ORIFICE DISCHARGE COEFFICIENTS FOR CARBOXYMETHYLCELLULOSE SOLUTIONS

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PREFACE

The discharge coefficients of sharp-edged orifices obtained in this work for carboxymethylcellulose water solutions (CMC) were correlated using the generalized Reynolds number derived by Metzner and Reed for pseudoplastic fluids. The discharge coefficients are compared with the data obtained by previous workers for Newtonian fluids. Also included is a discussion of static pressure distribution of pseudoplastic fluid flowing through the orifices.

I received aid from a number of people during the course of this project. I am indebted to Dr. Kenneth J. Bell, my adviser, for his aid and suggestions in relation to my study in this graduate school as well as to my thesis work. Mr. Don Adams gave many helpful suggestions and aid in the entire course of my study. Messrs. Gene E. McCroskey, Arlin Harris, and Preston Wilson were very helpful in the construction of the apparatus. I wish to express gratitude to Mrs. Don Adams who typed this thesis.

I am indebted to Oklahoma State University, which provided me with an institutional assistantship, and the Monsanto Chemical Company, which provided financial support for the experimental facilities.

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CHAPTER I

INTRODUCTION

Because of its convenience and simplicity, an orifice meter is a commonly used device for flow rate measurement of fluids in pipe lines of chemical plants.

No data have been represented in papers concerning orifice discharge coefficients for non-Newtonian fluids; whereas for Newtonian fluids, complete studies have been presented in an ASME report on fluid meters (1) and by Tuve and Sprenkle (2) thirty years ago.

Obtaining experimental data and correlating it in applicable form are required for reliable guidance in the design of orifice meters for non-Newtonian fluids.

The following goals were set for this project:

1. Design, construct, and operate apparatus to obtain the orifice discharge coefficients and pressure drops between various taps with three different orifice apertures (β = 0.8, 0.6, and 0.2) and two fluid concentrations (0.7 percent and 1.5 percent CMC in water).
2. Correlate these data as a function of flow rate, orifice dimensions, and the physical and rheological properties of non-Newtonian fluids.

CHAPTER II

LITERATURE SURVEY

Fluid Flow Through an Orifice Aperture

Figure 1 illustrates diagrammatically the static pressure distribution in the vicinity of a typical sharp-edged orifice in a pipe.

It has been observed that there is a considerable and sharp increase in the static pressure, termed the impact pressure, which is usually one to twenty percent of differential pressure, immediately upstream of the orifice plate due to the change in the direction of the streamlines (4). The vena contracta is the point of minimum static pressure and minimum cross-sectional area of the jet of fluid after it emerges from the orifice. The jet enters the relatively stagnant fluid behind the orifice plate; and, as the jet expands to fill the pipe downstream from the vena contracta, it entrains some of the surrounding fluid.

Most of the overall energy loss in the orifice arises from the viscous interaction and accompanying eddy formation downstream from the orifice.

Engel and Davies (5) have theoretically calculated the impact pressure based on the Bakhmeteff and Prandtl power law velocity profile and obtained remarkably good agreement with experimental results for $Re > 10^4$ (see Figure 2).

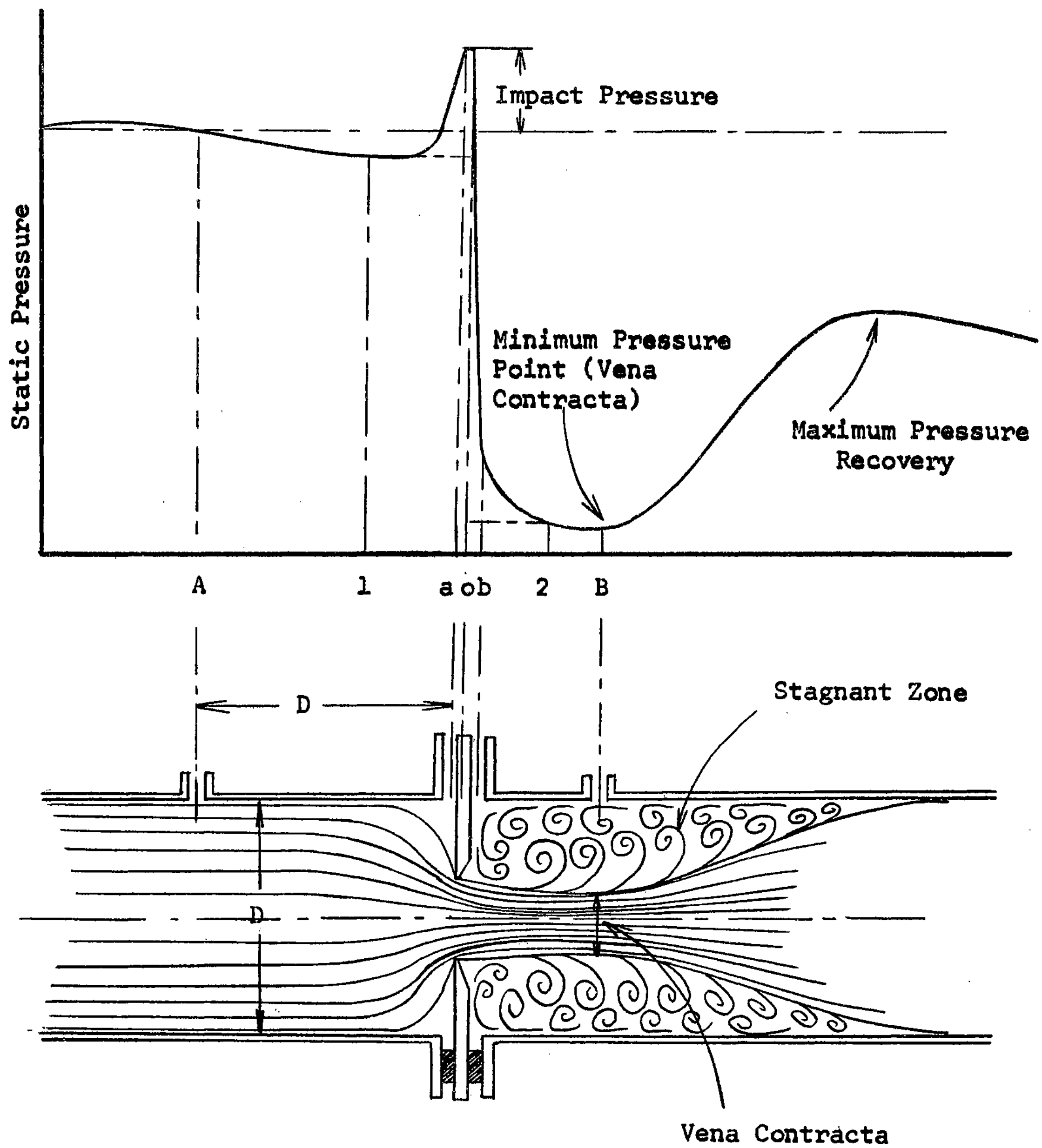


Figure 1. Schematic Diagram Showing Static Pressure Distribution Along a Pipeline in the Vicinity of an Orifice Plate

Connection
A-B: Vena Contracta Tapping
a-b: Corner Tapping

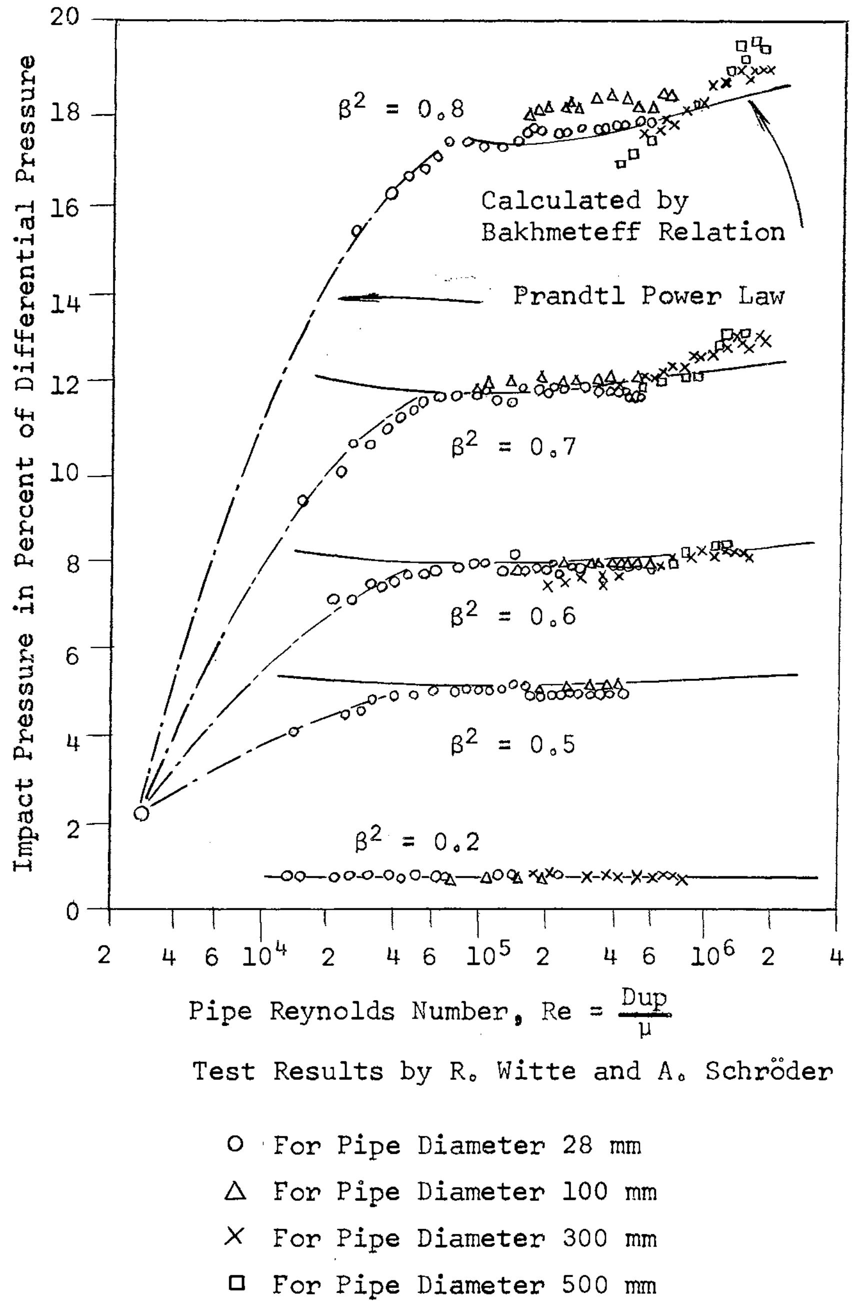


Figure 2. Impact Pressure in Percent of the Differential Pressure Measured Between Upstream Tapping Points A and a--See Figure 1

The jet contraction is thoroughly investigated in the ASME report on fluid meters (1); and it has been found that the amount of contraction depends primarily upon the diameter ratio, β, and the fluid properties:

1. The ratio of the jet area at the vena contracta to the area of the orifice decreases as β decreases.
2. The jet contraction decreases as the viscosity of the fluid increases.

These results would be expected because:

1. As the fluid particles near the wall of the channel converge toward the orifice, they attain greater radial velocity inward when β is small than when β is large.
2. As the viscosity increases, the effect of friction of the fluid against the surface of the channel extends farther toward the center; and the radial velocity of the streamlines from near the wall is small in proportion to the axial velocity of the streamlines at the center, thus making the vena contracta larger.

In this work, three inlet and six outlet pressure taps were used in order to study the points of minimum and maximum static pressure on the downstream side of the orifice as well as the magnitude of maximum static pressure on the upstream side. Connections between one upstream tap and each of six downstream taps gave the static pressure distribution along the pipe. The impact pressure could be measured as the pressure difference between the upstream corner tap and another tap on the same side (see Figure 5 and Table IV).

Orifice Discharge Coefficients for Newtonian Fluids

The general orifice discharge coefficient for incompressible fluids is derived from the extended Bernoulli equation or mechanical energy balance over an orifice between arbitrary positions 1 and 2 (see Figure 1):

$$\frac{u_2^2 - u_1^2}{2\ g_c} + \frac{P_2 - P_1}{\rho} + \ell_w = 0\ . \qquad (1)$$

Assuming that the energy loss ℓ_w from 1 to 2 is represented by some multiple of the pressure drop $(P_2 - P_1)/\rho$ and substituting $\ell_w = (C_v^2 - 1)\ (P_2 - P_1)/\rho$, Equation 1 is then written

$$C_v^2\ \frac{P_2 - P_1}{\rho} + \frac{u_2^2 - u_1^2}{2\ g_c} = 0\ . \qquad (2)$$

In order to eliminate the practical difficulty of evaluating the unknown velocity term u_2, the downstream velocity is more conveniently taken as the velocity through the orifice itself, u_o. To compensate the error thus introduced, a discharge coefficient, C_o, is defined by

$$C_o^2\ \frac{P_2 - P_1}{\rho} + \frac{u_o^2 - u_1^2}{2\ g_c} = 0\ . \qquad (3)$$

Substitution of $\beta = D_o/D$, $\Delta P = P_2 - P_1$, and $u_o D_o^2 = u_1 D^2$ gives the general discharge coefficient:

$$C_o = \frac{u_o}{\sqrt{\dfrac{2\ g_c\ (\Delta P/\rho)}{(1 - \beta^4)}}}\ . \qquad (4)$$

The discharge coefficient thus defined would also include various other effects, such as velocity profile effect, boundary layer effect, and roughness effect in the orifice itself.

The numerical values of C_o for sharp-edged orifices for Newtonian fluids with corner taps (see Figure 1) have been empirically determined by Tuve and Sprenkle (2) as a function of β and the orifice Reynolds number,

$$Re_o = \frac{D_o\, u_o\, \rho}{\mu}, \tag{5}$$

ranging from 4 to 10^5 (see Figure 3). The value of C_o depends on the location of the pressure taps.

The orifice discharge coefficients with flange taps, vena contracta taps, and pipe taps are thoroughly investigated and tabulated over a large range of Reynolds numbers defined by Equation 5, extending to $Re_o = 10^7$ in Reference 1.

The ASME report states:

> Some investigators have represented the ratio of minimum jet area to the orifice area by a separate factor, that is, the contraction coefficient C_c. Doing this, however, is of no practical advantage and including the effects of contraction in the orifice discharge coefficient is more convenient.

However, it is clear that separate treatment of C_c from C_o would be a vital step for theoretical analysis of discharge characteristics.

Von Mises (6) has estimated the discharge coefficient from theory with some success. Taking the position 2 in Figure 1 at the vena contracta and the position 1 at one pipe diameter upstream and substituting a coefficient of contraction of the jet,

$$C_c = \frac{A_2}{A_o}, \tag{6}$$

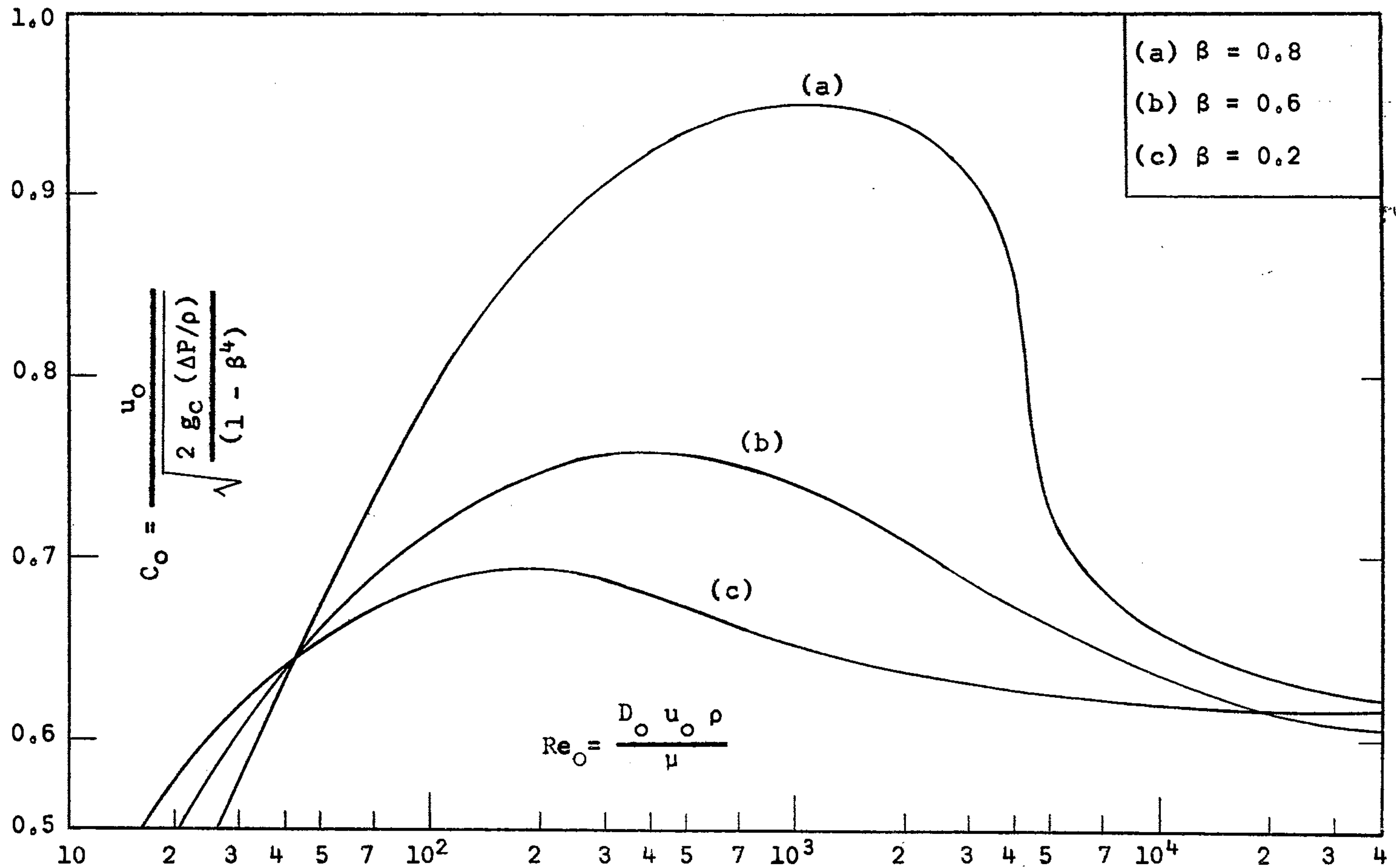


Figure 3. Orifice Discharge Coefficients for Newtonian Fluids (G. L. Tuve and R. E. Sprenkle (2))

and $u_1 = \beta^2 u_o$ into Equation 2 and Equation 3 gives

$$\frac{P_2 - P_1}{\rho} = - \frac{1}{C_v^2} \left(\frac{1}{C_c^2} - \beta^4 \right) \frac{u_o^2}{2 g_c} \tag{7}$$

and

$$\frac{P_2 - P_1}{\rho} = - \frac{1}{C_o^2} (1 - \beta^4) \frac{u_o^2}{2 g_c} , \tag{8}$$

respectively. By equating Equations 7 and 8 and rearranging, it yields

$$C_o = C_v C_c \sqrt{\frac{1 - \beta^4}{1 - C_c^2 \beta^4}} . \tag{9}$$

Vos Mises has calculated the value of C_c from the theory of ideal fluids of two dimensional jets with a flat velocity profile flowing into a fluid of much lower density. This gives a good estimation of C_c for a sharp-edged orifice, which is substituted into Equation 9 with an appropriate value of C_v (usually taken to be 0.98) with various values of β to give good agreement with the empirical value of 0.61 for $Re_o > 50,000$.

Equation 9 is not valid for lower Reynolds numbers, for which C_o should include a correlation for the upstream velocity distribution and perhaps viscous dissipation effects.

All of these orifice discharge coefficients discussed above are obtained for Newtonian fluids and correlated to a Reynolds number defined as in Equation 5. Equation 5 is not valid for non-Newtonian fluids due to the difference in viscosity arising from changing shear rates through an orifice and across the stream as compared to the constant viscosity of Newtonian fluids. A more general Reynolds number definition is required to correlate discharge coefficients for non-Newtonian fluids.

Non-Newtonian Pseudoplastic Fluids

It has been found experimentally (3) that the shear curve for this type of fluid passes through the origin on a shear stress-shear rate plot, and its slope decreases with increasing shear rate, tending to become linear at very high shear rates. The relationship between shear rate and shear stress for pseudoplastic fluids may be represented closely over wide ranges of shear rate (tenfold to thousandfold) by a two constant power function of the form

$$\tau = K \left(\frac{du}{dy} \right)^n \tag{10}$$

The constant, n, characterizes the degree of non-Newtonian behavior; n is less than unity for pseudoplastic fluids, and the further n deviates from unity, the more the fluid behavior deviated from Newtonian fluid behavior. The companion parameter, K, is a physical property of a fluid and is called the consistency index. While two fluids might exhibit the same flow behavior index, n, the more viscous fluid would have the larger consistency index.

It has been reported (10) that CMC-water solutions exhibit slightly viscoelastic behavior at the higher concentrations. It will be appropriate to apply the power law equation for CMC-water solutions used in this study, most of which fall in the category of low concentration.

Reynolds Number for Non-Newtonian

Pseudoplastic Fluids

Metzner and Reed (3) have presented a generalized form of the Reynolds number to be applied to non-Newtonian pseudoplastic fluids. Their argument is as follows:

Rabinowitsch and Mooney (9) have developed an expression for the rate of shear at the wall of a tube for a time-independent fluid in laminar flow:

$$\left(\frac{du}{dy} \right)_w = 3 \left(\frac{8Q}{\pi D^3} \right) + \frac{D\Delta P}{4L} \frac{d\ (8Q/\pi D^3)}{d\ (D\Delta P/4L)} \quad . \tag{11}$$

Integration of Equation 11 and substitution of $u = 4Q/\pi D^2$ and

$$n' = \frac{d\ \ell n\ (D\Delta P/4L)}{d\ \ell n\ (8V/D)}$$

gives

$$\frac{D\Delta P}{4L} = K' \left(\frac{8u}{D} \right)^{n'} \tag{12}$$

where n' is the flow behavior index and K' is the consistency index; these must not be confused with the n and K of Equation 10. Equation 10 and Equation 12 can be related under the generally acceptable assumption that n' and K' are constant;

$$n' = n \tag{13}$$

$$K' = K \left(\frac{3n + 1}{4n} \right)^n \quad . \tag{14}$$

Metzner then substituted Equation 12 into the Fanning friction factor equation

$$f = \left(\frac{D \Delta P}{4L} \right) \Big/ \frac{u^2 \rho}{2 g_c} \tag{15}$$

Comparing this to f = 16/Re for the fully developed laminar flow region for a Newtonian fluid gives the following generalized Reynolds number:

$$Re = \frac{D^{n'} u^{2-n'} \rho}{\gamma} \tag{16}$$

$$\gamma = g_c K' 8^{n'-1} \tag{17}$$

Orifice Discharge Coefficients for

Non-Newtonian Fluids

No data are available in the literature relative to orifice discharge characteristics for non-Newtonian fluids.

The discharge coefficient for corner connections was measured in this work for comparison with the data by other investigators for Newtonian fluids with the corner connections. This coefficient includes the effects of orifice configuration, flow conditions, and varying apparent viscosities of non-Newtonian fluids due to varying shear stress. These effects are much less considerable for the corner tapping than for other tappings.

It was hoped that the relationship between orifice discharge coefficient for Newtonian fluids and orifice Reynolds number might be valid for non-Newtonian fluids with the non-Newtonian behavior being accounted for in the generalized Reynolds number.

CHAPTER III

EXPERIMENTAL APPARATUS

General Arrangement

The fluid being circulated was pumped from a holding barrel into a two-inch Schedule 40 pipe where it flowed through a ten-foot long approach section pipe, then through an orifice plate, and back into the holding barrel (see Figure 4).

All data were obtained by means of the calibration tank system shown in Figure 4 which has a marked scale inside indicating the volume of ten liters between upper and lower marks. A Moyno 1L6, type CDQ, positive displacement pump was used for circulating the liquid. A variable speed drive attached to the electric motor of three horse power was used to control the flow rate. The 250-foot long, 1/2-inch O.D. copper coil connected to both the steam line and the water supply pipe was placed inside the holding barrel for liquid temperature control. The pipe containing the orifice assembly was straight for 10 feet (L/D = 80) on the upstream side and 22.5 inches (L/D = 14) on the downstream side, both longer than standard requirements to eliminate entrance and outlet effects.

Three manometers of 30 inches, 60 inches, and 60 inches length, containing carbon tetrachloride, tetrabromoethane, and mercury, respectively, were used to measure the differential pressures for low, medium,

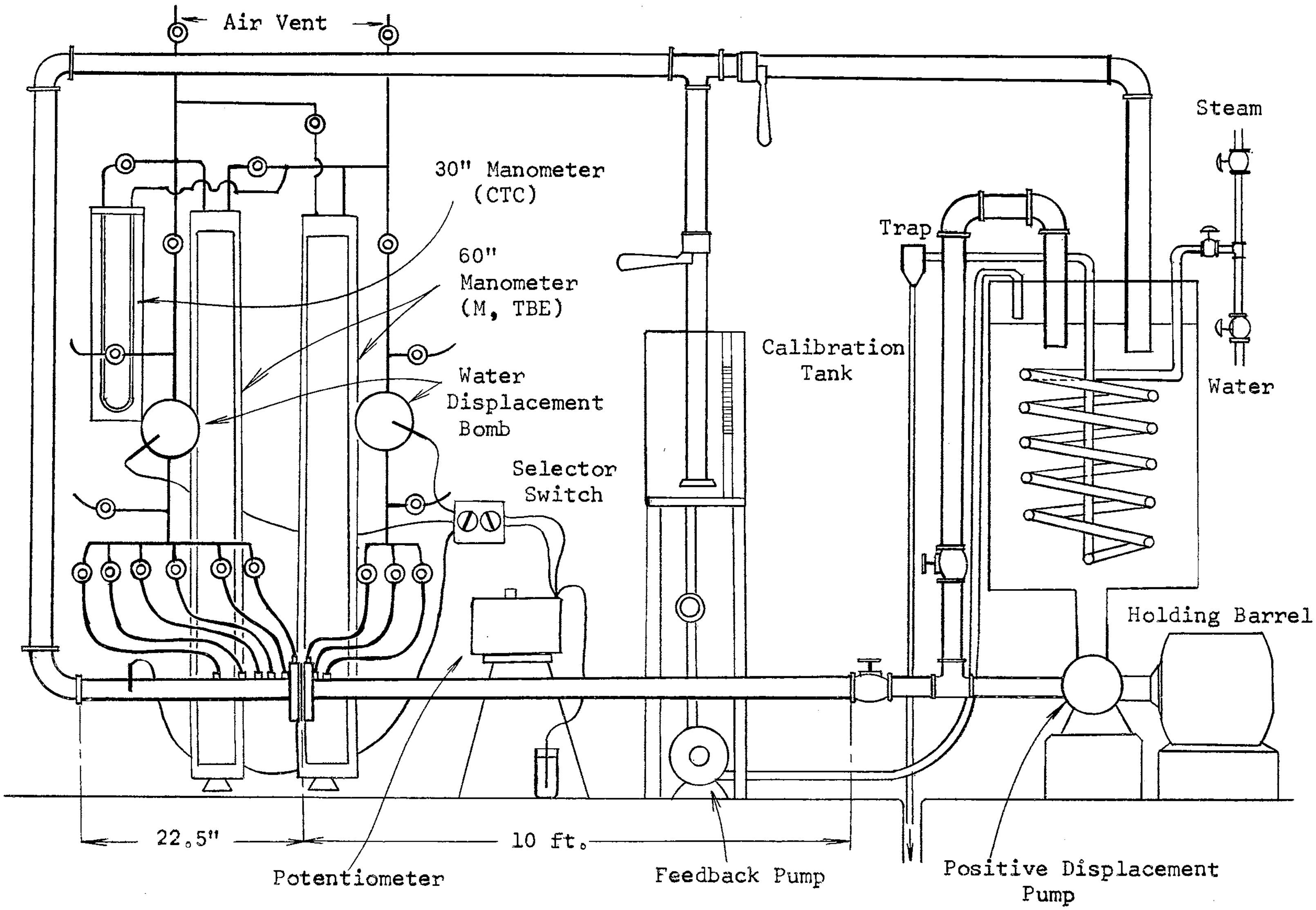


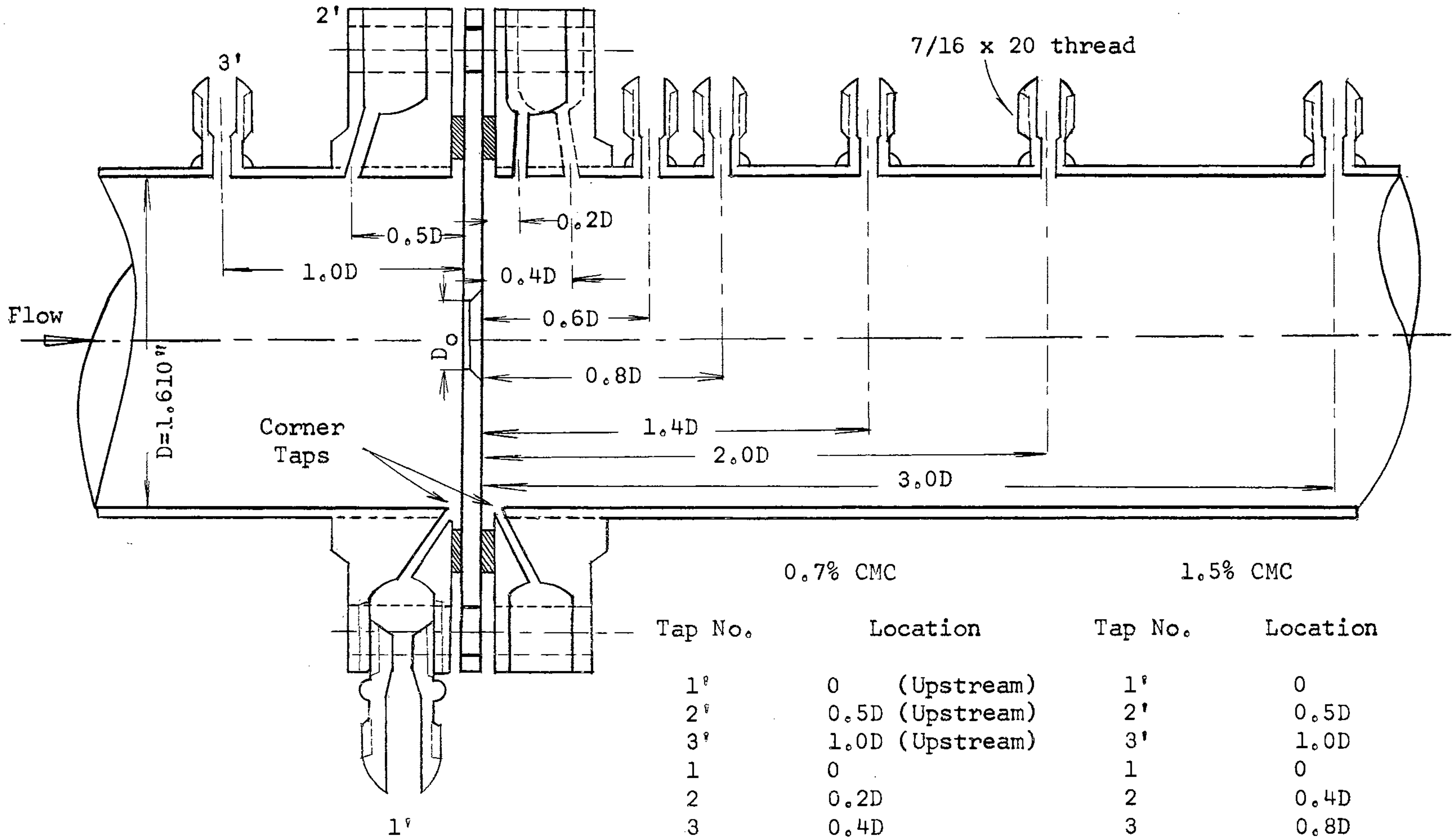
Figure 4. Flow System

and high flow rates, respectively. The manometers were connected to the orifice assembly which had three upstream and six downstream pressure taps with 1/4-inch copper tubing. Copper-constantan thermocouples were used to measure the bulk fluid temperature one foot downstream of the orifice plate. The manometer fluid temperatures were measured by the copper-constantan thermocouples placed in the two water displacement bombs. In order to obtain the quick response of manometer readings to the differential pressure and prevent CMC from entering manometer system, water displacement bombs filled with 1/2 gallon of water were placed between the manometer system and the orifice assembly so that the manometer fluids always contacted water; and most of the small diameter tubing was filled with water. A selector switch was used to select the proper thermocouple. Thermocouple output was measured on a portable Leeds and Northrup potentiometer. Standard tables were used to obtain the temperature from the potentiometer readings.

Orifice Assembly

The orifice test section shown in Figure 5 was of 2-inch Schedule 40 pipe with welded flanges and so arranged so that it could be taken apart readily for changing orifices. The pressure taps on the inlet side, three in number, were 3/32-inch diameter holes capped with 1/8-inch to 1/4-inch brass tube fittings welded on the pipe wall arranged in line: (1) on the flange face, (2) 0.5D, and (3) 1.0D upstream from the orifice plate along the pipe. The outlet pressure connections are the same as the inlet side connections in dimensions and arranged in line with the intervals shown in Figure 5.

The orifice plates were 0.0625-inch thick; and orifice diameters



0.7% CMC		1.5% CMC	
Tap No.	Location	Tap No.	Location
1'	0 (Upstream)	1'	0
2'	0.5D (Upstream)	2'	0.5D
3'	1.0D (Upstream)	3'	1.0D
1	0	1	0
2	0.2D	2	0.4D
3	0.4D	3	0.8D
4	0.6D	4	1.4D
5	0.8D	5	2.0D
6	2.0D	6	3.0D

Figure 5. Orifice Assembly

were 0.322, 0.966, and 1.288 inches, giving β = 0.2, 0.6, and 0.8, respectively, as shown in Figure 6.

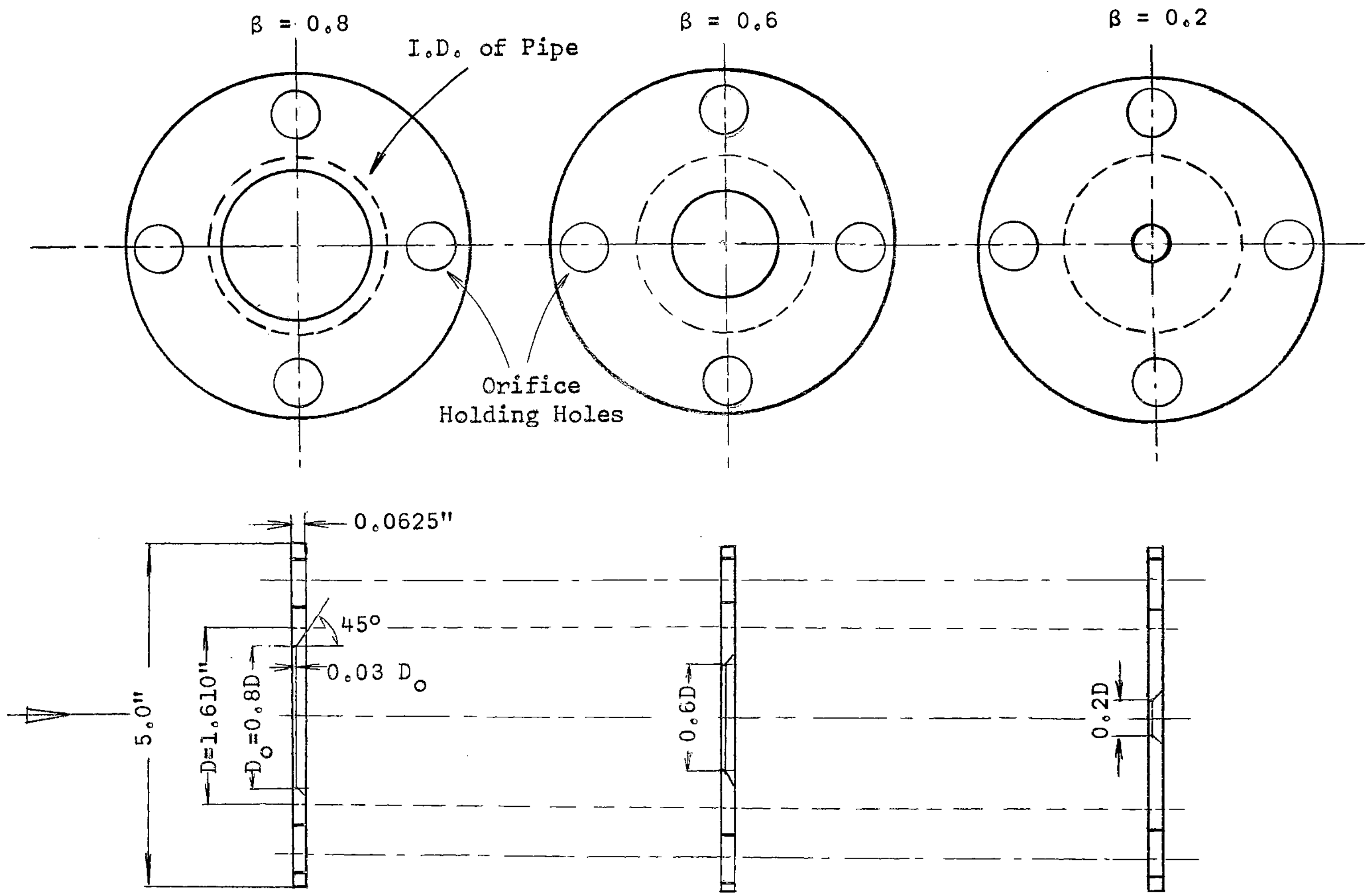


Figure 6. Orifice Plates

CHAPTER IV

EXPERIMENTAL PROCEDURE

Operation

Ample time (from 30 to 60 minutes) was allowed before taking data on each run to insure steady state. Tests made under conditions which varied in the course of the test were rejected. The pump was operated at constant speed during a run. The flow rate was controlled by the variable speed drive attached to the electric motor. The bypass valve was not used to obtain the lower flow rate because of unstable flow rates and manometer readings. Special precautions were taken against air entrainment in the manometer system and in the test fluid.

Observations

The orifice pressure drop for any connection was recorded three times in the time interval of 2 to 10 minutes to insure steady state. Discharge was measured by a Swiss-made precision stopwatch as the time necessary for 10 liters of liquid to flow into the calibration tank. Several of the time measurements were made to average the flow rate. Temperatures in the line were read every six minutes, and manometer temperatures were obtained several times in each run. Fluid viscosities were determined by a Fann V-G model 35 viscometer, and specific gravities were determined by a Fisher precision hydrometer.

CHAPTER V

REPRESENTATION AND DISCUSSION OF RESULTS

Orifice Discharge Coefficient

The orifice discharge coefficients were calculated using the general definition of Equation 4. The mean velocities through the orifice plates and pressure drops were calculated from volume flow rate and manometer readings, respectively. The orifice Reynolds numbers were calculated using Equation 16. The calculations were executed by an IBM 7040 computer. The results are tabulated in Table I, Appendix B.

Orifice coefficient versus Reynolds number curves obtained with corner connections are shown in Figure 7 for three different diameter ratios and two CMC concentrations. These are compared to the results obtained by Tuve and Sprenkle for Newtonian fluids. The discrepancies between coefficients at the same Reynolds number in different manometer fluids are a measure of experimental error in the manometer readings.

The following are found from this figure:

1. The discharge coefficients in this work, on the average, are lower than those of Tuve and Sprenkle. This would indicate that pseudoplastic fluids create more pressure drop through the orifice than Newtonian fluids do for the same Metzner and Reed Reynolds number because of their physical and rheological

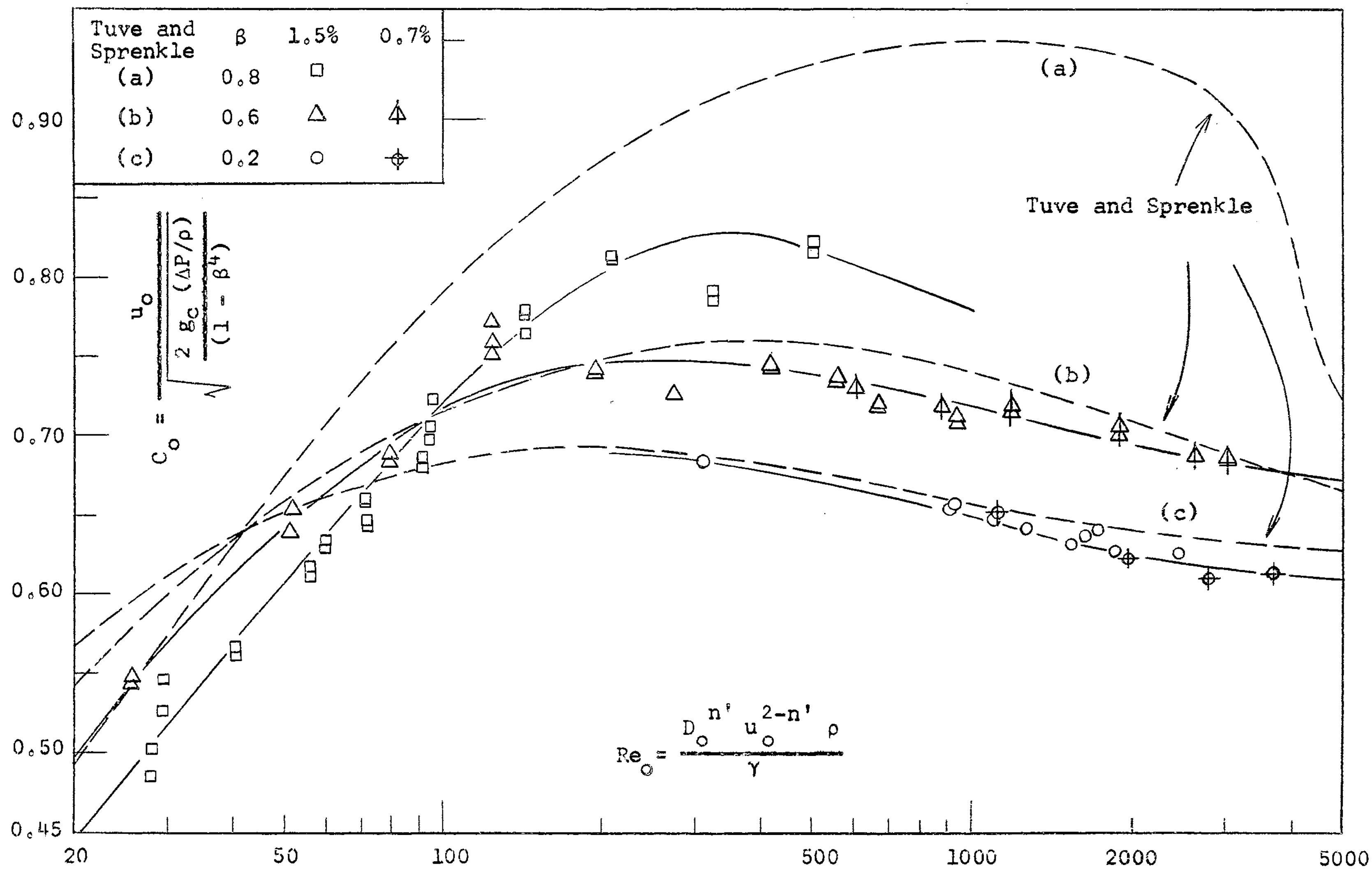


Figure 7. Orifice Discharge Coefficient Vs. Reynolds Number (Corner Connections)

properties.

2. The trends of the correlation curves of orifice coefficients versus generalized Reynolds number for pseudoplastic fluids agree with those for Newtonian fluids very well, especially for the smaller diameter ratios.

3. Agreement of orifice coefficients obtained with different fluids, but at like Reynolds number, tends to support the validity of the generalized Reynolds number as the abscissa to the orifice discharge coefficients for non-Newtonian fluids (see Table III, Appendix B).

Flow Pattern Around the Orifice Plate

The differential pressures between the upstream corner tap and six downstream taps are shown in Figure 8(a), (b), (c), (d), and (e) as a function of downstream tap locations for various Reynolds numbers. The criterion of vena contracta position in the following discussion is the point of minimum static pressure and presumably minimum cross-sectional area of the jet of fluid after it emerges from the orifice aperture (see Figure 1).

The following are found in these figures:

1. No large jet contraction appears to exist over the range of Reynolds numbers observed in this work.

2. The vena contracta tends to appear to be further downstream from the orifice plate for larger Reynolds numbers or for fluids of lower consistency.

3. For $Re_o < 900$, the vena contracta appears to be at the orifice plate regardless of orifice diameter or fluid consistency.

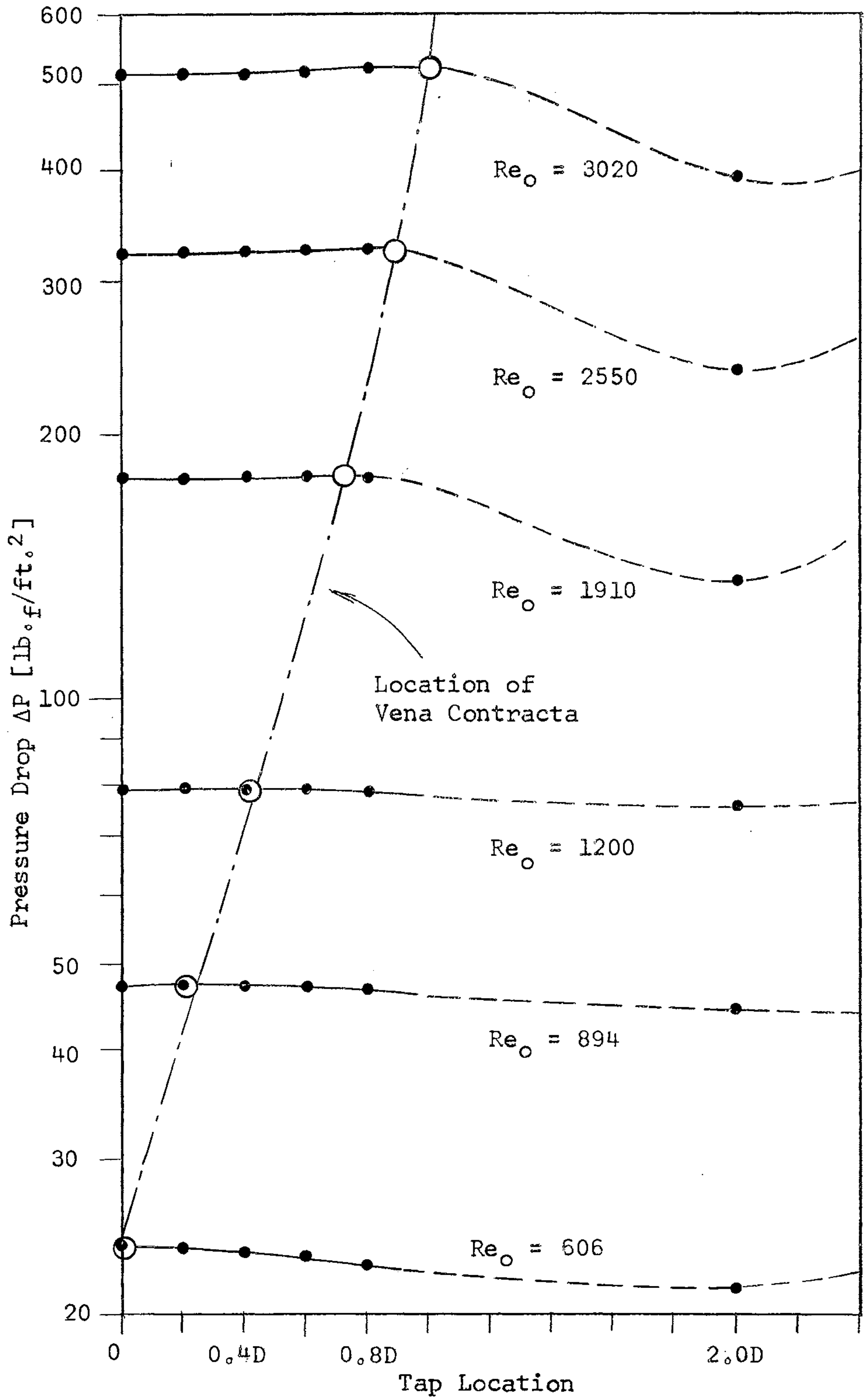


Figure 8(a). Static Pressure Distribution in the Vicinity of the Orifices for β = 0.6 and 0.7% CMC

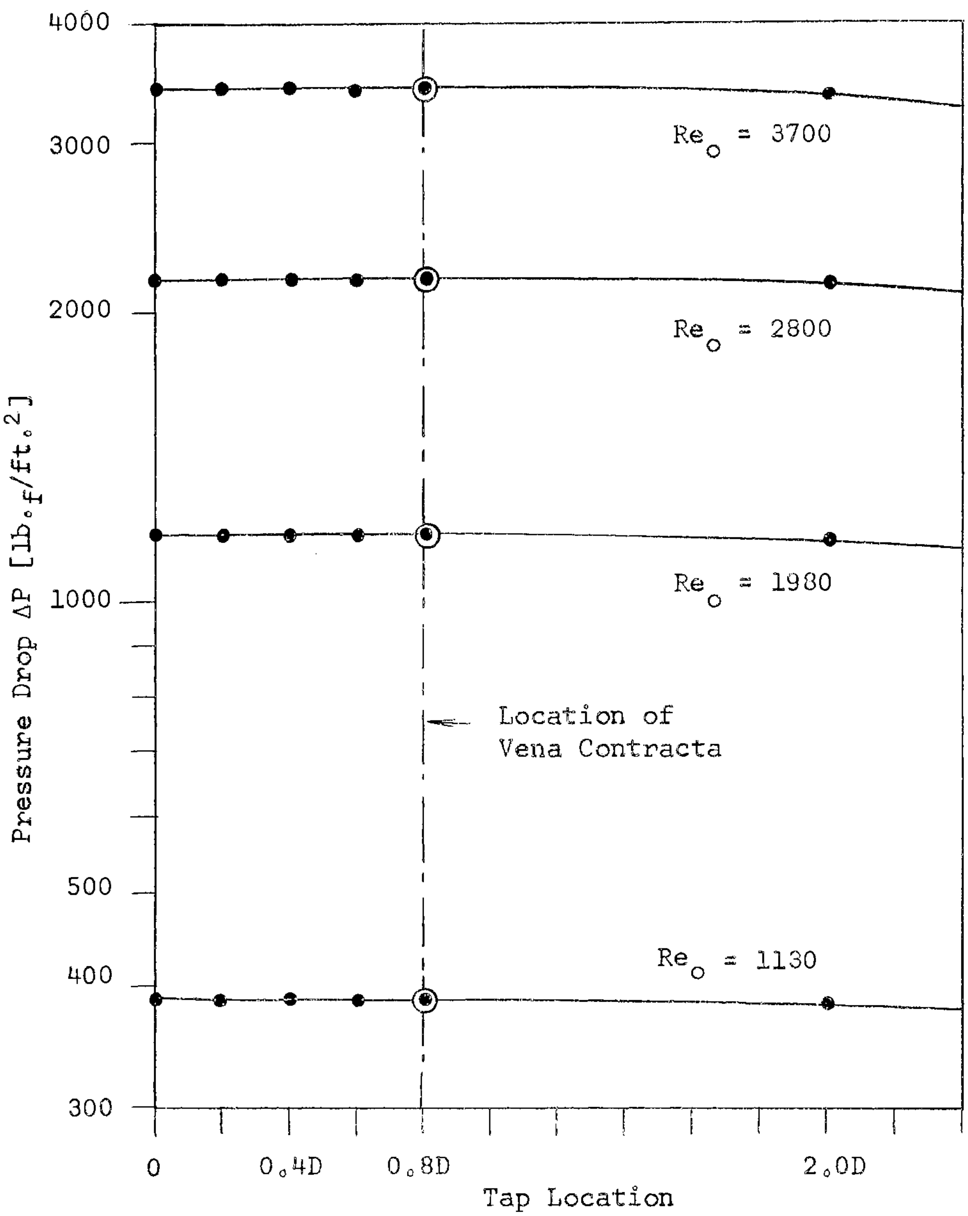


Figure 8(b). Static Pressure Distribution in the Vicinity of the Orifices for β = 0.2 and 0.7% CMC

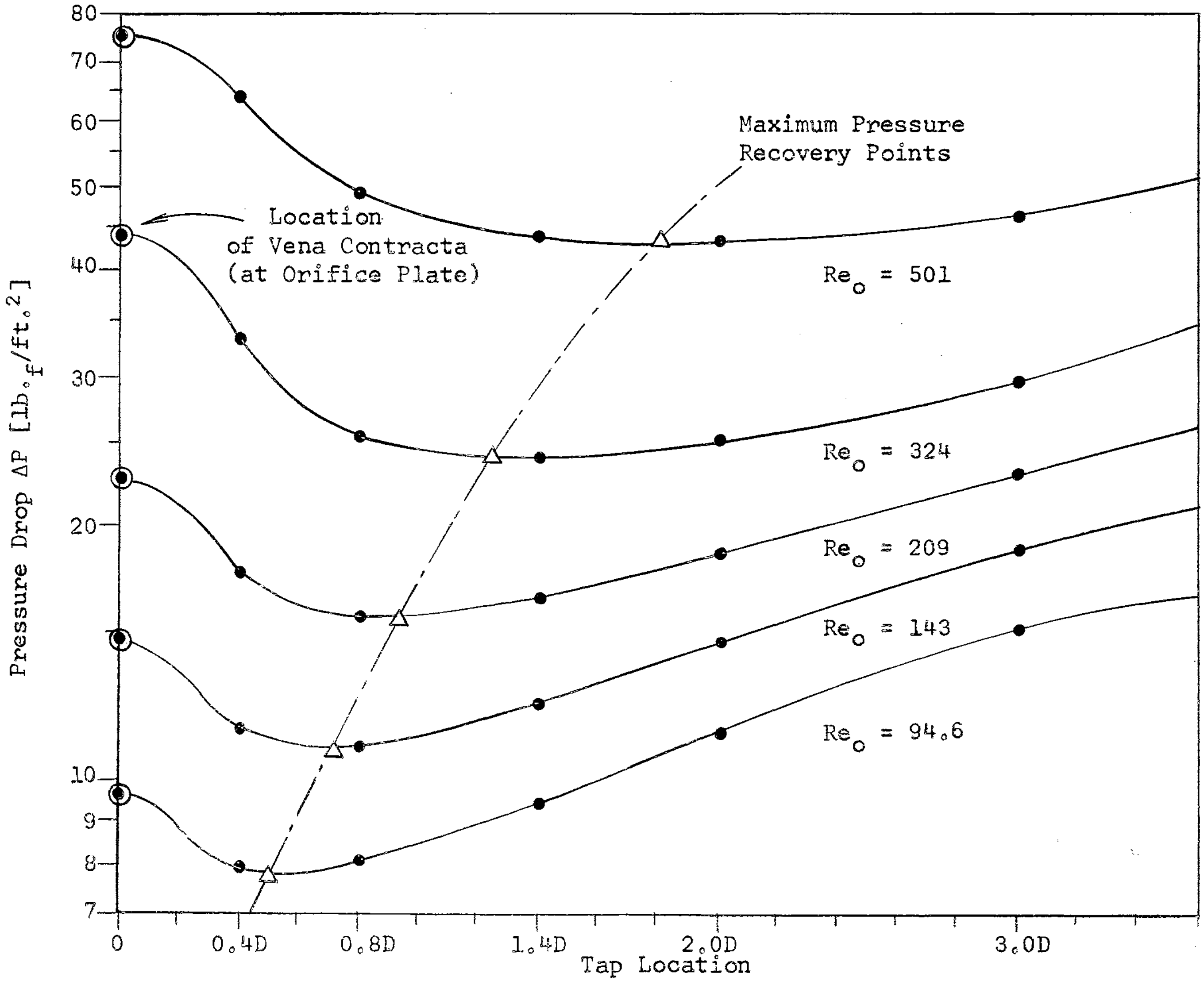


Figure 8(c). Static Pressure Distribution in the Vicinity of the Orifices for β = 0.8 and 1.5% CMC

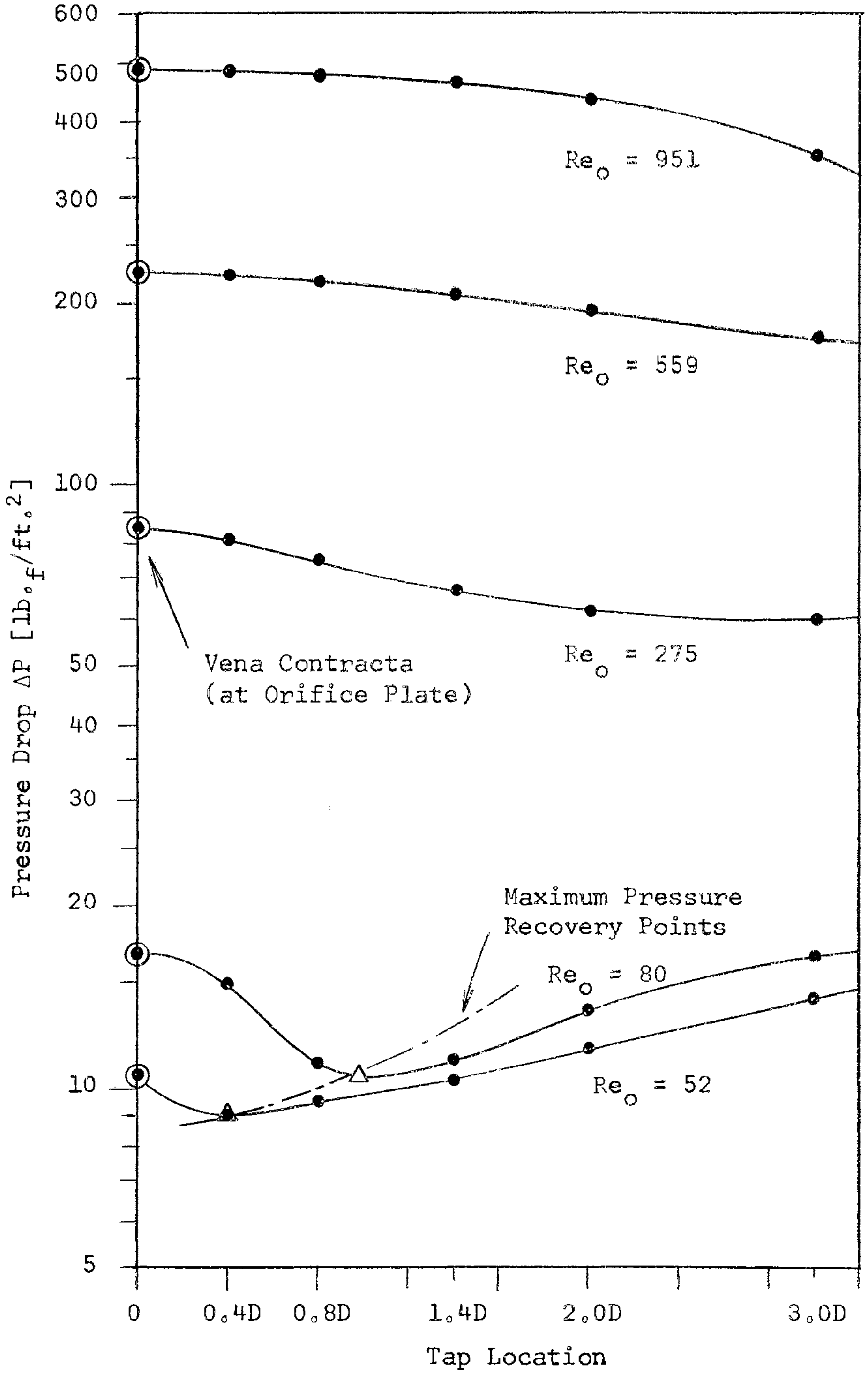


Figure 8(d). Static Pressure Distribution in the Vicinity of the Orifices for β = 0.6 and 1.5% CMC

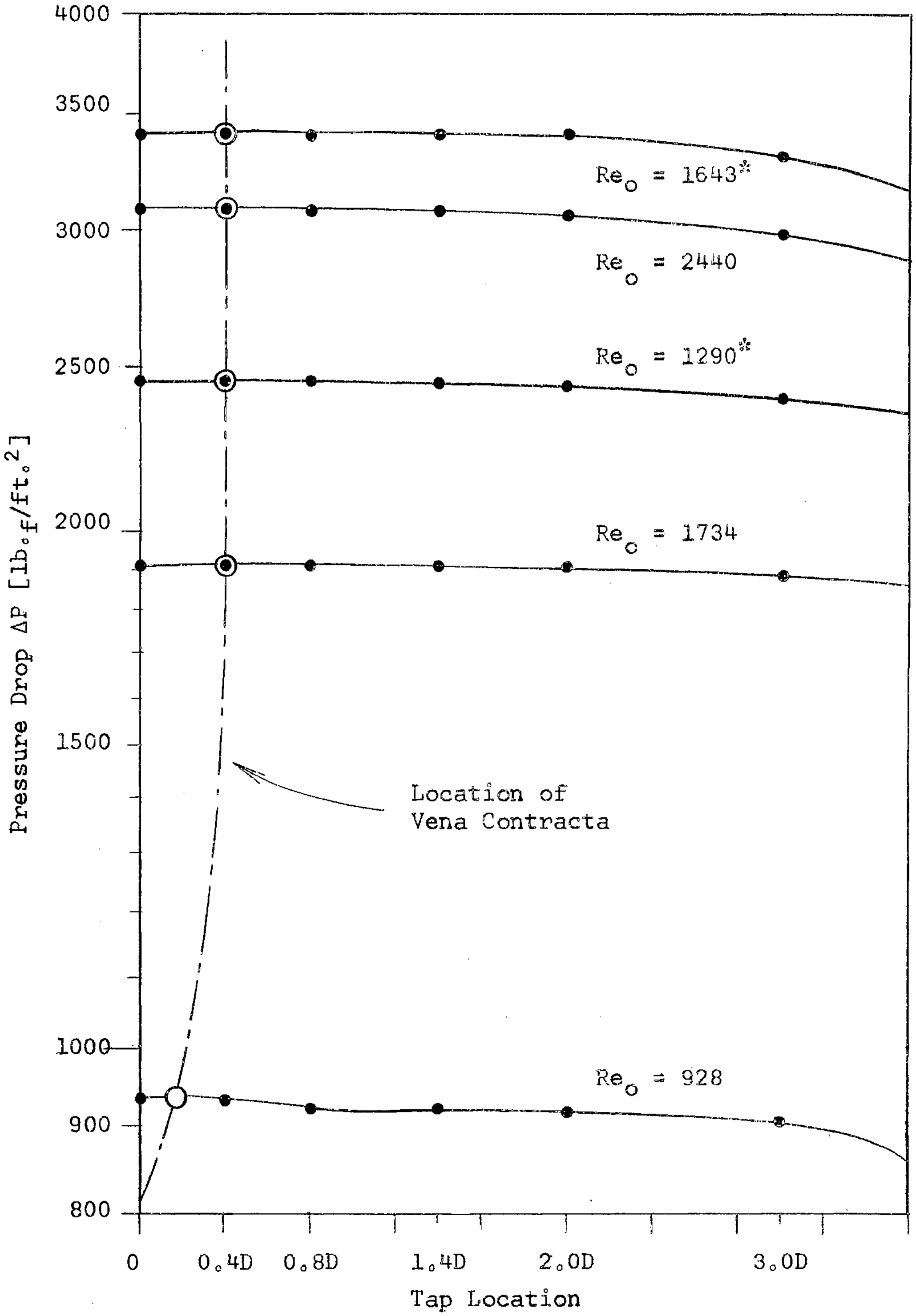


Figure 8(e). Static Pressure Distribution in the Vicinity of the Orifices for β = 0.2 and 1.5% CMC

* Concentration is more than 1.5%.

These results would be expected because:

1. Over the laminar and transitional regimes in this work, radial viscous momentum transport is sufficient to suppress the jet and minimize distinctive jet contraction.
2. As the Reynolds number increases and the consistency decreases, the axial momentum transport becomes predominant over radial transport, due to viscous shear and eddy motion, and makes the jet expand less rapidly.
3. For $Re_o < 900$, the jet which emerges from the orifice aperture tends to creep along the channel wall due to predominant viscous shear compared to smaller inertial terms.

Another important factor related to contraction phenomena is impact pressure. Observed impact pressures are tabulated in Table III, Appendix B, and it was found that:

1. Maximum impact pressure does not necessarily occur at the upstream corner of the orifice plate.
2. Impact pressure does not show a significant correlation with Reynolds number.

These discrepancies may be attributed to the indicated method of measuring the impact pressure as described on page 5 and in Table III, Appendix B.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The general conclusions from this study are briefly as follows:

1. Orifice coefficients for the entire range of laminar and critical flows (Re = 20-4,000) may be correlated satisfactorily (within ±6 percent) on the basis of the Metzner and Reed Reynolds numbers, as shown in the composite curves of Figure 9.

2. Tuve and Sprenkle's orifice coefficient versus Reynolds number curves for β less than 0.6 for Newtonian fluids may be used for approximate design purposes for non-Newtonian pseudoplastic fluids using the Metzner and Reed Reynolds number.

3. A orifice with a diameter ratio of 0.6 is recommended for commercial use because of relatively stable performance and absence of large pressure loss.

4. The flow structure in the vicinity of the orifice plate for pseudoplastic fluids is similar to that for Newtonian fluids.

Recommendations

The following are recommended:

1. Try to develop a theoretical approach for prediction of

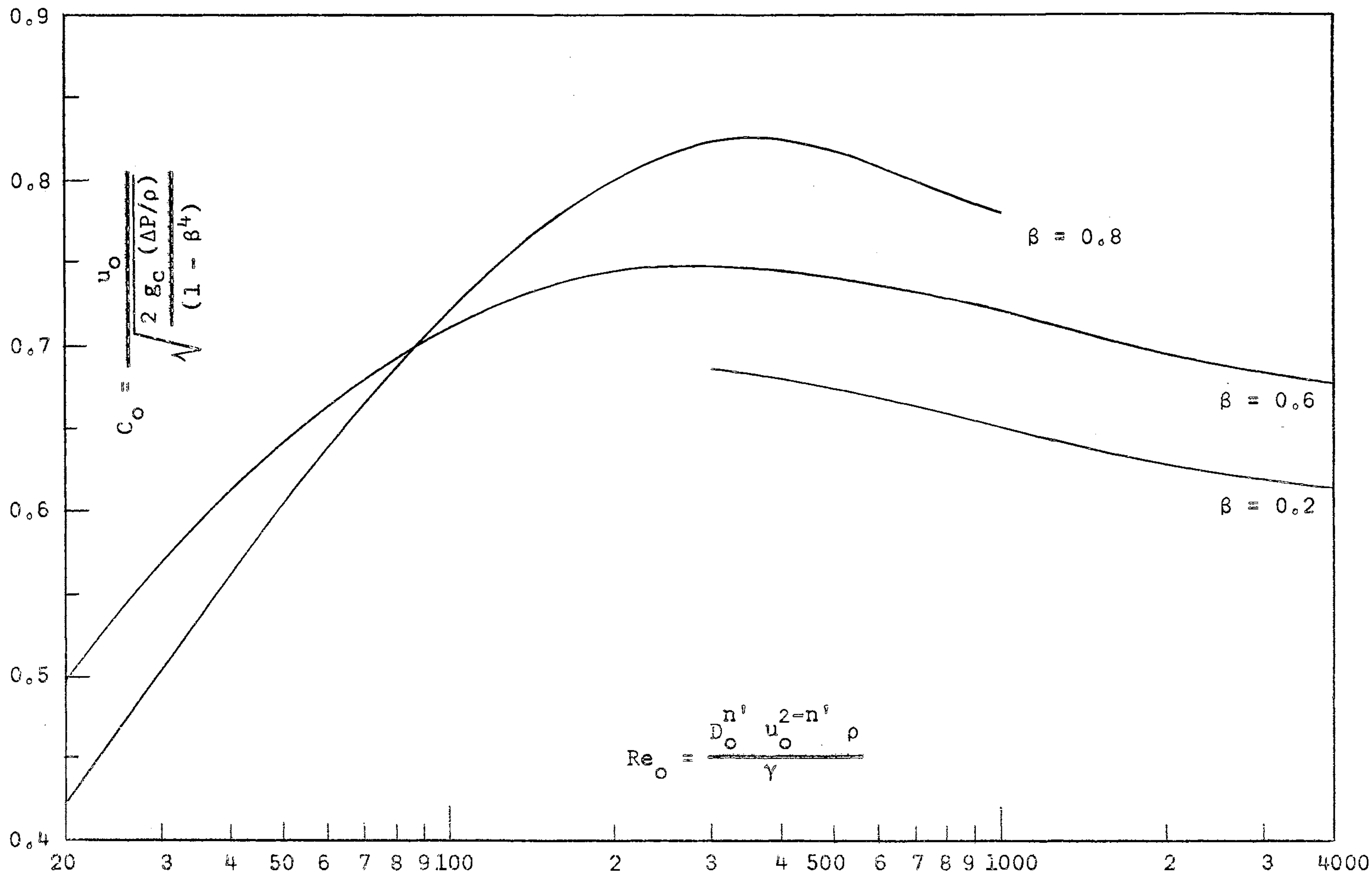


Figure 9. Composite Curves of Orifice Discharge Coefficients (Corner Connections)

discharge characteristics of orifices for non-Newtonian fluids.

2. Try to develop orifice discharge coefficient for viscoelastic fluid by means of theoretical and experimental approaches.

3. Visual study of the flow of non-Newtonian fluids through an orifice should be carried out using transparent pipe and orifice assembly so that the contraction stagnation phenomena in the vicinity of the orifice will be better understood.

4. Detailed investigation of the velocity distribution across the upstream as well as the jets issuing from the orifice aperture should be executed by inserting a transverse pitot tube.

5. Finally, other types of orifice plates should be studied for commercial use, such as a quarter-circle edged orifice which yields much less permanent pressure loss than the sharp-edged type and gives a constant orifice coefficient over a large range of Reynolds numbers.

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APPENDIX A

NOMENCLATURE

A_o - Cross-sectional area of orifice aperture, ft.^{2}

A_1 - Cross-sectional area of main pipe, ft.^{2}

A_2 - Cross-sectional area of flow at vena contracta, ft.^{2}

C_o - Orifice discharge coefficient

C_c - Coefficient of contraction

C_v - Discharge coefficient for some point of orifice

D_o - Diameter of orifice aperture, ft.

f - Fanning's friction factor

g_c - Conversion factor, 32.17, lb.$_m$-ft./lb.$_f$-sec.^{2}

K' - Consistency index for the generalized equation, lb.$_f$-sec.$^{n'}$/ft.^{2}

K - Consistency index for pseudoplastic fluids behavior expression, lb.$_f$-sec.^{n}/ft.^{2}

L - Tube length, ft.

ℓ_w - Energy loss of flow, lb.$_f$-ft./sec.^{2}-ft.^{3}

P - Pressure, lb.$_f$/ft.^{2}

Q - Flow rate viscometer tube, ft.^{3}/sec.

R - Radius, ft.

Re - Reynolds number

Re_o - Reynolds number for orifices

u - Velocity, ft./sec.

V - Flow rate through orifice and pipe, ft.^{3}/sec.

$\frac{du}{dy}$ - Shear rate, 1/sec.

$\left(\frac{du}{dy}\right)_w$ - Shear rate at the wall, 1/sec.

ΔP - Pressure drop across section being considered, $lb._f/ft.^2$

τ - Shear stress, $lb._f/ft.^2$

μ - Viscosity, lb./ft. sec.

ρ - Density, $lb./ft.^3$

γ - Some index of viscosity for pseudoplastic fluids, $lb.^{m'}/ft.\text{-}sec.^{2-n'}$

β - Diameter ratio, D_o/D

APPENDIX B

EXPERIMENTAL AND CALCULATED DATA

TABLE I

EXPERIMENTAL AND CALCULATED DATA

FOR DISCHARGE COEFFICIENTS

Nomenclature

β = Orifice diameter ratio : -
T = Temperature : °F
T.F. = Test fluid
M.F. = Manometer fluid
V = Flow rate : ft^3/sec
u = Orifice velocity : ft/sec
Re = Orifice Reynolds number : -
T.C. = Tap connection(see Fig.5)
Δh = Difference in manometer readings: inch
ΔP = Pressure drop : lb_f/ft^2
M = Mercury
TBE = Tetrabromoethane
CTC = Carbon tetrachlorid

Run Number 1

β = 0.2 V = 0.0210
T = 78.8 u = 36.5
T.F. = 0.7% CMC Re = 3700
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	52.53	3429	0.614
2	52.52	3428	0.614
3	52.57	3432	0.614
4	52.51	3422	0.614
5	52.48	3426	0.615
6	52.02	3396	0.617
2' - 1	52.41	3421	0.615
2	52.46	3424	0.615
3	52.48	3426	0.614
4	52.49	3426	0.615
5	52.51	3428	0.614
6	52.03	3396	0.617
3' - 1	52.49	3426	0.615
2	52.50	3427	0.614
3	52.45	3424	0.615
4	52.40	3420	0.615
5	52.42	3422	0.615
6	51.95	3391	0.618

Run Number 2

β = 0.6 V = 0.0861
T = 78.8 u = 16.9
T.F. = 0.7% CMC Re = 3020
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	7.86	513	0.688
2	7.85	512	0.688
3	7.88	514	0.687
4	7.92	517	0.685
5	7.97	520	0.683
6	6.02	393	0.786
2' - 1	8.01	523	0.681
2	8.05	525	0.680
3	8.02	524	0.681
4	8.09	528	0.678
5	8.17	533	0.675
6	6.17	403	0.776
3' - 1	8.10	529	0.678
2	8.12	530	0.677
3	8.14	531	0.676
4	8.15	532	0.676
5	8.16	533	0.675
6	6.18	403	0.776

TABLE I (Continued)

Run Number 2
β = 0.6 V = 0.0861
T = 78.8 u = 16.9
T.F. = 0.7% CMC Re = 3020
M.F. = TBE

T.C.		Δh	ΔP	Co
1'	- 1	50.02	512	0.689
	2	50.10	513	0.688
	3	50.30	515	0.687
	4	50.55	517	0.685
	5	50.85	520	0.683
	6	38.33	392	0.787
2'	- 1	51.10	523	0.681
	2	51.35	525	0.680
	3	51.15	523	0.681
	4	51.60	528	0.678
	5	52.15	534	0.674
	6	39.45	404	0.776
3'	- 1	51.30	525	0.680
	2	51.85	530	0.676
	3	52.00	532	0.676
	4	52.05	533	0.675
	5	52.05	533	0.675
	6	39.55	405	0.775

Run Number 4
β = 0.6 V = 0.0682
T = 78.8 u = 13.4
T.F. = 0.7% CMC Re = 2550
M.F. = TBE

T.C.		Δh	ΔP	Co
1'	- 1	31.41	321	0.688
	2	31.65	324	0.686
	3	31.72	324	0.685
	4	31.72	324	0.685
	5	31.80	325	0.684
	6	23.21	238	0.800
2'	- 1	31.46	322	0.688
	2	31.63	324	0.686
	3	31.70	324	0.685
	4	31.78	325	0.684
	5	31.83	326	0.684
	6	23.21	238	0.800
3'	- 1	31.37	321	0.688
	2	31.46	322	0.688
	3	31.54	323	0.687
	4	31.56	323	0.686
	5	31.69	324	0.685
	6	23.05	326	0.803

Run Number 4
β = 0.6 V = 0.0682
T = 78.8 u = 13.4
T.F. = 0.7% CMC Re = 2550
M.F. = M

T.C.		Δh	ΔP	Co
1'	- 1	4.91	321	0.689
	2	4.96	324	0.686
	3	4.97	324	0.685
	4	4.97	324	0.685
	5	4.98	325	0.684
	6	3.62	236	0.802
2'	- 1	4.92	321	0.688
	2	4.93	322	0.687
	3	4.96	324	0.686
	4	4.97	324	0.685
	5	4.98	325	0.684
	6	3.62	326	0.802
3'	- 1	4.89	319	0.690
	2	4.92	321	0.688
	3	4.92	321	0.688
	4	4.93	322	0.688
	5	4.93	322	0.688
	6	3.60	235	0.805

Run Number 6
β = 0.6 V = 0.0520
T = 78.8 u = 10.2
T.F. = 0.7% CMC Re = 1910
M.F. = M

T.C.		Δh	ΔP	Co
1'	- 1	2.72	178	0.706
	2	2.73	178	0.704
	3	2.73	178	0.704
	4	2.73	178	0.704
	5	2.73	178	0.704
	6	2.10	137	0.803
2'	- 1	2.72	178	0.706
	2	2.74	179	0.703
	3	2.74	179	0.703
	4	2.74	179	0.703
	5	2.74	179	0.703
	6	2.11	138	0.801
3'	- 1	2.72	178	0.706
	2	2.72	178	0.706
	3	2.73	178	0.704
	4	2.73	178	0.704
	5	2.73	178	0.704
	6	2.12	138	0.799

TABLE I (Continued)

Run Number 6

β = 0.6 V = 0.0520
T = 78.8 u = 10.2
T.F. = 0.7% CMC Re = 1910
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	17.44	178	0.704
2	17.45	178	0.704
3	17.46	179	0.704
4	17.47	179	0.703
5	17.48	179	0.703
6	13.47	138	0.801
2' - 1	17.45	178	0.704
2	17.48	179	0.704
3	17.48	179	0.703
4	17.52	179	0.702
5	17.52	179	0.703
6	13.54	138	0.799
3' - 1	17.45	178	0.704
2	17.43	178	0.704
3	17.44	178	0.704
4	17.45	178	0.704
5	17.47	179	0.703
6	13.54	138	0.799

Run Number 6

β = 0.6 V = 0.0353
T = 78.8 u = 6.94
T.F. = 0.7% CMC Re = 1200
M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	25.55	79.4	0.717
2	25.55	79.4	0.717
3	25.53	79.3	0.717
4	25.44	79.0	0.719
5	25.38	78.8	0.720
6	24.47	76.0	0.733
2' - 1	25.46	79.1	0.718
2	25.46	79.1	0.718
3	25.45	79.0	0.716
4	25.41	78.9	0.719
5	25.38	78.8	0.720
6	25.45	76.3	0.731
3' - 1	25.47	79.0	0.719
2	25.45	79.1	0.718
3	25.42	79.0	0.718
4	25.38	78.9	0.719
5	24.65	78.8	0.720
6	24.65	76.6	0.730

Run Number 7

β = 0.6 V = 0.0353
T = 78.8 u = 6.94
T.F. = 0.7% CMC Re = 1200
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	7.70	78.8	0.720
2	7.70	78.8	0.720
3	7.69	78.7	0.720
4	7.68	78.6	0.721
5	7.66	78.4	0.722
6	7.38	75.5	0.735
2' - 1	7.69	78.7	0.720
2	7.69	78.7	0.720
3	7.69	78.7	0.720
4	7.68	78.6	0.721
5	7.66	78.4	0.722
6	7.41	75.8	0.734
3' - 1	7.66	78.4	0.721
2	7.69	78.7	0.720
3	7.67	78.5	0.721
4	7.64	78.2	0.722
5	7.62	78.0	0.723
6	7.43	76.0	0.733

Run Number 8

β = 0.6 V = 0.0274
T = 78.8 u = 5.39
T.F. = 0.7% CMC Re = 894
M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	15.26	47.4	0.721
2	15.27	47.4	0.720
3	15.22	47.3	0.722
4	15.16	47.1	0.723
5	15.07	46.8	0.725
6	14.31	44.4	0.744
2' - 1	15.23	47.3	0.721
2	15.23	47.3	0.721
3	15.20	47.2	0.722
4	15.15	47.0	0.723
5	15.07	46.8	0.725
6	14.32	44.5	0.744
3' - 1	15.28	47.4	0.720
2	15.28	47.4	0.720
3	15.23	47.3	0.721
4	15.19	47.2	0.722
5	15.12	47.0	0.724
6	14.37	44.6	0.742

TABLE I (Continued)

Run Number 9

β = 0.6   V = 0.0198
T = 78.8   u = 3.89
T.F. = 0.7% CMC   Re = 606
M.F. = CTC

T.C.		Δh	ΔP	Co
1' -	1	7.72	24.0	0.730
	2	7.70	23.9	0.731
	3	7.65	23.8	0.734
	4	7.63	23.7	0.735
	5	7.56	23.5	0.738
	6	6.87	21.3	0.774
2' -	1	8.20	25.5	0.709
	2	8.19	25.4	0.709
	3	8.14	25.3	0.711
	4	7.79	24.2	0.727
	5	7.66	23.8	0.733
	6	7.03	21.8	0.765
3' -	1	7.74	24.0	0.730
	2	7.74	24.0	0.730
	3	7.70	23.9	0.731
	4	7.64	23.7	0.734
	5	7.53	23.4	0.740
	6	7.00	21.7	0.767

Run Number 10

β = 0.2   V = 0.0164
T = 78.8   u = 28.9
T.F. = 0.7% CMC   Re = 2800
M.F. = M

T.C.		Δh	ΔP	Co
1' -	1	33.28	2172	0.612
	2	33.29	2173	0.612
	3	33.29	2173	0.612
	4	33.31	2174	0.612
	5	33.34	2176	0.612
	6	32.98	2153	0.615
2' -	1	33.30	2174	0.612
	2	33.30	2174	0.612
	3	33.32	2175	0.612
	4	33.33	2176	0.612
	5	33.33	2176	0.612
	6	32.98	2153	0.615
3' -	1	33.26	2171	0.612
	2	33.28	2172	0.612
	3	33.30	2174	0.612
	4	33.31	2174	0.612
	5	33.30	2174	0.612
	6	32.94	2150	0.615

Run Number 11

β = 0.2   V = 0.0122
T = 78.8   u = 21.6
T.F. = 0.7% CMC   Re = 1980
M.F. = M

T.C.		Δh	ΔP	Co
1' -	1	17.99	1174	0.623
	2	17.99	1174	0.623
	3	17.99	1174	0.623
	4	17.99	1174	0.623
	5	17.99	1174	0.623
	6	17.82	1163	0.626
2' -	1	17.97	1173	0.623
	2	17.97	1173	0.623
	3	17.97	1173	0.623
	4	17.98	1174	0.623
	5	17.99	1174	0.623
	6	17.81	1163	0.626
3' -	1	17.97	1173	0.623
	2	17.97	1173	0.623
	3	17.97	1173	0.623
	4	17.97	1173	0.623
	5	17.98	1174	0.623
	6	17.80	1162	0.626

Run Number 14

β = 0.2   V = 0.00738
T = 78.8   u = 13.0
T.F. = 0.7% CMC   Re = 1130
M.F. = TBE

T.C.		Δh	ΔP	Co
1' -	1	38.03	389	0.653
	2	38.03	389	0.653
	3	37.98	389	0.653
	4	38.02	389	0.653
	5	37.96	388	0.653
	6	37.54	384	0.657
2' -	1	37.92	388	0.653
	2	37.88	388	0.654
	3	37.89	388	0.654
	4	37.88	388	0.654
	5	37.72	386	0.655
3' -	6	37.25	381	0.659
	1	37.62	385	0.656
	2	37.40	383	0.658
	3	37.46	383	0.657
	4	37.24	381	0.659
	5	37.26	381	0.659
	6	36.73	376	0.664

TABLE I (Continued)

Run Number 14

β = 0.2 V = 0.00738
T = 78.8 u = 13.0
T.F. = 0.7% CMC Re = 1120
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	5.95	388	0.653
2	5.95	388	0.653
3	5.95	388	0.653
4	5.95	388	0.653
5	5.95	388	0.653
6	5.87	383	0.658
2' - 1	5.94	388	0.654
2	5.94	388	0.654
3	5.94	388	0.654
4	5.94	388	0.654
5	5.90	385	0.656
6	5.82	380	0.660
3' - 1	5.89	384	0.656
2	5.85	382	0.659
3	5.85	382	0.659
4	5.81	379	0.661
5	5.81	379	0.661
6	5.75	375	0.664

Run Number 15

β = 0.8 V = 0.0853
T = 86.0 u = 9.43
T.F. = 1.5% CMC Re = 501
M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	24.33	75.6	0.822
2	20.50	63.7	0.896
3	15.99	49.7	1.014
4	14.18	44.0	1.077
5	13.97	43.4	1.085
6	14.97	46.5	1.048
2' - 1	23.77	73.8	0.832
2	19.97	62.0	0.907
3	15.79	49.0	1.020
4	13.78	42.8	1.092
5	13.47	41.8	1.105
6	14.46	44.9	1.066
3' - 1	24.82	77.1	0.814
2	21.14	65.6	0.882
3	17.01	52.8	0.983
4	15.03	46.7	1.046
5	14.67	45.6	1.059
6	15.79	49.0	1.020

Run Number 15

β = 0.8 V = 0.0853
T = 86.0 u = 9.43
T.F. = 1.5% CMC Re = 501
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	7.33	75.0	0.825
2	6.10	62.4	0.904
3	4.85	49.6	1.014
4	4.33	44.3	1.074
5	4.23	43.3	1.086
6	4.52	46.2	1.051
2' - 1	7.15	73.2	0.835
2	6.01	61.5	0.911
3	4.77	48.8	1.023
4	4.17	42.7	1.094
5	4.09	41.8	1.105
6	4.38	44.8	1.067
3' - 1	7.45	76.2	0.818
2	6.35	65.0	0.886
3	5.13	52.5	0.986
4	4.56	46.7	1.046
5	4.44	45.4	1.060
6	4.72	48.3	1.028

Run Number 15

β = 0.8 V = 0.0853
T = 86.0 u = 9.43
T.F. = 1.5% CMC Re = 501
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	1.17	76.4	0.818
2	0.97	63.3	0.898
3	0.77	50.2	1.008
4	0.67	43.7	1.081
5	0.67	43.7	1.081
6	0.71	46.3	1.050
2' - 1	1.15	75.1	0.825
2	0.97	63.3	0.898
3	0.78	50.9	1.002
4	0.66	43.1	1.089
5	0.64	41.8	1.106
6	0.70	45.7	1.057
3' - 1	1.20	78.3	0.807
2	1.02	66.6	0.876
3	0.82	53.5	0.977
4	0.73	47.6	1.035
5	0.72	47.0	1.042
6	0.77	50.3	1.008

TABLE I (Continued)

Run Number 16
β = 0.8, V = 0.0625
T = 86.0, u = 6.90
T.F. = 1.5% CMC, Re = 324
M.F. = CTC

T.C.		Δh	ΔP	Co
1' -	1	14.20	44.1	0.788
	2	10.63	33.0	0.910
	3	8.34	25.6	1.028
	4	7.80	24.0	1.063
	5	8.19	25.3	1.037
	6	9.67	29.6	0.955
2' -	1	12.25	38.1	0.848
	2	9.46	29.4	0.965
	3	7.75	23.9	1.066
	4	7.42	22.8	1.090
	5	7.93	24.4	1.054
	6	9.24	28.4	0.976
3' -	1	13.19	40.6	0.817
	2	10.69	33.0	0.908
	3	9.02	27.9	0.988
	4	8.69	26.6	1.007
	5	9.15	28.3	0.981
	6	10.51	32.4	0.916

Run Number 16
β = 0.8, V = 0.0625
T = 86.0, u = 6.90
T.F. = 1.5% CMC, Re = 324
M.F. = TBE

T.C.		Δh	ΔP	Co
1' -	1	4.31	43.7	0.788
	2	3.22	31.3	0.911
	3	2.50	24.8	1.034
	4	2.35	24.2	1.067
	5	2.47	25.4	1.041
	6	2.89	30.0	0.962
2' -	1	3.72	37.2	0.848
	2	2.87	29.4	0.965
	3	2.34	23.5	1.069
	4	2.23	23.5	1.095
	5	2.38	24.2	1.060
	6	2.78	29.4	0.981
3' -	1	3.97	41.1	0.821
	2	3.23	33.3	0.910
	3	2.73	28.1	0.990
	4	2.60	26.8	1.014
	5	2.77	28.7	0.983
	6	3.17	32.6	0.918

Run Number 16
β = 0.8, V = 0.0625
T = 86.0, u = 6.90
T.F. = 1.5% CMC, Re = 324
M.F. = M

T.C.		Δh	ΔP	Co
1' -	1	0.67	44.1	0.791
	2	0.48	33.0	0.934
	3	0.38	25.9	1.050
	4	0.37	24.2	1.064
	5	0.39	25.4	1.037
	6	0.46	30.0	0.955
2' -	1	0.57	38.0	0.858
	2	0.45	29.4	0.965
	3	0.36	24.1	1.079
	4	0.36	24.1	1.079
	5	0.37	24.6	1.064
	6	0.45	28.7	0.965
3' -	1	0.63	41.0	0.816
	2	0.51	33.2	0.907
	3	0.43	28.0	0.987
	4	0.41	27.0	1.011
	5	0.44	28.4	0.976
	6	0.50	32.6	0.916

Run Number 17
β = 0.8, V = 0.0458
T = 86.0, u = 5.07
T.F. = 1.5% CMC, Re = 209
M.F. = CTC

T.C.		Δh	ΔP	Co
1' -	1	7.33	22.8	0.805
	2	6.54	20.3	0.852
	3	5.01	15.6	0.974
	4	5.29	16.4	0.947
	5	5.95	18.5	0.893
	6	7.30	22.7	0.806
2' -	1	6.55	20.3	0.851
	2	6.21	19.3	0.874
	3	4.79	14.9	0.996
	4	4.85	15.1	0.989
	5	5.52	17.1	0.927
	6	6.88	21.4	0.831
3' -	1	7.68	23.8	0.786
	2	6.08	18.9	0.884
	3	5.69	17.7	0.914
	4	6.01	18.7	0.889
	5	6.65	20.6	0.845
	6	7.98	24.8	0.771

TABLE I (Continued)

Run Number 17

β = 0.8, V = 0.0458

T = 86.0, u = 5.07

T.F. = 1.5% CMC, Re = 209

M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	2.18	22.3	0.813
2	1.69	17.3	0.923
3	1.54	15.8	0.967
4	1.61	16.5	0.946
5	1.76	18.0	0.905
6	2.17	22.2	0.815
2' - 1	1.94	19.9	0.862
2	1.59	16.3	0.952
3	1.48	15.1	0.987
4	1.48	15.1	0.987
5	1.64	16.8	0.937
6	2.05	21.0	0.838
3' - 1	2.27	23.2	0.797
2	1.81	18.5	0.892
3	1.79	18.3	0.897
4	1.80	18.4	0.895
5	1.98	20.3	0.853
6	2.37	24.3	0.780

Run Number 18

β = 0.8, V = 0.0353

T = 86.0, u = 3.90

T.F. = 1.5% CMC, Re = 143

M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	4.70	14.6	0.774
2	3.67	11.4	0.876
3	3.58	11.1	0.888
4	4.00	12.4	0.840
5	4.69	14.6	0.775
6	6.01	18.7	0.685
2' - 1	4.19	13.0	0.820
2	3.61	11.2	0.884
3	3.57	11.1	0.889
4	4.05	12.6	0.834
5	4.80	14.9	0.766
6	5.51	17.1	0.715
3' - 1	5.15	16.0	0.740
2	4.21	13.1	0.818
3	4.10	12.7	0.829
4	4.59	14.3	0.784
5	5.17	16.0	0.738
6	6.61	20.5	0.653

Run Number 18

β = 0.8, V = 0.0353

T = 86.0, u = 3.90

T.F. = 1.5% CMC, Re = 143

M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	1.40	14.3	0.782
2	1.08	11.0	0.890
3	1.08	11.0	0.890
4	1.19	12.2	0.848
5	1.38	14.1	0.788
6	1.80	18.4	0.690
2' - 1	1.25	12.8	0.827
2	1.09	11.2	0.886
3	1.07	10.9	0.894
4	1.21	12.4	0.841
5	1.45	14.8	0.768
6	1.66	17.0	0.718
3' - 1	1.53	15.6	0.748
2	1.27	13.0	0.821
3	1.22	12.5	0.838
4	1.38	14.1	0.788
5	1.56	16.0	0.741
6	1.97	20.2	0.659

Run Number 19

β = 0.8, V = 0.0264

T = 86.0, u = 2.91

T.F. = 1.5% CMC, Re = 94.6

M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	3.14	9.75	0.707
2	2.55	7.92	0.785
3	2.63	8.17	0.773
4	3.05	9.47	0.718
5	3.70	11.49	0.652
6	4.90	15.22	0.566
2' - 1	2.65	8.23	0.770
2	2.08	6.46	0.869
3	2.26	7.02	0.834
4	2.70	8.39	0.763
5	3.34	10.37	0.686
6	4.41	13.70	0.597
3' - 1	3.50	10.87	0.670
2	2.95	9.16	0.730
3	3.08	9.57	0.714
4	3.53	10.96	0.667
5	4.10	12.73	0.619
6	5.16	16.03	0.552

TABLE I (Continued)

Run Number 19			
β = 0.8		V = 0.0264	
T = 86.0		u = 2.91	
T.F. = 1.5% CMC		Re = 94.6	
M.F. = TBE			
T.C.	Δh	ΔP	Co
1' - 1	0.90	9.21	0.728
2	0.72	7.37	0.814
3	0.76	7.78	0.792
4	0.86	9.11	0.732
5	1.08	11.05	0.664
6	1.44	14.74	0.576
2' - 1	0.79	8.08	0.777
2	0.60	6.14	0.892
3	0.66	6.75	0.850
4	0.79	8.08	0.777
5	1.00	10.23	0.691
6	1.31	13.41	0.603
3' - 1	1.05	10.74	0.674
2	0.89	9.11	0.732
3	0.91	9.31	0.724
4	1.04	10.64	0.677
5	1.22	12.48	0.625
6	1.56	15.96	0.553

Run Number	20
β	0.8
T	86.0
T.F.	1.5%CMC
M.F.	TBE
V	0.0218
u	2.42
Re	71.7
T.C.	1' - 1
Δh	0.750
ΔP	7.68
Co	0.661

Run Number	20	21	21	22	22
β	0.8	0.8	0.8	0.8	0.8
T	86.0	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	CTC	CTC	TBE	CTC	TBE
V	0.0218	0.0192	0.0192	0.0116	0.0116
u	2.42	2.12	2.12	1.29	1.29
Re	71.7	59.5	59.5	29.4	29.4
T.C.	1' - 1	1' - 1	1' - 1	1' - 1	1' - 1
Δh	2.46	2.06	0.630	1.100	0.310
ΔP	7.64	6.40	6.45	3.42	3.17
Co	0.662	0.635	0.632	0.528	0.548

TABLE I (Continued)

Run Number	23	23	24	24	25
β	0.8	0.8	0.8	0.8	0.8
T	86.0	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	CTC	TBE	CTC	TBE	CTC
V	0.0266	0.0266	0.0221	0.0221	0.0186
u	2.94	2.94	2.44	2.44	2.05
Re	93.2	93.2	71.8	71.8	56.0
T.C.	1' - 1	1' - 1	1' - 1	1' - 1	1' - 1
Δh	3.45	1.02	2.69	0.80	2.05
ΔP	10.7	10.4	8.36	8.19	6.37
Co	0.680	0.689	0.641	0.648	0.616

Run Number	25	26	26	27	27
β	0.8	0.8	0.8	0.8	0.8
T	86.0	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	TBE	CTC	TBE	CTC	TBE
V	0.0186	0.0147	0.0147	0.0115	0.0115
u	2.05	1.62	1.62	1.27	1.27
Re	56.0	40.2	40.2	28.2	28.2
T.C.	1' - 1	1' - 1	1' - 1	1' - 1	1' - 1
Δh	0.62	1.55	0.46	1.28	1.27
ΔP	6.34	4.81	4.71	3.98	3.68
Co	0.618	0.562	0.568	0.482	0.501

Run Number 28
β = 0.6 V = 0.0866
T = 86.0 u = 17.0
T.F. = 1.5% CMC Re = 951
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	47.36	485	0.711
2	47.16	482	0.713
3	46.51	476	0.718
4	45.43	465	0.726
5	42.61	436	0.750
6	34.20	350	0.837
2' - 1	47.21	483	0.712
2	47.01	481	0.714
3	46.29	474	0.719
4	45.22	462	0.728
5	42.59	436	0.750
6	34.15	349	0.837
3' - 1	47.35	484	0.711
2	47.11	482	0.713
3	46.47	476	0.718
4	45.28	463	0.727
5	42.77	438	0.748
6	34.25	350	0.836

Run Number 28
β = 0.6 V = 0.0866
T = 86.0 u = 17.0
T.F. = 1.5% CMC Re = 951
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	7.39	482	0.713
2	7.35	480	0.715
3	7.24	473	0.720
4	7.07	462	0.729
5	6.63	433	0.752
6	5.34	348	0.838
2' - 1	7.36	480	0.714
2	7.32	478	0.716
3	7.21	470	0.722
4	7.04	460	0.730
5	6.64	433	0.752
6	5.34	348	0.838
3' - 1	7.38	481	0.713
2	7.33	478	0.716
3	7.24	472	0.720
4	7.04	460	0.730
5	6.65	434	0.751
6	5.34	348	0.838

TABLE I (Continued)

Run Number 29

β = 0.6 V = 0.0611
T = 86.0 u = 12.0
T.F. = 1.5% CMC Re = 559
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	22.12	226	0.734
2	21.75	222	0.740
3	21.25	217	0.749
4	20.24	207	0.767
5	19.05	195	0.791
6	16.99	174	0.838

Run Number 29

β = 0.6 V = 0.0611
T = 86.0 u = 12.0
T.F. = 1.5% CMC Re = 559
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	3.44	224	0.737
2	3.38	221	0.744
3	3.31	216	0.751
4	3.15	206	0.770
5	2.97	194	0.793
6	2.65	173	0.840

Run Number 30

β = 0.6 V = 0.0370
T = 86.0 u = 7.28
T.F. = 1.5% CMC Re = 274
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	8.28	84.7	0.728
2	7.97	82.0	0.742
3	7.33	75.0	0.774
4	6.58	67.3	0.816
5	6.06	62.0	0.851
6	5.82	60.0	0.868

Run Number 30

β = 0.6 V = 0.0370
T = 86.0 u = 7.28
T.F. = 1.5% CMC Re = 274
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	1.30	84.8	0.728
2	1.25	81.6	0.742
3	1.13	73.8	0.780
4	1.03	67.2	0.817
5	0.93	60.7	0.860
6	0.90	58.8	0.874

Run Number 31

β = 0.6 V = 0.0115
T = 86.0 u = 2.26
T.F. = 1.5% CMC Re = 52.1
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	0.98	10.02	0.658
2	0.84	8.60	0.710
3	0.90	9.21	0.686
4	0.95	9.72	0.668
5	1.07	10.94	0.630
6	1.29	13.20	0.574

Run Number 31

β = 0.6 V = 0.0115
T = 86.0 u = 2.26
T.F. = 1.5% CMC Re = 52.1
M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	3.40	10.60	0.641
2	2.92	9.06	0.692
3	3.05	9.47	0.680
4	3.31	10.28	0.649
5	3.74	11.62	0.611
6	4.48	13.91	0.558

Run Number 32

β = 0.6 V = 0.0686
T = 86.0 u = 13.5
T.F. = 1.5% CMC Re = 673
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	29.18	298	0.718

Run Number 32

β = 0.6 V = 0.0686
T = 86.0 u = 13.5
T.F. = 1.5% CMC Re = 673
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	4.54	296	0.720

TABLE I (Continued)

Run Number	33	33	34	34	34
β	0.6	0.6	0.6	0.6	0.6
T	86.0	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	TBE	M	CTC	TBE	M
V	0.0485	0.0495	0.0288	0.0288	0.0288
u	9.7	9.7	5.6	5.6	5.6
Re	422	422	194	194	194
T.C.	1' - 1	1' - 1	1' - 1	1' - 1	1' - 1
Δh	14.15	2.19	15.8	4.82	0.75
ΔP	144	142	48.9	49.3	48.9
Co	0.744	0.748	0.745	0.742	0.744

Run Number	35	35	36	36
β	0.6	0.6	0.6	0.6
T	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	CTC	TBE	CTC	TBE
V	0.0214	0.0214	0.0070	0.0070
u	4.2	4.2	1.4	1.4
Re	126	126	25.8	25.8
T.C.	1' - 1	1' - 1	1' - 1	1' - 1
Δh	8.32	2.58	1.75	0.53
ΔP	26.0	26.4	5.44	5.42
Co	0.762	0.753	0.547	0.548

Run Number 37
β = 0.6 V = 0.0154
T = 86.0 u = 3.04
T.F. = 1.5% CMC Re = 79.9
M.F. = CTC

T.C.	Δh	ΔP	Co
1' - 1	5.33	16.6	0.686
2	4.73	14.6	0.729
3	3.55	11.0	0.842
4	3.58	11.1	0.838
5	4.38	13.6	0.758
6	5.27	16.4	0.690

Run Number 37
β = 0.6 V = 0.0154
T = 86.0 u = 3.04
T.F. = 1.5% CMC Re = 79.9
M.F. = TBE

T.C.	Δh	ΔP	Co
1' - 1	1.60	16.4	0.690
2	1.42	14.5	0.733
3	1.24	12.6	0.784
4	1.26	12.9	0.780
5	1.33	14.0	0.760
6	1.58	16.2	0.694

Run Number 39
β = 0.2 V = 0.0183
T = 86.0 u = 32.3
T.F. = 1.5% CMC Re = 1290
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	37.60	2454	0.642
2	37.60	2454	0.642
3	37.55	2451	0.643
4	37.48	2446	0.643
5	37.37	2439	0.644
6	36.58	2387	0.651

Run Number 41
β = 0.2 V = 0.0114
T = 86.0 u = 20.3
T.F. = 1.5% CMC Re = 928
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	14.33	953	0.654
2	14.27	932	0.655
3	14.14	923	0.658
4	14.11	921	0.659
5	14.05	917	0.660
6	13.89	907	0.664

TABLE I (Continued)

Run Number 38

β = 0.2   V = 0.0214
T = 86.0   u = 37.8
T.F. = 1.5% CMC   Re = 1643
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	52.25	3411	0.6384
2	52.24	3410	0.6385
3	52.23	3409	0.6386
4	52.18	3406	0.6389
5	52.14	3403	0.6391
6	51.00	3316	0.6475
2' - 1	52.43	3423	0.6374
2	52.50	3425	0.6372
3	52.30	3414	0.6381
4	52.24	3410	0.6385
5	52.04	3397	0.6397
6	50.65	3306	0.6484
3' - 1	52.23	3409	0.6386
2	52.23	3409	0.6386
3	52.10	3401	0.6394
4	52.03	3396	0.6398
5	52.00	3394	0.6400
6	51.00	3319	0.6472

Run Number 46

β = 0.2   V = 0.0201
T = 86.0   u = 35.5
T.F. = 1.5% CMC   Re = 2441
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	47.32	3089	0.628
2	47.32	3089	0.628
3	47.11	3075	0.630
4	47.07	3072	0.630
5	47.03	3070	0.630
6	45.80	2990	0.639

Run Number 47

β = 0.2   V = 0.0161
T = 86.0   u = 28.5
T.F. = 1.5% CMC   Re = 1734
M.F. = M

T.C.	Δh	ΔP	Co
1' - 1	29.39	1918	0.641
2	29.37	1917	0.641
3	29.34	1915	0.642
4	29.30	1913	0.642
5	29.24	1909	0.643
6	28.80	1880	0.648

Run Number	40	42	43	44	45
β	0.2	0.2	0.2	0.2	0.2
T	86.0	86.0	86.0	86.0	86.0
T.F.	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC	1.5%CMC
M.F.	M	M	M	M	TBE
V	0.0146	0.0131	0.0169	0.0192	0.0052
u	25.9	23.2	29.9	34.00	9.22
Re	939	1114	1575	1882	313.8
T.C.	1' - 1	1' - 1	1' - 1	1' - 1	1' - 1
Δh	22.91	18.98	33.00	43.44	17.10
ΔP	1495	1239	2154	2836	175.0
Co	0.659	0.6491	0.633	0.629	0.686

TABLE II

VISCOSITY DATA ANALYSIS AND SPECIFIC GRAVITY

Nomenclature

T	=	Temperature	: °F
T.F.	=	Test fluid	
S.G.	=	Specific gravity	: -
S	=	Rotation speed of cylinder	: RPM
M	=	Deflection	: degree
S.S.	=	Shear stress	: $dyne/cm^2$
S.R.	=	Shear rate	: 1/sec
K	=	Consistency index	: $lb_f\text{-}sec^{n'}/ft^2$
γ	=	Viscosity index	: $lb_f/ft\text{-}sec^{2-n'}$

Sample Number 1 (Run Number 1 and 2)

	S	M	S.S.	S.R.	K	γ
T = 78.8						
T.F. = 0.7% CMC	600	100.0	1204	1042	2.45	1.55
S.G. = 1.003	300	61.5	740	521	2.53	1.61
n' = 0.753	200	45.0	542	348	2.52	1.60
γ = 1.58	100	26.0	313	174	2.45	1.56

Sample Number 2 (Run Number 4)

	S	M	S.S.	S.R.	K	γ
T = 78.8						
T.F. = 0.7% CMC	600	88.1	1108	1039	1.73	1.16
S.G. = 1.002	300	52.7	663	520	1.78	1.20
n' = 0.785	200	38.2	480	346	1.77	1.20
γ = 1.18	100	21.6	272	173	1.73	1.16

Sample Number 3 (Run Number 6 and 7)

	S	M	S.S.	S.R.	K	γ
T = 78.8						
T.F. = 0.7% CMC	600	84.9	1081	1038	1.57	1.07
S.G. = 1.002	300	50.5	643	519	1.62	1.11
n' = 0.794	200	36.4	463	346	1.61	1.10
γ = 1.09	100	20.5	261	173	1.57	1.07

TABLE II (Continued)

Sample Number 4 (Run Number 8)

		S	M	S.S.	S.R.	K	Y
T	= 78.8						
T.F.	= 0.7% CMC	600	84.4	1085	1038	1.48	1.03
S.G.	= 1.002	300	49.8	640	519	1.53	1.06
n'	= 0.801	200	36.0	463	346	1.53	1.06
Y	= 1.04	100	20.1	258	173	1.48	1.03

Sample Number 5 (Run Number 9,10 and 11)

		S	M	S.S.	S.R.	K	Y
T	= 78.8						
T.F.	= 0.7% CMC	600	83.8	1076	1038	1.48	1.02
S.G.	= 1.002	300	49.8	639	519	1.53	1.06
n'	= 0.800	200	35.9	461	346	1.53	1.06
Y	= 1.04	100	20.0	256	173	1.48	1.03

Sample Number 6 (Run Number 13)

		S	M	S.S.	S.R.	K	Y
T	= 78.8						
T.F.	= 0.7% CMC	600	79.8	1048	1036	1.26	0.90
S.G.	= 1.002	300	46.8	615	518	1.30	0.93
n'	= 0.816	200	33.5	440	345	1.30	0.93
Y	= 0.92	100	18.5	243	173	1.26	0.90

Sample Number 7 (Run Number 14)

		S	M	S.S.	S.R.	K	Y
T	= 78.8						
T.F.	= 0.7% CMC	600	78.9	1036	1035	1.25	0.89
S.G.	= 1.002	300	46.1	605	518	1.29	0.92
n'	= 0.816	200	33.0	433	345	1.28	0.91
Y	= 0.90	100	18.3	240	173	1.25	0.90

Sample Number 8 (Run Number 15)

		S	M	S.S.	S.R.	K	Y
T	= 86.0						
T.F.	= 1.5% CMC	300	223	1018	534	25.6	11.9
S.G.	= 1.001	200	177	810	356	25.8	12.0
n'	= 0.586	100	117	535	178	25.6	12.0
Y	= 12.0						

TABLE II (Continued)

Sample Number 9 (Run Number 16)

		S	M	S.S.	S.R.	K	γ
T	= 86.0						
T.F.	= 1.5% CMC	300	223	1018	534	25.2	11.8
S.G.	= 1.001	200	176	803	356	25.2	11.8
n'	= 0.590	100	116	533	178	25.2	11.8
γ	= 11.8						

Sample Number 10 (Run Number 17)

		S	M	S.S.	S.R.	K	γ
T	= 86.0						
T.F.	= 1.5% CMC	300	222	1016	534	25.2	11.8
S.G.	= 1.002	200	177	810	356	25.5	11.9
n'	= 0.590	100	116	533	178	25.2	11.8
γ	= 11.8						

Sample Number 11 (Run Number 18)

		S	M	S.S.	S.R.	K	γ
T	= 86.0						
T.F.	= 1.5% CMC	300	224	1023	534	26.1	12.1
S.G.	= 1.002	200	178	812	356	26.3	12.2
n'	= 0.584	100	118	539	178	26.2	12.1
γ	= 12.1						

Sample Number 12 (Run Number 19)

		S	M	S.S.	S.R.	K	γ
T	= 86.0						
T.F.	= 1.5% CMC	300	223	1021	535	26.6	12.2
S.G.	= 1.002	200	178	815	356	26.8	12.4
n'	= 0.581	100	118	540	178	26.6	12.2
γ	= 12.3						

Sample Number 13 (Run Number 20, 21 and 22)

		S	M	S.S.	S.R.	K	γ
T	= 86.0						
T.F.	= 1.5% CMC	300	225	1031	535	27.0	12.4
S.G.	= 1.002	200	180	823	356	27.2	12.5
n'	= 0.580	100	119	546	178	27.0	12.4
γ	= 12.4						

TABLE II (Continued)

Sample Number 14 (Run Number 23, 24, 25, 26 and 27)

	S	M	S.S.	S.R.	K	Y
T = 86.0						
T.F. = 1.5% CMC	300	228	1041	535	27.8	12.7
S.G. = 1.002	200	182	835	357	28.1	12.9
n' = 0.577	100	121	554	178	27.9	12.7
Y = 12.8						

Sample Number 15 (Run Number 28)

	S	M	S.S.	S.R.	K	Y
T = 86.0						
T.F. = 1.5% CMC	300	231	1057	535	28.1	12.9
S.G. = 1.000	200	183	838	357	28.1	12.9
n' = 0.578	100	122	561	178	28.1	12.9
Y = 12.9						

Sample Number 16 (Run Number 29 and 30)

	S	M	S.S.	S.R.	K	Y
T = 86.0						
T.F. = 1.5% CMC	300	239	1094	535	29.3	13.4
S.G. = 1.000	200	190	870	357	29.4	13.4
n' = 0.576	100	127	581	178	29.3	13.4
Y = 13.4						

Sample Number 17 (Run Number 31, 32, 33, 34, 35 and 36)

	S	M	S.S.	S.R.	K	Y
T = 86.0						
T.F. = 1.5% CMC	300	236	1080	536	31.0	13.8
S.G. = 1.000	200	189	865	357	31.2	14.0
n' = 0.565	100	127	581	178	31.0	13.9
Y = 13.9						

Sample Number 18 (Run Number 37

	S	M	S.S.	S.R.	K	Y
T = 86.0						
T.F. = 1.5% CMC	300	235	1075	536	30.4	13.7
S.G. = 1.000	200	188	858	357	30.6	13.7
n' = 0.567	100	126	577	179	30.4	13.7
Y = 13.7						

TABLE II (Continued)

Sample Number 19 (Run Number 38)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	300	224	1028	536	28.4	12.8
S.G. = 1.002	200	180	822	357	28.6	12.9
n' = 0.571	100	120	549	178	28.4	12.8
γ = 12.9						

Sample Number 20 (Run Number 39 and 40)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	300	226	1032	535	27.8	12.7
S.G. = 1.001	200	180	824	357	28.0	12.8
n' = 0.575	100	120	549	178	27.8	12.7
γ = 12.7						

Sample Number 21 (Run Number 41, 42, 43, 44 and 45)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	600	224	1025	1060	12.9	6.50
S.G. = 0.999	300	141	645	530	12.6	6.33
n' = 0.628	200	111	508	353	12.8	6.42
γ = 6.4	100	72	332	177	12.9	6.48

Sample Number 22 (Run Number none)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	600	222	1014	1060	12.6	6.38
S.G. = 0.998	300	140	638	530	12.3	6.21
n' = 0.629	200	110	501	353	12.4	6.29
γ = 6.3	100	72	327	177	12.6	6.36

Sample Number 23 (Run Number 46)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	600	192	881	1067	14.1	6.65
S.G. = 0.999	300	132	606	533	14.7	6.91
n' = 0.593	200	102	469	356	14.4	6.80
γ = 6.8	100	67	306	178	14.2	6.68

TABLE II (Continued)

Sample Number 24 (Run Number 47)

	S	M	S.S.	S.R.	K	γ
T = 86.0						
T.F. = 1.5% CMC	600	194	890	1064	13.2	6.35
S.G. = 0.999	300	134	613	532	13.8	6.65
n' = 0.604	200	102	467	355	13.4	6.47
γ = 6.5	100	66	303	177	13.3	6.40

SAMPLE CALCULATIONS

Pressure Drop, Reynolds Number, and Orifice Coefficient

These were calculated from the manometer reading, flow rate, and viscometer data as follows:

$$\Delta P = \Delta h \text{ (Sp. Gr. of manometer fluid} - 0.998) (62.43) (\text{in.}/12 \text{ ft.})$$

$$C_o = \frac{u_o}{\left[\frac{2 g_c \Delta P}{\rho (1 - \beta^4)}\right]^{1/2}}$$

$$Re_o = \frac{D n' u_o^{2-n'} \rho}{\gamma}$$

where Sp. Gr. of manometer fluids available in the literature were

1.595 for carbon tetrachloride

2.965 for tetrabromoethane

13.546 for mercury

at 20°C and for consistency, 0.998 was used for Sp. Gr. of water at 20°C.

From Table I, Run No. 2, tap connection 1'-1 and from corresponding Table II, Run No. 2:

Δh = 7.86 inches, Manometer Fluid = Mercury

$D_o = (1.610)\ (0.6)\ (1/12)$ ft., $\beta = 0.6$

$u_o = 16.9$ ft./sec., $g_c = 32.17$ lb.$_m$-ft./lb.$_f$-sec.^{2}

$\rho = (1.003)\ (62.43)$ lb.$_m$/ft.^{3}, $\gamma = (1.58)\ (0.00672)$ lb.$_m$/ft.-sec.

$n' = 0.753$

$\Delta P = (7.86)\ (13.546 - 0.998)\ (62.43)\ (1/12)$

$= 513$ lb.$_f$/ft.^{2}

$$C_o = (16.9) \left(\frac{2\ (32.17)\ (513)}{(1.003)\ (62.43)\ (1 - 0.13)} \right)^{1/2} = 0.688$$

$$Re_o = \left(\frac{0.688 \times 1.610}{12} \right)^{0.753} \left(\frac{1}{1.58 \times 0.00672} \right) (16.9)^{2-0.753} (1.003)$$

$= 3020$

Viscosity Data Analysis

These calculations were executed by the IBM 7040 computer by means of the least square method to find n' from shear stress versus shear rate plots on log-log coordinates and then obtain γ. Shear stress and shear rate are calculated by

$$\tau = \frac{K_s M}{2\pi\ r^2\ L}$$

$$\frac{du}{dy} = \frac{2 r_2^{2/n'}\ \Omega}{n'\ (r_2^{2/n'} - r_1^{2/n'})}$$

where

K_s = spring constant of viscometer, dyne-cm./deg.

M = angular deflection read from viscometer, deg.

r_1 = outer radius of inner cylinder of viscometer, cm.

r_2 = inner radius of outer cylinder of viscometer, cm.

L = length of the inner cylinder, cm.

Ω = rotation speed of outer cylinder, radians/sec.

From Table II, Run No. 2:

SPEED $3\Omega/\pi$ (R.P.M.)	DEFLECTION M (deg.)	SHEAR STRESS τ (dyne/cm.^{2})	SHEAR RATE du/dy (1/sec.)
600.00	100.0	1204	1043
300.00	61.5	740	521
200.00	45.0	542	348
100.00	26.0	313	174

Determining the best straight line fitting the shear stress-shear rate plots on log-log coordinates, find the slope

$$n' = 0.753 .$$

Calculating K and K' for each shear rate by Equations 10, 13, 14, and 17:

$$K = \frac{\tau}{\left(\frac{du}{dy} \right)^n} \qquad (10)$$

$$n' = n \qquad (13)$$

$$K' = K \left(\frac{3n + 1}{4n} \right)^n \qquad (14)$$

$$\gamma = g_c \ K' \ 8^{n'-1} \qquad (17)$$

K g/cm. sec.$^{1-n'}$	K' g/cm. sec.$^{1-n'}$
2.45	2.60
2.54	2.69
2.52	2.67
2.45	2.60

Taking the average of these four values of K' to obtain finally,

$$\gamma = g_c \, K' \, 8^{n'-1} = (980)\,(2.64)\,(8)^{0.753-1}$$

$$= 1.59 \text{ Poise } (\text{g/cm. sec.}^{1-n'}) \;.$$

TABLE III

COMPARISON OF COEFFICIENTS AT LIKE REYNOLDS NUMBERS IN DISSIMILAR CONDITIONS

β	0.6		0.6	
Run Number	8	28	9	29
Re_o	894	950	606	559
Concentration (%CMC)	0.7	1.5	0.7	1.5
Orifice Velocity, u_o	5.39	17.0	3.89	12.0
n'	0.801	0.578	0.800	0.576
γ	1.04	12.9	1.00	13.4
Co	0.721	0.711	0.730	0.734
Difference in Co	1.4%		-0.55%	

β	0.2		0.2	
Run Number	11	44	14	42
Re_o	1980	1880	1130	1110
Concentration (%CMC)	0.7	1.5	0.7	1.5
Orifice Velocity, u_o	21.7	34.0	13.1	23.2
n'	0.800	0.628	0.816	0.628
γ	1.04	6.44	0.904	6.44
Co	0.623	0.629	0.653	0.649
Difference in Co	-0.98%		0.61%	

TABLE IV

IMPACT PRESSURE DATA

β	Run No.	Concentration % CMC	Re_o	ΔP_1 at 1' - 1	ΔP_2 at 2' - 1
0.8	15	1.5	501	75.56	73.82
0.8	16	1.5	324	44.70	38.05
0.8	17	1.5	209	22.76	20.34
0.8	18	1.5	143	14.60	13.01
0.8	19	1.5	94.6	9.752	8.230
0.6	2	0.7	3020	513.1	522.9
0.6	4	0.7	2560	321.4	321.9
0.6	6	0.7	1910	178.5	178.6
0.6	7	0.7	1200	79.35	79.07
0.6	8	0.7	894	47.39	47.30
0.6	9	0.7	606	23.98	25.47
0.6	28	1.5	951	484.6	483.1
0.2	1	0.7	3700	3429.1	3421.2
0.2	10	0.7	2800	2172.5	2173.8
0.2	11	0.7	1980	1174.4	1173.1
0.2	14	0.7	1130	389.2	388.0
0.2	38	1.5	1640	3411.0	3422.5

β	Run No.	ΔP_3 at 3' - 1	Impact Pressure $\Delta P'$	Per cent $\Delta P'$ to $\Delta P_{min.}$ %
0.8	15	77.09	1.74	2.36
0.8	16	40.96	6.05	15.9
0.8	17	23.85	2.42	11.9
0.8	18	10.87	1.59	12.2
0.8	19	10.87	1.522	17.5
0.6	2	528.8	-15.7	-3.05
0.6	4	321.0	0.9	0.3
0.6	6	178.6	-0.1	-0.06
0.6	7	79.04	0.28	0.39
0.6	8	47.46	0.09	0.2
0.6	9	24.04	1.43	6.22
0.6	28	484.5	1.5	0.30
0.2	1	3426.5	7.9	0.23
0.2	10	2171.2	2.6	0.12
0.2	11	1173.1	1.3	0.11
0.2	14	385.0	4.2	0.30
0.2	38	3409.5	13.0	0.382

$\Delta P'$ = the greatest value among the differences of $\Delta P_1 - \Delta P_2$, $\Delta P_1 - \Delta P_3$, and $\Delta P_2 - \Delta P_3$.

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