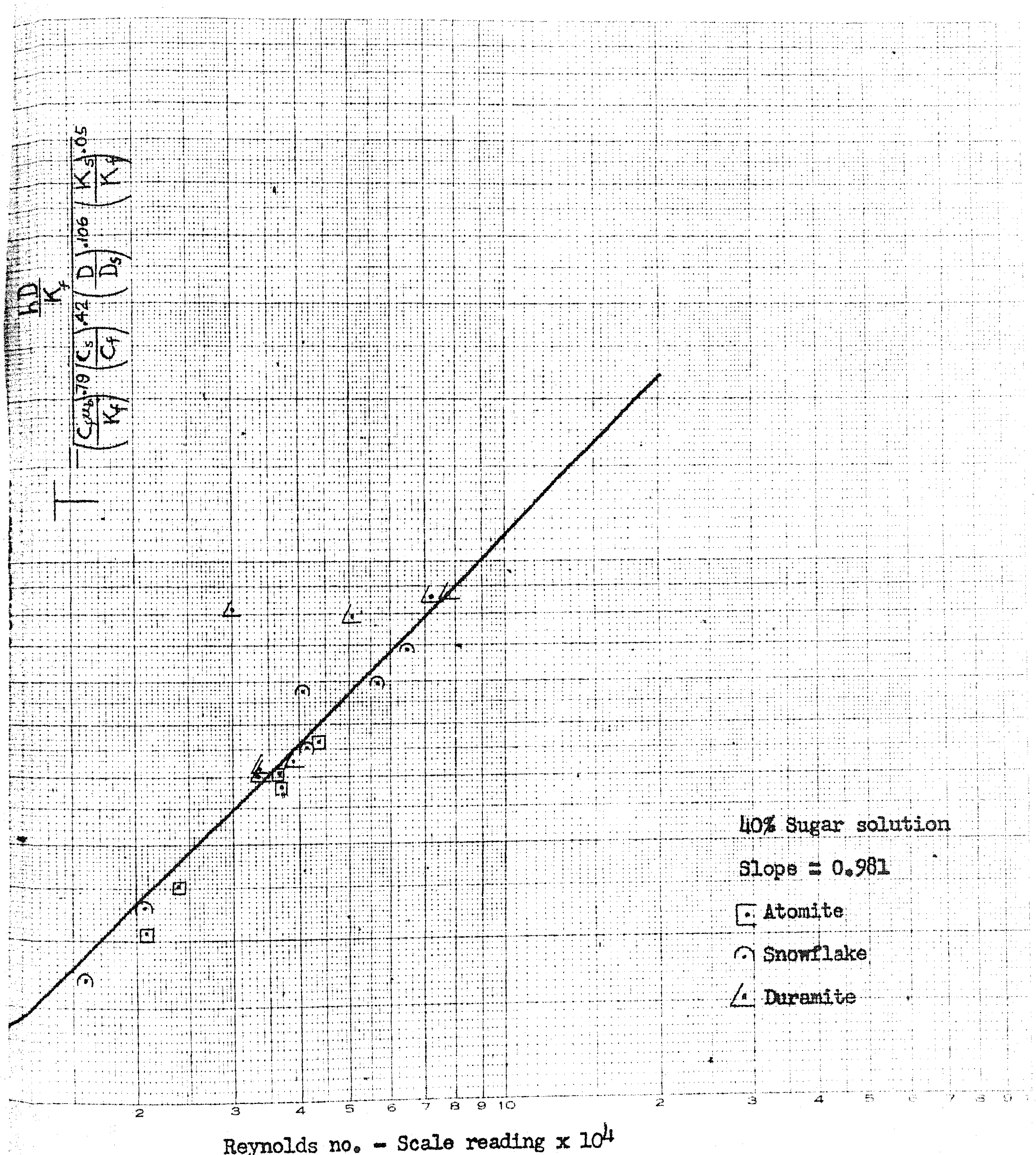


Fig. 7

Correlation of heat transfer data by equation of Franks & Rinaldi

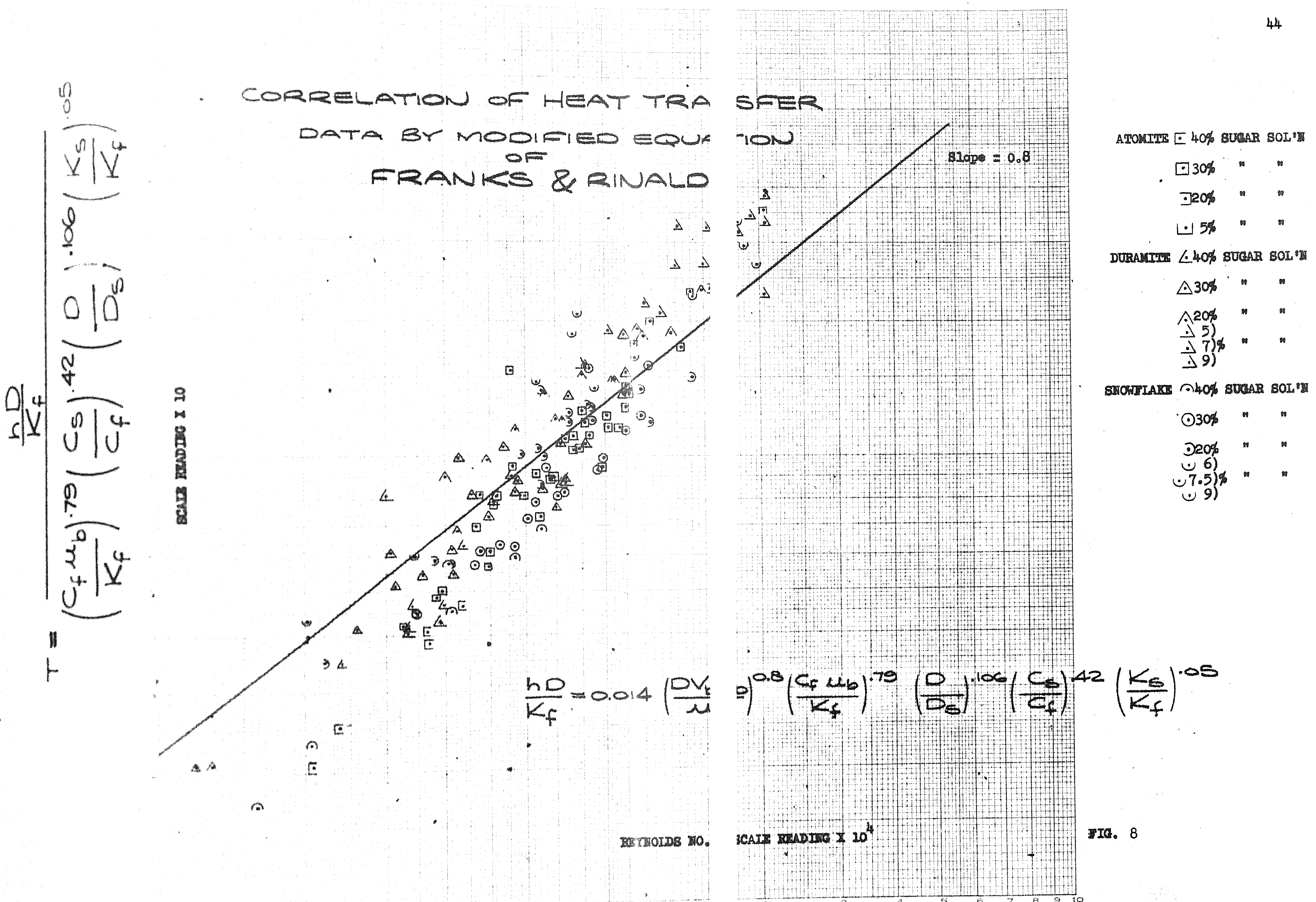

CORRELATION OF HEAT TRANSFER
DATA BY MODIFIED EQUATION
OF
FRANKS & RINALDO
$T = \dfrac{\frac{hD}{K_f}}{\left(\frac{C_f \mu_b}{K_f}\right)^{.79}\left(\frac{C_s}{C_f}\right)^{.42}\left(\frac{D}{D_s}\right)^{.106}\left(\frac{K_s}{K_f}\right)^{.05}}$
SCALE READING X 10
Slope = 0.8
ATOMITE 40% SUGAR SOL'N
30% " "
20% " "
5% " "
DURAMITE 40% SUGAR SOL'N
30% " "
20% " "
5) 7)% 9) " "
SNOWFLAKE 40% SUGAR SOL'N
30% " "
20% " "
6) 7.5)% 9) " "
$\frac{hD}{K_f} = 0.014 \left(\frac{DV\rho}{\mu}\right)^{0.8}\left(\frac{C_f \mu_b}{K_f}\right)^{.79}\left(\frac{D}{D_s}\right)^{.106}\left(\frac{C_s}{C_f}\right)^{.42}\left(\frac{K_s}{K_f}\right)^{.05}$
REYNOLDS NO. SCALE READING X 10^4
2 3 4 5 6 7 8 9 10

FIG. 8

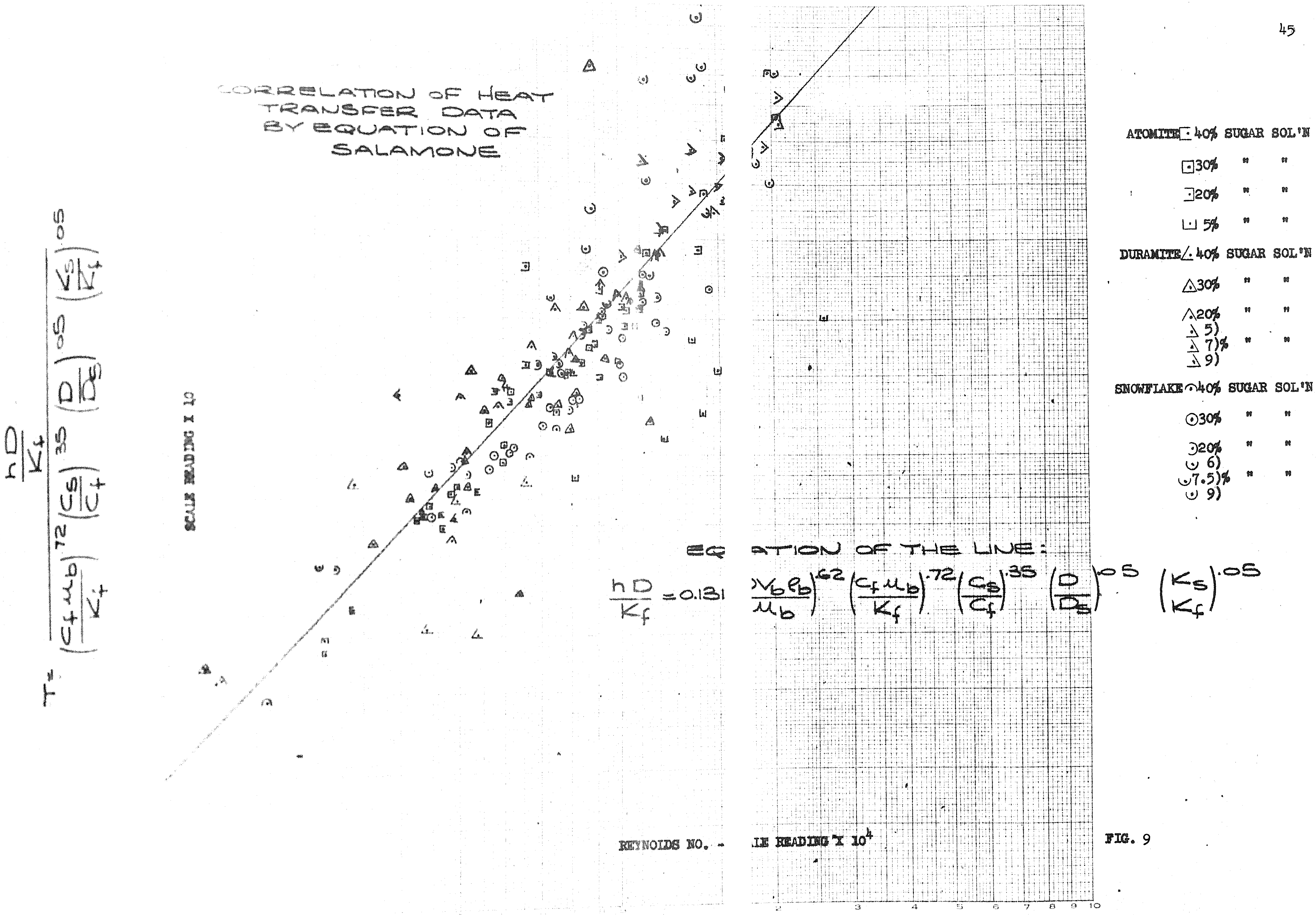

CORRELATION OF HEAT TRANSFER DATA BY EQUATION OF SALAMONE
$T = \dfrac{\frac{hD}{K_f}}{\left(\frac{C_f \mu_b}{K_f}\right)^{.72}\left(\frac{C_s}{C_f}\right)^{.35}\left(\frac{D}{D_s}\right)^{.05}\left(\frac{K_s}{K_f}\right)^{.05}}$
SCALE READING X 10
REYNOLDS NO. - SCALE READING X 10^4
EQUATION OF THE LINE:
$\frac{hD}{K_f} = 0.131 \left(\frac{DV_b \rho_b}{\mu_b}\right)^{.62}\left(\frac{C_f \mu_b}{K_f}\right)^{.72}\left(\frac{C_s}{C_f}\right)^{.35}\left(\frac{D}{D_s}\right)^{.05}\left(\frac{K_s}{K_f}\right)^{.05}$
ATOMITE 40% SUGAR SOL'N
30% " "
20% " "
5% " "
DURAMITE 40% SUGAR SOL'N
30% " "
20% " "
5) 7)% 9) " "
SNOWFLAKE 40% SUGAR SOL'N
30% " "
20% " "
6) 7.5)% 9) " "
2 3 4 5 6 7 8 9 10

FIG. 9

DISCUSSION OF CORRELATED RESULTS

From Fig. 8 it may be seen that the line through the plotted data has a slope of 0.8 and is representative between the Reynolds numbers of 50,000 to 200,000. The slope represents the best average slope of the individual plotted data of Figs. 4, 5, 6 and 7. The runs shown below 50,000 were disregarded in drawing this line.

The authors obtained an intercept of 0.014 versus the Franks and Rinaldi intercept of 0.0138. This displacement of curve is probably the result of oxide formation on the wall of the heat exchanger, and the previously described particle coating on the tube surface.

The calculated values for 'h' were obtained using 0.014 as the constant in the Franks and Rinaldi(8) equation.

TABLE NO. 6

CORRELATED RESULTS FOR SUSPENSIONS

RUN NO.	Re x 10^3	Re.$^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.106}$	FIL CAL	EFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A" $FT.^2$/$FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	Eq. of SALAMONE **
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 7%													
1	91.1	93.6	2.316	1.00	0.534	2.11	247	3635	-32.0	2.034	2657	191.1	275.8
2	111.0	110.0	2.24	1.00	0.534	2.11	278	4045	-31.15	2.034	2657	220.1	316.8
3	165.8	145.0	2.05	1.00	0.534	2.11	336	5710	-41.2	2.034	2657	339.0	485.0
4	178.0	159.0	2.09	1.00	0.534	2.11	387	5705	-32.0	2.034	2657	261.0	377.3
5	205.5	180.0	2.13	1.00	0.538	2.11	427	7440	-42.55	3.369	4409	232.0	619.0
6	178.9	159.0	2.192	1.00	0.538	2.11	388	5670	-31.5	3.369	4409	319.0	460.0
7	149.8	130.0	2.248	1.00	0.538	2.11	326	4900	-33.45	3.369	4409	269.0	397.2
8	132.0	126.0	2.291	1.00	0.538	2.11	322	6090	-47.2	3.369	4409	328.0	474.5
9	153.0	133.0	2.263	1.00	0.538	2.11	298	4263	-30.0	3.369	4409	175.0	253.1
10	185.0	170.0	2.173	1.00	0.538	2.11	467	6400	-27.0	3.859	5041	280.0	404.5
11	163.0	144.0	2.250	1.00	0.538	2.11	355	7670	-53.7	3.859	5041	267.0	385.0
12	130.4	125.0	2.220	1.00	0.538	2.11	303	4800	-36.75	4.290	5604	154.0	233.0
13	81.9	85.0	2.545	1.00	0.54	2.11	242	3295	-25.7	4.727	6175	383.0	486.0
14	206.5	185.0	2.045	1.00	0.528	2.11	429	6440	-32.4	1.479	1932	343.0	486.0
15	190.5	165.0	1.93	1.00	0.528	2.11	361	5450	-33.8	1.479	1932	321.0	458.0
16	153.6	133.0	1.975	1.00	0.528	2.11	297	5225	-42.9	1.479	1932	258.0	368.0
17	120.0	119.0	2.06	1.00	0.528	2.11	278	4370	-36.4	1.479	1932	311.0	445.0
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 7%													
18	20.2	27.82	2.405	1.00	0.53	2.31	81	905	- 9.94	1.89	5756	43.2	57.2
19	85.7	88.39	2.56	1.00	0.53	2.31	276	3164	-12.76	1.89	5756	141.9	215.5
20	104.7	103.8	2.433	1.00	0.53	2.31	308	3515	-12.11	1.89	5756	165.3	249.2
21	142.1	132.5	2.331	1.00	0.53	2.31	380	4652	-18.31	1.89	5756	227.0	342.3
22	184.7	163.4	2.20	1.00	0.53	2.31	443	5719	-22.4	1.89	5756	294.8	443.0
23	196.7	171.9	2.192	1.00	0.53	2.31	464	5183	-10.38	1.89	5756	268.3	403.9
24	34.4	42.6	2.84	1.00	0.53	2.31	148	1491	- 0.74	2.583	7867	59.9	91.6
25	63.6	69.6	2.733	1.00	0.53	2.31	231	3473	-33.2	2.583	7867	146.1	222.8
26	179.6	159.8	2.27	1.00	0.53	2.31	449	6374	-29.4	2.911	8866	317.3	477.7
27	76.2	80.4	2.525	1.00	0.534	2.31	250	4164	-39.8	3.154	9606	187.1	285.3
28	83.7	85.4	2.60	1.00	0.534	2.31	608	9319	-35.0	3.154	9606	423.0	645.0
29	90.3	108.5	2.58	1.00	0.534	2.31	394	5200	-24.25	3.154	9606	270.0	411.0
30	78.1	82.1	2.59	1.00	0.547	2.31	258	5281	-50.4	4.334	13,200	207.3	349.8

$$* \quad \frac{hD/K_f}{(C_f u_b/K_f)^{.79}\,(C_s/C_f)^{.42}\,(D/D_s)^{.106}\,(K_s/K_f)^{.05}}$$

$$** \quad \frac{hD/K_f}{(C_f \ \text{[illegible]}\ K_f)^{.72}\,(C_s/C_f)^{.35}\,(D/D_s)^{.05}\,(K_s/K_f)^{.05}}$$

TABLE NO. 6

CORRELATED RESULTS FOR SUSPENSIONS

RUN NO.	$Re \times 10^3$	$Re^{.8} \times 10^2$	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.106}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	$\phi \times 10^{-2}$ VALUES	"A" $FT.^2$/$FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 7%													
31	153.6	133.0	2.56	1.00	0.547	2.31	3054	4490	-32.0	4.334	13,200	230.0	351.0
32	132.0	126.0	2.54	1.00	0.547	2.31	3819	4493	-15.0	4.334	13,200	258.0	389.7
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 5%													
33	205.5	178.0	2.15	1.00	0.529	2.54	5140	7600	-32.35	1.368	10,010	363.2	570.0
34	114.6	112.4	2.445	1.00	0.529	2.54	3670	4720	-23.3	1.368	10,010	199.5	317.0
35	103.2	103.0	2.435	1.00	0.529	2.54	3370	4050	-16.8	2.108	15,430	169.4	280.0
36	139.4	132.0	2.39	1.00	0.529	2.54	4240	5440	-22.07	2.108	15,430	233.5	380.5
37	167.5	151.5	2.305	1.00	0.529	2.54	4705	7000	-32.75	2.108	15,430	311.0	506.0

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. pg. 47

TABLE NO. 6

CORRELATED RESULTS

RUN NO.	Re x 10^3	$Re^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.1}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A_2" $FT.^2$ / $FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%													
38	40.5	48.55	3.3	1.00	0.553	2.11	1726	2270	-23.95	1.624	2115	89.5	133.6
39	69.6	75.25	3.105	1.00	0.553	2.11	2422	2900	-16.48	1.624	2115	121.2	167.9
40	94.6	95.80	2.91	1.00	0.553	2.11	3032	3320	- 8.68	1.96	2553	147.2	216.5
41	107.3	106.40	2.81	1.00	0.553	2.11	3230	4155	-22.25	1.96	2553	191.0	279.5
42	147.5	136.9	2.7	1.00	0.553	2.11	4035	4920	-17.98	1.96	2553	233.8	343.0
43	48.6	56.45	3.28	1.00	0.553	2.11	2019	2561	-21.15	3.69	4805	98.9	127.8
44	71.7	77.50	3.095	1.00	0.553	2.11	2615	2920	-10.5	4.055	5285	121.4	181.0
45	92.9	93.60	3.095	1.00	0.553	2.11	3155	3565	-11.5	4.055	5285	148.0	223.0
46	38.8	46.9	3.565	1.00	0.553	2.11	1796	1775	+ 1.18	2.89	3770	42.9	64.7
47	41.3	49.1	3.585	1.00	0.553	2.11	1156	1870	-38.15	3.175	4140	67.9	102.0
48	65.7	72.7	3 .42	1.00	0.553	2.11	2675	3670	-27.1	3.175	4140	139.6	208.7
49	81.5	85.4	3.15	1.00	0.553	2.11	2915	3900	-25.28	3.175	4140	160.2	238.5
50	107.7	107.5	2.908	1.00	0.553	2.11	3405	4210	-19.12	3.175	4140	186.3	273.5
51	12.7	19.33	5.085	1.00	0.553	2.11	1014	820	+23.7	4.48	5840	20.8	32.3
52	57.4	64.45	3.285	1.00	0.553	2.11	2308	2965	-22.15	4.48	5840	115.8	172.6
53	89.7	91.50	3.01	1.00	0.553	2.11	3000	3555	-15.16	4.48	5840	151.9	224.7

RUN NO.	Re x 10^3	$Re^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.1}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A_2" $FT.^2$ / $FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%													
54	59.1	65.5	3.16	1.00	0.553	2.31	2462	2740	-10.1	1.526	4650	102.0	159.2
55	64.9	71.0	3.115	1.00	0.553	2.31	2632	2269	+15.59	1.733	5280	85.7	126.1
56	101.6	101.8	2.86	1.00	0.553	2.31	3485	3450	+ 1.01	1.733	5280	141.8	218.5
57	142.7	127.6	3.265	1.00	0.553	2.31	4975	4160	+19.6	1.733	5280	149.2	234.0
58	75.5	79.7	2.97	1.00	0.553	2.31	2825	3145	-10.14	1.733	5280	124.5	192.5
59	41.1	49.15	3.45	1.00	0.553	2.31	2000	1693	+14.12	1.733	5280	58.3	91.5
60	75.0	79.7	3.26	1.00	0.553	2.31	3070	3255	- 5.68	1.733	5280	118.5	104.5
61	83.6	71.8	3.095	1.00	0.553	2.31	2642	3390	-22.8	2.325	7080	129.0	201.5
62	154.4	141.6	2.89	1.00	0.553	2.31	4865	5850	-16.85	2.325	7080	238.5	369.0
63	108.5	106.2	3.335	1.00	0.553	2.31	4185	3985	+ 5.82	2.97	9040	141.7	222.2
64	113.6	108.7	3.01	1.00	0.553	2.31	3895	3062	+27.2	2.97	9040	119.6	186.0
65	85.0	87.4	3.22	1.00	0.553	2.31	3350	3315	+ 1.05	3.425	10,420	121.4	188.5
66	64.1	70.2	3.46	1.00	0.553	2.31	2880	3040	- 5.26	3.425	10,420	104.4	163.8
67	21.7	29.5	4.42	1.00	0.553	2.31	1505	1283	+17.31	2.97	9040	35.2	56.2
68	38.4	46.9	3.96	1.00	0.553	2.31	2171	1950	+11.32	3.425	10,420	89.9	93.8

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. pg. 47

TABLE NO. 6

CORRELATED RESULTS

RUN NO.	Re x 10^3	$Re^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{..}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A" $FT.^2$ / $FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%													
69	66.2	71.8	3.55	1.00	0.553	2.31	3002	3035	- 1.19	3.58	10,890	101.7	160.0
70	82.6	85.70	3.3	1.00	0.553	2.31	3340	3665	- 8.87	3.58	10,890	131.9	206.0
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 20%													
71	59.6	66.30	3.68	1.00	0.553	2.54	3140	2760	+13.76	1.336	9940	81.5	135.5
72	80.7	84.30	3.51	1.00	0.553	2.54	3810	3850	- 1.04	1.463	10,880	118.9	197.0
73	90.1	92.55	3.27	1.00	0.553	2.54	3960	3730	+ 6.17	1.545	11,500	121.8	200.9
74	99.6	99.20	3.27	1.00	0.553	2.54	4245	3945	+ 7.61	2.005	14,950	128.8	212.2
75	100.0	100.0	3.34	1.00	0.553	2.54	2765	4520	-38.85	2.96	22,000	144.6	238.9
76	92.0	93.6	3.38	1.00	0.553	2.54	4140	3970	+ 4.25	2.96	22,000	125.5	207.5
77	79.3	83.0	3.42	1.00	0.553	2.54	3710	3400	+ 9.12	2.96	22,000	104.1	175.4
78	55.7	63.0	3.72	1.00	0.553	2.54	3041	5375	-43.45	4.43	22,000	157.0	261.1
79	47.5	55.15	4.06	1.00	0.553	2.54	2882	3100	- 7.05	4.43	32,920	82.2	138.4
80	58.8	63.0	3.83	1.00	0.553	2.54	3130	3390	- 7.67	4.84	32,920	95.4	159.2
81	83.4	86.3	3.58	1.00	0.553	2.54	4005	3670	+ 9.13	5.88	35,900	110.4	147.4
82	92.2	93.6	3.68	1.00	0.553	2.54	4770	3955	+14.28	0.60	43,700	115.7	192.6
83	50.8	58.4	3.51	1.00	0.553	2.54	2659	2555	+4.07	0.60	4400	78.4	130.0
84	73.8	78.2	3.23	1.00	0.553	2.54	3275	3250	+ 7.69	0.60	4400	108.2	130.8
85	100.9	100.9	3.07	1.00	0.553	2.54	4010	3900	+ 2.82	0.60	4400	137.0	224.0
86	133.3	126.3	2.93	1.00	0.553	2.54	4800	4750	+ 1.05	0.60	4400	174.7	283.5

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. pg. 47

TABLE NO. 6

CORRELATED RESULTS

RUN NO.	Re x 10^3	$Re^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.106}$	LM COEFF. (h) LC.	LM COEFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A" $FT.^2$ / $FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%													
87	11.9	18.25	5.77	1.00	0.571	2.11	76	924	+16.45	2.06	3683	21.9	34.5
88	35.9	44.3	4.65	1.00	0.571	2.11	36	1884	+13.32	2.06	3683	54.6	84.3
89	53.5	61.10	3.24	1.00	0.571	2.11	59	2530	-18.61	2.54	3311	105.1	119.5
90	74.3	79.60	3.97	1.00	0.571	2.11	07	4060	-18.54	2.54	3311	136.4	211.8
91	100.2	104.90	3.78	1.00	0.571	2.11	80	4385	- 4.67	2.54	3311	154.3	233.8
92	98.9	100.0	3.93	1.00	0.571	2.11	39	5535	- 2.52	2.54	3311	187.1	284.7
93	30.3	38.55	4.79	1.00	0.573	2.11	11	2162	-11.60	3.0	3910	61.1	94.4
94	56.7	63.50	4.46	1.00	0.573	2.11	57	2780	+ 6.36	3.0	3910	83.5	128.7
95	26.3	34.38	5.05	1.00	0.573	2.11	04	1550	+16.01	3.76	4910	41.4	64.4
96	45.5	53.80	4.57	1.00	0.573	2.11	62	2795	- 8.33	3.76	4910	82.1	126.4
97	57.85	64.80	4.05	1.00	0.573	2.11	54	2680	+ 2.76	3.76	4910	88.1	134.3
98	69.8	75.25	3.89	1.00	0.573	2.11	74	2240	+37.23	3.76	4910	76.8	114.3
99	78.5	82.50	3.96	1.00	0.573	2.11	55	1414	+ 9.90	3.76	4910	47.6	725.8
100	31.2	39.45	5.59	1.00	0.573	2.11	72	2108	+ 7.77	4.64	6050	51.2	80.33
101	41.5	49.15	4.90	1.00	0.573	2.11	07	2271	+10.39	4.64	6050	62.3	96.6
102	42.9	50.85	4.62	1.00	0.573	2.11	45	3400	-28.08	4.64	6050	99.1	153.1
103	49.6	57.10	4.16	1.00	0.573	2.11	91	2290	+ 8.77	4.64	6050	73.4	147.3
104	72.0	77.10	4.02	1.00	0.573	2.11	67	3250	+ 0.52	4.64	6050	107.0	163.0
105	99.0	99.30	3.90	1.00	0.573	2.11	99	4110	- 0.27	4.64	6050	139.0	211.5
106	41.5	50.00	4.64	1.00	0.573	2.11	14	1890	+27.72	3.464	4525	54.7	84.6
107	65.5	71.25	4.26	1.00	0.573	2.11	85	2700	+17.96	3.464	4525	84.5	129.4
108	72.0	77.50	4.19	1.00	0.573	2.11	09	2815	+21.10	3.69	4814	89.3	137.0
109	81.6	85.00	4.20	1.00	0.573	2.11	43	3345	+11.89	3.464	4525	106.3	162.8
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%													
110	34.9	43.03	4.82	1.00	0.572	2.31	357	1764	+25.1	2.513	7654	44.82	72.95
111	52.3	59.51	4.44	1.00	0.572	2.31	362	2315	+28.8	2.91	8857	63.54	103.03
112	66.7	72.35	4.20	1.00	0.572	2.31	3656	3267	+28.8	3.245	9883	94.06	151.59
113	83.35	86.34	3.94	1.00	0.572	2.31	09	5146	+41.12	3.245	9883	157.27	252.61
114	89.2	91.26	4.08	1.00	0.572	2.31	391	3340	+33.57	3.245	9883	98.7	158.63
115	108.2	106.50	3.64	1.00	0.572	2.31	258	3770	+22.21	3.648	11111	123.02	195.70
116	46.2	53.89	4.47	1.00	0.572	2.31	561	2120	- 2.81	4.175	15,221	57.36	92.87
117	63.0	69.08	4.21	1.00	0.572	2.31	476	2759	+40.36	3.99	14,557	78.99	127.16

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. pg. 47

TABLE NO. 6

CORRELATED RESULTS

RUN NO.	Re x 10^3	$Re^{.8}$ x 10^2	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.106}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	ϕ x 10^{-2} VALUES	"A" $FT.^2$ / $FT.^3$ of suspension	"T" VALUES: Eq. of FRANKS & RINALDI *	"T" VALUES: Eq. of SALAMONE **
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%													
118	72.8	77.62	4.05	1.00	0.572	2.31	3041	2800	+31.36	3.99	14,557	83.02	133.23
119	47.5	55.11	4.50	1.00	0.572	2.31	3520	2284	+ 7.74	2.91	8863	61.84	100.27
120	60.3	66.75	4.36	1.00	0.572	2.31	3958	2610	-23.0	2.91	8863	72.61	117.36
121	70.2	75.35	4.19	1.00	0.572	2.31	4340	2839	+29.55	2.91	8863	81.8	132.36
122	56.5	63.32	4.25	1.00	0.572	2.31	4573	2203	+21.23	1.02	7449	62.81	101.14
123	86.5	89.01	3.75	1.00	0.572	2.31	2892	2913	+36.41	1.02	7449	93.34	148.87
124	100.1	100.05	3.64	1.00	0.572	2.31	3379	3484	+22.47	1.02	7449	114.5	182.17
125	112.5	109.90	3.54	1.00	0.572	2.31	3664	4693	+30.85	1.02	7449	158.3	251.18
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 30%													
126	32.5	40.73	5.0	1.00	0.572	2.54	2465	1903	+29.53	1.472	9732	41.93	71.86
127	46.5	54.17	4.2	1.00	0.572	2.54	2754	2664	+ 3.38	1.472	9732	69.78	118.05
128	62.9	69.02	3.92	1.00	0.572	2.54	3276	3269	+ 2.14	1.472	9732	91.56	154.14
129	76.5	80.72	3.64	1.00	0.572	2.54	3557	3426	+ 3.82	1.472	9732	103.4	172.23
130	96.8	90.42	3.86	1.00	0.572	2.54	4773	4057	+17.64	1.388	10,156	115.53	194.29
131	49.5	56.98	4.33	1.00	0.572	2.54	3114	2222	+40.14	3.259	23,846	56.84	96.22
132	64.5	70.40	4.24	1.00	0.572	2.54	3785	2832	+33.65	3.259	23,846	73.65	124.45
133	76.4	84.26	4.19	1.00	0.572	2.54	4485	4212	+ 6.48	3.259	23,846	110.87	187.46
134	88.7	90.84	4.14	1.00	0.572	2.54	4786	3553	+34.7	3.259	23,846	94.5	159.71
135	39.2	47.31	4.15	1.00	0.572	2.54	2482	1848	+32.14	2.076	15,190	50.16	84.59
136	51.7	59.00	4.1	1.00	0.572	2.54	2927	2993	- 2.21	2.076	15,190	81.64	137.39
137	69.3	74.57	4.0	1.00	0.572	2.54	3750	3228	+16.17	2.076	15,190	89.82	151.01
138	38.1	46.23	4.25	1.00	0.572	2.54	2480	1860	+33.33	3.882	28,405	48.53	81.91
139	34.5	42.73	5.01	1.00	0.572	2.54	2701	2030	+33.05	4.31	31,537	45.04	76.94
140	50.0	57.43	4.52	1.00	0.572	2.54	3294	2525	+30.46	4.09	29,927	61.58	104.66
141	68.2	73.64	4.25	1.00	0.572	2.54	3996	3463	+15.39	4.31	31,537	89.44	150.95

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. Pg. 47

TABLE NO. 6

CORRELATED RESULTS

RUN NO.	$Re \times 10^3$	$Re^{.8} \times 10^2$	$(C_f u_b/K_f)^{.79}$	$(K_s/K_f)^{.05}$	$(C_s/C_f)^{.42}$	$(D/D_s)^{.1}$	FILM COEFF. (h) CALC.	FILM COEFF. (h) EXPTAL	% DEV.	$\phi \times 10^{-2}$ VALUES	"A" $FT.^2$/$FT.^3$ of suspension	"T" VALUES Eq. of FRANKS & RINALDI *	"T" VALUES Eq. of SALAMONE **
DURAMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%													
142	24.0	32.25	6.28	1.00	0.589	2.109	2125	1594	-33.55	2.21	2875	34.8	69.7
143	39.6	47.95	5.69	1.00	0.589	2.109	2756	1918	-43.7	2.21	2875	46.7	92.65
144	43.8	52.35	5.33	1.00	0.589	2.109	2830	2441	-15.94	2.74	3575	53.1	124.8
145	34.0	42.65	5.83	1.00	0.589	2.109	2515	2012	-25.0	3.16	4125	46.45	95.3
146	55.5	63.20	5.31	1.00	0.589	2.109	3405	3440	+ 1.02	3.16	4125	90.1	178.6
147	71.9	77.00	5.07	1.00	0.585	2.109	3940	3150	-25.1	3.85	3024	86.33	153.2
148	50.8	58.40	5.39	1.00	0.585	2.109	3162	3065	- 3.17	3.85	3024	79.35	141.8
149	33.2	41.35	6.25	1.00	0.585	2.109	2592	1794	-44.5	3.85	3024	40.12	72.7
150	32.5	41.80	6.39	1.00	0.584	2.109	2685	1897	-41.5	4.94	3879	41.45	75.4
151	73.6	78.50	5.06	1.00	0.584	2.109	4010	3152	-27.2	5.08	3983	86.9	154.2
152	30.03	38.20	5.21	1.00	0.59	2.109	2196	3018	-28.2	0.55	1646	81.9	135.4
153	39.05	47.13	6.80	1.00	0.59	2.109	3176	2294	+51.5	0.55	1646	42.87	72.46
SNOWFLAKE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%													
154	64.6	70.51	5.53	1.00	0.589	2.31	4250	3002	+41.5	0.88	2692	68.75	114.1
155	41.3	49.32	6.22	1.00	0.589	2.31	3324	2204	+50.8	0.88	2692	45.15	75.5
156	20.6	33.99	7.20	1.00	0.589	2.31	2627	1291	+103.5	0.88	2692	23.06	39.30
157	56.7	63.49	6.20	1.00	0.589	2.31	4280	2903	+47.4	2.65	8077	59.54	99.6
158	40.7	48.74	6.62	1.00	0.589	2.31	3490	3000	+16.35	2.65	8077	57.71	97.0
159	15.8	22.85	8.40	1.00	0.589	2.31	2052	1094	+87.5	2.65	8077	16.8	29.0
ATOMITE - AVERAGE CONCENTRATION OF SUGAR SOLUTION - 40%													
160	36.9	45.02	8.27	1.00	0.589	2.54	4438	2914	+52.3	1.43	10,441	40.8	73.7
161	37.0	45.13	7.30	1.00	0.589	2.54	3903	2412	+61.8	1.43	10,441	38.4	68.8
162	20.9	28.55	7.30	1.00	0.589	2.54	2444	1281	+90.8	1.43	10,441	20.6	36.9
163	43.5	51.43	7.71	1.00	0.591	2.54	4697	3080	+52.5	2.86	20,934	46.4	83.1
164	23.7	31.60	9.04	1.00	0.591	2.54	3361	1949	+72.4	2.86	20,934	25.2	45.8

* Eq. of Franks & Rinaldi, Cf. pg. 47

** Eq. of Salamone, Cf. pg. 47

SUMMARY AND CONCLUSION

A reasonable correlation between experimental values for 'h' and calculated 'h' values was obtained using the viscosity as determined by the Curtis and Gullett equation(7). The equation, $u/u_w = (AK/GC)^{.105}$, represents the effect of velocity, concentration, particle size, particle thermal conductivity and heat capacity of the suspending medium upon the apparent or bulk viscosity on water slurries. The average deviation being 14.4%.

In applying this equation to slurries where the suspending media was a dilute sugar solution the equation was found to give reasonable results between the limiting viscosity values of 1.5#/ft. hr. to 4.0#/ft. hr. when used in the modified Franks and Rinaldi equation(8) for heat transfer coefficients. This deviation was found to be 16.1%.

Although a satisfactory correlation was obtained, certain assumptions were necessary, which require confirmation through collection and interpretation of additional data.

The particle size values obtained from the manufacturer were accepted at face value. The accuracy of these values and the uniformity of different batches of the same material should be investigated.

The shape of the particles investigated was assumed to be spherical, the particle shape should actually be determined and data obtained for both spherical and non-spherical particles(7).

The Franks and Rinaldi equation was used to calculate the heat transfer film coefficient. The bulk of the data falls within 20% of the mean of these points; well within the limits of accuracy expected in an investigation of this nature.

Hence the equation developed by Curtis and Gullett(7) can be used between the limiting slurry viscosities of 1.5 to 4.0#/ft. hr. in predicting the film coefficient for heat transfer of non-Newtonian suspensions.

The above mentioned equations can therefore be used in the design of heat transfer data for slurries and a reasonable degree of accuracy can be expected.

Additional data for slurries of other suspending media is desirable, as well as, further investigation for predicting the upper limit of concentration when materials of higher density are used. This phase offers considerable room for further investigation.

The authors feel that the amount of data above 40,000 Reynolds number is presently sufficient to formulate the conclusions herein drawn regarding dilute sugar solution suspensions of solids, but are fully aware of the fact that the range below 40,000 Reynolds number presents considerable work for future investigations.

It is suggested that an improved technique of slurry sampling for the purpose of obtaining the apparent bulk density of the suspension be devised. Centrifuging the sample would give a more accurate method of determining the weight fraction of solids and the percent concentration of the sugar solution or other dispersing liquid.

Since viscosity of the non-Newtonian solution is of such importance in the calculations, it would be advisable to check slurry samples by experimenters, such as Weltman & Kuhn(16), and Krieger & Elrod(21), who are devising equipment for this purpose. The need for an accurate method of determining these viscosities is recognized in the field, and correlation of results by calculation using the equation of Curtis and Gullett(7) and by instrumentation methods would be worth considering.

Additional work is desirable in re-evaluating the exponents of the Franks and Rinaldi equation in view of all the available data.

LIST OF SYMBOLS AND UNITS

A............Surface area of particles, sq.ft/cu.ft. of suspension.

A_1............Heat transfer surface, sq.ft.

C, C_f........Specific heat of fluid or suspending medium, BTU/(LB)(°F).

C_s............Specific heat of suspended solid, BTU/(LB)(°F).

D............Pipe diameter, ft.

D_s............Average diameter of suspended solid particles, ft.

g_c............Dimensional constant, 32.2(LB)(FT.)/(LB)(SEC)^2

G............Mass velocity, LB./Sec.-Sq.Ft.

h............Film coefficient of heat transfer, BTU/(HR.)(°F)(SQ.FT.)

K,K_f.........Thermal conductivity of fluid or suspending medium, BTU/(HR.)(°F)(FT)

K_s............Thermal conductivity of suspended solid, BTU/(HR.)(°F)(FT.)

L............Length of pipe, ft., any linear dimension.

M............Any mass dimension.

q............Heat transfer rate, BTU/HR.

t............Temperature, °F, any temperature dimension.

Δt_m............Logarithmic mean temperature difference between average inside pipe surface temperature and inlet and outlet slurry temperature °F.

v............Linear velocity, ft./sec.

v_b...........Linear velocity of suspension, based on the bulk density of the suspension, ft./sec.

x............Weight fraction of solid.

ϕ ....Volume fraction of solid in suspension.

ρ ....Density of fluid,Lbs./Cu.Ft.

ρ_b ....Bulk density of suspension, Lbs./Cu.Ft.

ρ_s ....Density of solid, Lbs/Cu.Ft.

u ....Viscosity of fluid

u_w .... Viscosity of fluid at wall temperature.

u_b .... Apparent bulk viscosity of suspension.

Nu..............Nusselt number, hD/k, dimensionless.

Pr..............Prandtl number, $C_f u_b/k$, dimensionless.

Re..............Reynolds number, DV_b $/u_b$, dimensionless.

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APPENDIX

SAMPLE CALCULATIONS

SAMPLE RUN NO.58 (Snowflake-20% Sugar Solution)

1. SLURRY DENSITY: Weight Of Water @ 65°C To Fill Volumetric Flask = 11.62 Lbs.

$$\text{Slurry Density} = 62.37\ \frac{(12.688)}{11.62} = 68.1\ \text{Lbs./Ft}^3.$$

2. LINEAR VELOCITY OF SLURRY-FT./HR.

Observed Rate - 36sec. per 49 Lbs. Slurry

$$\frac{49.0}{36.} = 1.362\ \text{Lbs./Sec.}$$

Density Of Slurry = 68.1 Lbs./Ft^3.

$$\frac{1.362\ (3600)}{(68.1)(0.00211)} = 34{,}120\ \text{Ft./Hr.}$$

3. WEIGHT % SOLIDS

$$68.1\ \text{Lbs./Ft}^3. = \frac{68.1}{62.37}\ \text{Gm./cc} = 1.092\ \text{Gm./cc}$$

From Fig.2 - Weight % Snowflake = 4.3%

4. MEAN SPECIFIC HEAT OF SLURRY

Specific Heat Of 20% Sugar Solution = 0.86 BTU/Lbs.-°F. (Perry)

Specific Heat Of Slurry = 0.86 - (0.86-0.209)(0.043) = 0.832 BTU/Lbs.-°F.

5. SLURRY HEAT = q

$q = (\text{Rate})(\text{Temp.Rise})(\text{Sp.Ht.})$

$= 4900\ (1.8)(92.8-73.8)(.832)$

$q = 139{,}400$ BTU/Hr.

6. EXPERIMENTAL FILM COEFFICIENT OF HEAT TRANSFER

$h = q/a\Delta t_m$.

$q = 139{,}400$ BTU/Hr.

$A = (3.14)\ 0.622/(12)(8.0) = 1.30\ ft^2$.

(Theor.) or $1.30 \times 1.0625 = 1.38\ ft^2$.

Mil tolerance can give thickness 12.5% less or Average 6.25% less.

Arithmetic Average of all milivolt readings is 4.645 MV. Equivalent to outer surface temperature of 226.0 °F.

$$\text{Drop in temp. across wall } {}^{\circ}F = \frac{q\ (\text{Pipe wall thickness})}{K \text{ metal } A \text{ average}}$$

$$^{\circ}F = \frac{(139{,}400)(0.109/12)}{(90)(1.38)(0.731/0.622)} = 8.68\ ^{\circ}F.$$

Average Inner Temperature

226.0-8.68 218.32 °F.

K for Brass = 90 BTU/(Hr.)(°F) ft.

$$\Delta t_m = \frac{(218.32-165.0)-(218.32-199.0)}{\ln \dfrac{218.32-165.0}{218.32-199.0}}$$

$\Delta t_m = 33.65\ ^{\circ}F$.

$$h = 139{,}400/(1.38)(33.65)$$

$$h = 3002 \text{ BTU/(Hr.)(Sq.Ft.)}(^{\circ}\text{F})$$

7. MASS VELOCITY OF SLURRY

$$\text{Mass Velocity (G)} = 1.363 \frac{\#}{\text{sec.}} \frac{(1)}{(0.00211 \text{ ft.}^2)}$$

$$= 645 \frac{\#}{\text{sec.-ft.}^2}$$

8. Volume Fraction of Solid in Slurry

Weight % Snowflake in Slurry = 4.3%

Slurry Density = 68.1 Lbs./Ft.^{3}

Solid Particle Density = (2.71)(62.37 Lbs./Ft.^{3})

$$\text{Volume Fraction} = \frac{(0.043)(68.1)}{(2.71)(62.37)} = 0.01733 \frac{\text{ft.}^3 \text{solid}}{\text{ft.}^3 \text{slurry}}$$

9. SURFACE AREA OF PARTICLES

Spherical particles of the same diameter equal to the average diameter are assumed.

$$\text{Volume per solid particle} = \frac{\pi D^3}{6} \text{ ft}^3$$

$$N = \frac{\text{number of solid particles}}{\text{ft}^3 \text{ slurry}} = \frac{6\phi}{\pi D^3}$$

$$A = \frac{\text{surface area of solid particles}}{\text{ft}^3 \text{ slurry}}$$

$$= (N) \frac{\text{surface area}}{\text{particle}} = \frac{6\phi}{\pi D^3} \pi D^2 = \frac{6\phi}{D}$$

$$A = (6)\left(0.01733 \frac{\text{ft.}^3 \text{solid}}{\text{ft.}^3 \text{ slurry}}\right)$$

$$A = 5280 \text{ ft.}^2 \text{ solid surface /ft.}^3 \text{ slurry}$$

10. VISCOSITY OF SLURRY

$$u/u_w = 1.02\ (AK/GC)^{.105}$$

where $A = 5280 \dfrac{ft^2 \text{ solid surface}}{ft^3 \text{ slurry}}$

shown in calculation no.9

$K = 0.40$ BTU/(Hr.)(Sq.Ft.)(^oF/Ft.)

supplied by company

$G = 645 \dfrac{\#}{\text{sec. sq.ft.}}$

shown in calculation no.7

$C = 0.86$ BTU/(Lb.)(^oF) Perry's Handbook

$$u/u_w = 1.02 \left(\frac{(5280)(0.40)}{(645)(0.86)}\right)^{.105} = 1.177$$

u_w = Viscosity of 20% sugar solution at average temperature of slurry $= 1.355 \dfrac{\#}{\text{ft.hr.}}$

$$u_b = 1.177(1.355) = 1.60 \frac{\#}{\text{ft.hr.}}$$

11. HEAT SECTION REYNOLDS NUMBER

$$Re = \frac{D\ V_b}{u_b} = \frac{(0.052)(68.1)(34,120)}{1.60} = 75,450$$

12. CALCULATED FILM COEFFICIENT USING MODIFIED FRANK'S AND RINALDI'S EQUATION.

$$\frac{hD}{K_f} = 0.014\left[\frac{(D\ V_b)}{u_b}\right]^{.8}\left[\frac{C_f u_b}{K_f}\right]^{.79}\left[\frac{K_s}{K_f}\right]^{0.05}\left[\frac{C_s}{C_f}\right]^{.42}\left[\frac{D}{D_s}\right]^{.166}$$

$$\frac{h(0.622/12)}{(0.671)(0.517)} = 0.014(75,450)^{.8}\left[\frac{(0.86)(1.60)}{(0.671)(0.517)}\right]^{.79}$$

$$\left[\frac{(0.40)}{0.347}\right]^{0.05} \quad \left[\frac{(0.209)}{(0.86)}\right]^{0.42} \quad \left[\frac{(0.622/12)}{1.97 x 10^{-}}\right]^{.106}$$

h= 2825 BTU/Hr(°F) (sq.ft.)