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University of Cincinnati
Department of Chemical and Nuclear Engineering

Quarterly Progress Report
Period Ending March 31, 1973

"Investigation of Pressure Drops and
Heat Transfer Coefficients For
Loss of Coolant Evaluations"

Report No. C00-2152-7

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Contract AT(11-1)2152

"Investigation of Pressure Drops & Heat Transfer Coefficients for
Loss of Coolant Evaluation"

Quarterly Report for Period Jan. 1 to Mar. 31, 1973

This contract has as its objective the study of pressure drop and heat transfer phenomena of importance during a loss of coolant accident. The study is divided into 3 major experiments:

- a) Transient Pressure Drop Investigation
- b) Two-Phase Pressure Drop and Flow Pattern Study
- c) Transition Boiling and Reflooding Heat Transfer Tests

I. Transient Pressure Drop Investigation

These experiments are being performed by discharging Freon 113 from a large storage accumulator. The Freon lashes across a needle valve and then a 3-way valve directs a portion of the two-phase mixture to a storage accumulator and the remainder through the test section. By varying the position of the three-way valve a time varying flow is obtained through the test section.

During this quarter, a series of exploratory runs were made to determine the best way of obtaining transient pressure drop data. It was concluded that the most fruitful approach was to operate the 3-way valve in an oscillatory manner so as to obtain a nearly sinusoidally varying flow. When this is done, the flow resistance can be determined by measuring the displacement between the peaks of the

pressure and flow curves. This has the advantage of not requiring an absolute calibration of D/P cell signal. Such a calibration was found to be difficult for all of the strain gauge cells except the weigh cell.

The weigh cell, from which the receiving accumulator is suspended, was found to be too insensitive to follow the transient flow. The turbine flow meter, however, appears to satisfactorily follow the oscillating flow. In single phase flow, the total weight of fluid discharged obtained from the weigh cell agrees reasonably with the value obtained by integrating the turbine meter curve. It is therefore proposed that the weigh be used as a means for calibrating the turbine meter during two-phase experiments.

If the flow, w , may be assumed to follow

$$w = B + C \sin \omega t \quad (1)$$

Then the pressure drop across the sudden contraction is given by

$$\Delta p = \frac{(B + C \sin \omega t)^2}{2\rho A_2^2 g_c} \left[1 - \left(\frac{A_2}{A_1} \right)^2 + K_c + \left(\frac{A_2}{A_1} \right)^2 \frac{2f_1 L_1}{P_1} + \frac{2f_2 L_2}{P_2} \right] \\ + \frac{\omega C \cos \omega t}{g_c} \left[\frac{L_1}{A_1} + \frac{L_2}{A_2} \right] \quad (2)$$

By differentiating the above, and setting the differential equal to zero, we obtain

$$\omega \tan(\omega t) = \frac{[B + C \sin(\omega t)]}{[(L_1/A_1) + (L_2/A_2)]} \frac{[1 - \left(\frac{A_2}{A_1}\right)^2 + K_c + \left(\frac{A_2}{A_1}\right)^2 \frac{2f_1 L_1}{D_1} + \frac{2f_2 L_2}{D_2}]}{\rho A_2^2} \quad (3)$$

which can be solved numerically for the ω 's at which the pressure drop has a maxima or minima. The displacement θ of the peaks is then

$$\theta_{\max} = \frac{180}{\pi} (\omega_{\max} - \pi/2) \quad (4)$$

$$\theta_{\min} = \frac{180}{\pi} (\omega_{\min} - 0) \quad (5)$$

The predicted and observed values of θ are compared in fig. 1. It is seen that the agreement obtained is quite good.

The expansion results require a more careful analysis. Since the Bernoulic pressure rise and the frictional pressure drop are in opposite direction, a small pressure drop term remains. This term is small relative to the momentum storage terms and the maxima and minima occur very near the location at which the flow curve exhibits its maximum acceleration and deceleration. Since the actual flow curve deviates from a sine curve, large errors result if the flow curve is assumed to be a perfect sine wave. If, however, the pressure drop curve is determined by numerically differentiating the actual flow curve, good agreement between observation and prediction is obtained.

Experiments are now being conducted to determine how best to adapt the experimental technique to two-phase operation.

II. Two-Phase Pressure Drop and Flow Pattern Study

These experiments are being conducted in a recirculating loop using Freon 113. During this quarter, emphasis was placed on obtaining additional data on the pressure drop across sudden expansions and contractions. The contraction data are obtained directly while the expansion data are obtained by subtracting the contraction Δp from the total Δp across both expansion and contraction.

Values of the ratio of $K_{\text{two } \phi} / K_{\text{single } \phi}$ are plotted vs. the observed void fraction, α , in figs. 2 and 3. The contraction K 's appear to dip at low void fractions and then to climb steadily. It is seen that this climb at higher void fractions is in accord with the observation of Ferrel et al (1) which are also plotted. The expansion coefficients show an initial rise and then a drop to nearly constant value. Again the observations at high void fractions are in agreement with those of Ferrel et al (1).

The dip in contraction K 's at low α 's may be spurious. (Since the expansion K 's were derived from the contraction value, the dip in K_e at low α may, therefore, also be spurious) To obtain the area change K 's, it is necessary to subtract the pipe friction Δp from the observed Δp . In these calculations, Baroczy's (2) two-phase multipliers were used to obtain these values. It is believed that these values may be too high for the low α conditions. During the next quarter, pressure drop measurements across straight pipe sections will be acquired to check this supposition.

A new expansion - contraction test section is now being installed. This test section is of glass and will allow visual observation of the flow pattern at the area changes.

III. Transition Boiling and Reflooding Heat Transfer Tests

Experimental Work - These experiments are to be conducted in a heat transfer loop using hot mercury as a heat source. Boiling takes place in an annulus around the pipe containing the mercury.

These experiments were delayed pending the receipt of a new mercury pump. A canned-motor pump was received this quarter and installed in the loop. Tests of the system have indicated a lower mercury flow than expected. A large impeller has therefore been ordered. A revised flow indicator is also being obtained. Debugging operation of the loop is continuing with the present pump impeller.

Analysis of Transition Boiling Data

A number of approaches which might yield a general correlation of transition boiling heat transfer coefficients have been examined. None have been entirely satisfactory. One approach which has shown some promise assumes that the transition boiling coefficient, h_T , can be written as

$$h_T = h_B + h_c \quad (6)$$

where h_B = boiling component

h_c = forced convection component

The boiling component is taken as

$$h_B = S h_{cr} \exp[-K(\Delta T - \Delta T_{cr})] \quad (7)$$

where S = Chen's (3) boiling suppression factor due to the effect of flow rate and quality

h_{cr} = maximum pool boiling h (saturated) from Addom's (4) data for specified pressure.

ΔT_{cr} = ΔT at which max. pool boiling h occurs, obtained from Addom's data.

K = empirical constant = 0.012

The convective component is obtained from a modified version of Quinn's (5) equation

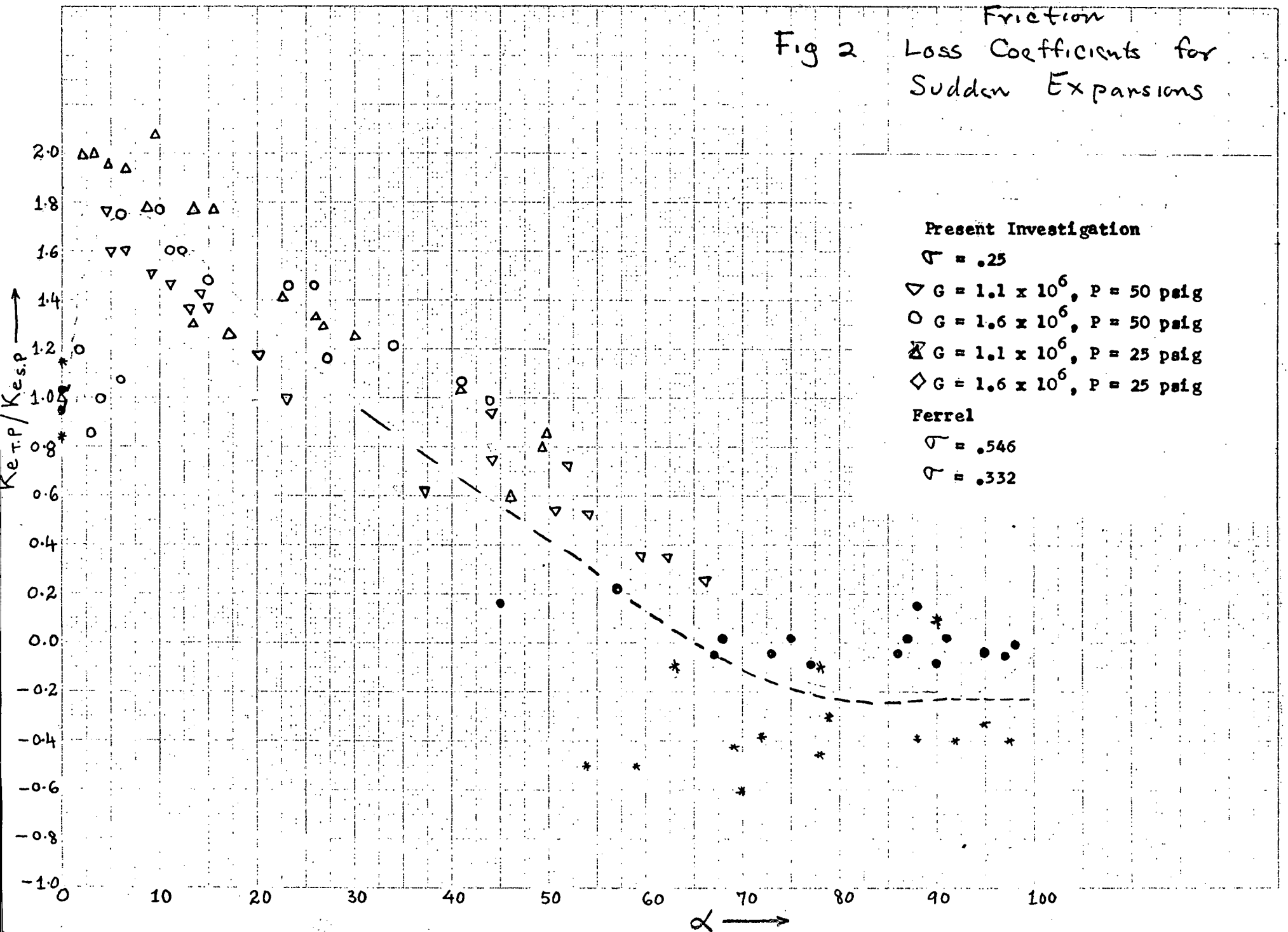
$$h_c = 0.0235 \left(\frac{\mu_B}{\mu_w} \right)^{0.14} \left(\frac{K_B}{D_H} \right) \rho_{v_B}^{1/3} \left(\frac{G_T D_H}{\mu_B} \right)^{0.8} (0.15 + 0.86 x) \quad (8)$$

where x is quality and other symbols have their usual meaning. Fig. 4 compares the heat transfer coefficients predicted by the foregoing model with a number of experimental observations. The agreement is reasonable in most cases. The relatively poor agreement shown by Ellison's (6) data may be due to the fact that this data was obtained with subcooled water. Subcooling is known to increase film boiling h 's and hence the convective component predicted would be too low.

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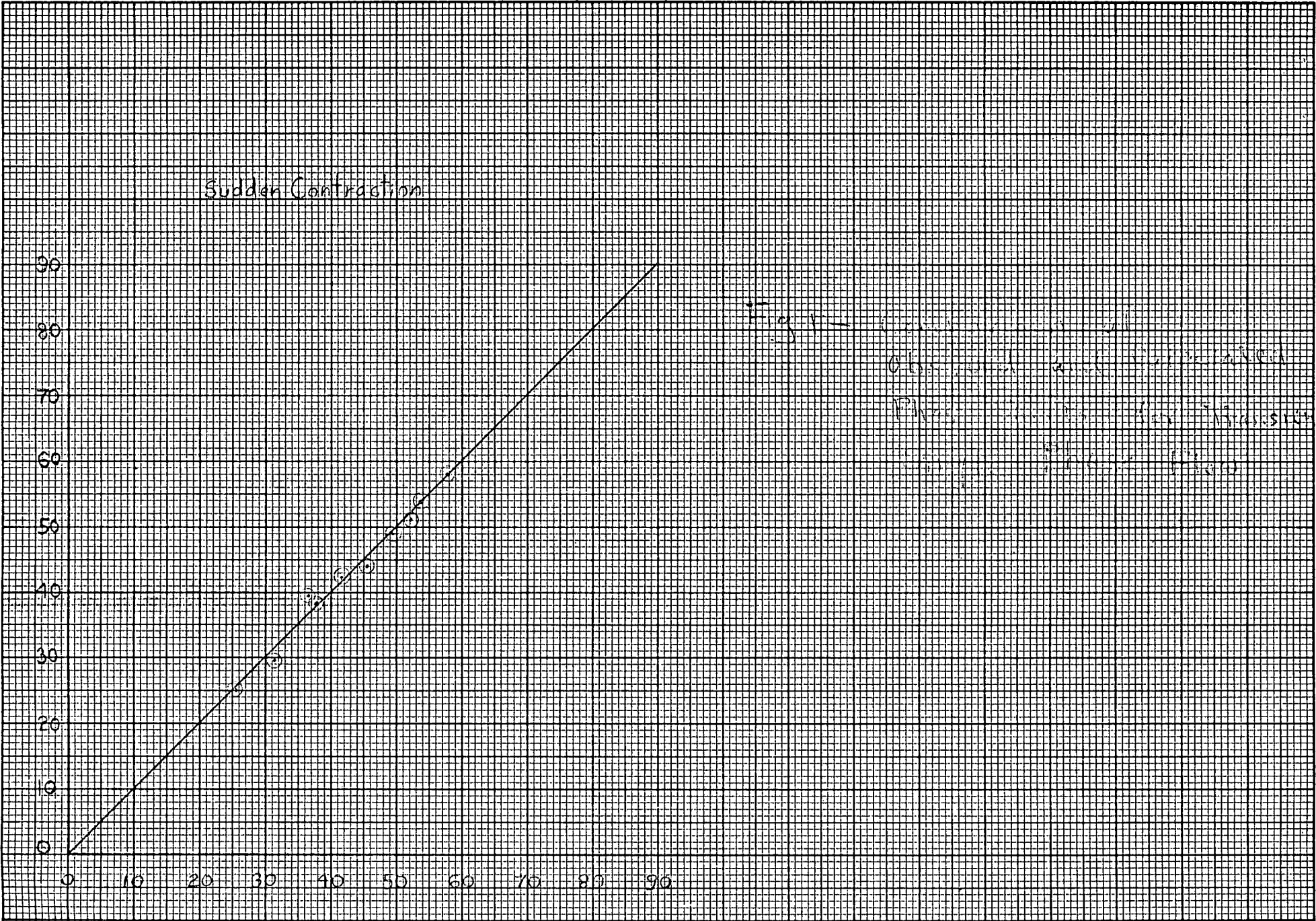
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Friction
Fig 2 Loss Coefficients for Sudden Expansions



Sudden Contraction

Phase Shift Predicted (θ_p)°



Phase Shift Observed (θ_o)°

Fig. 1
Observed and Predicted
Phase Shifts for Sudden
Contraction

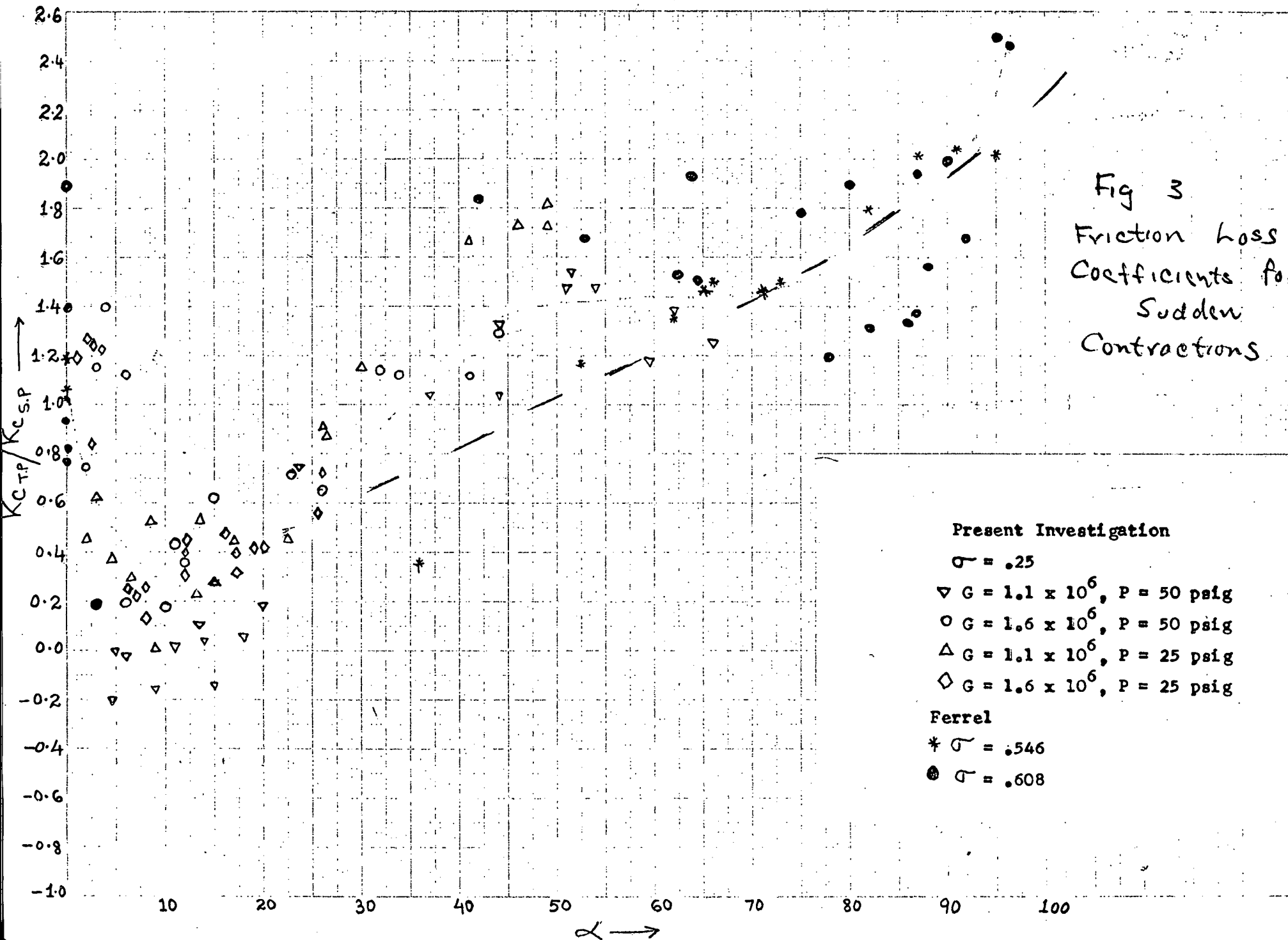
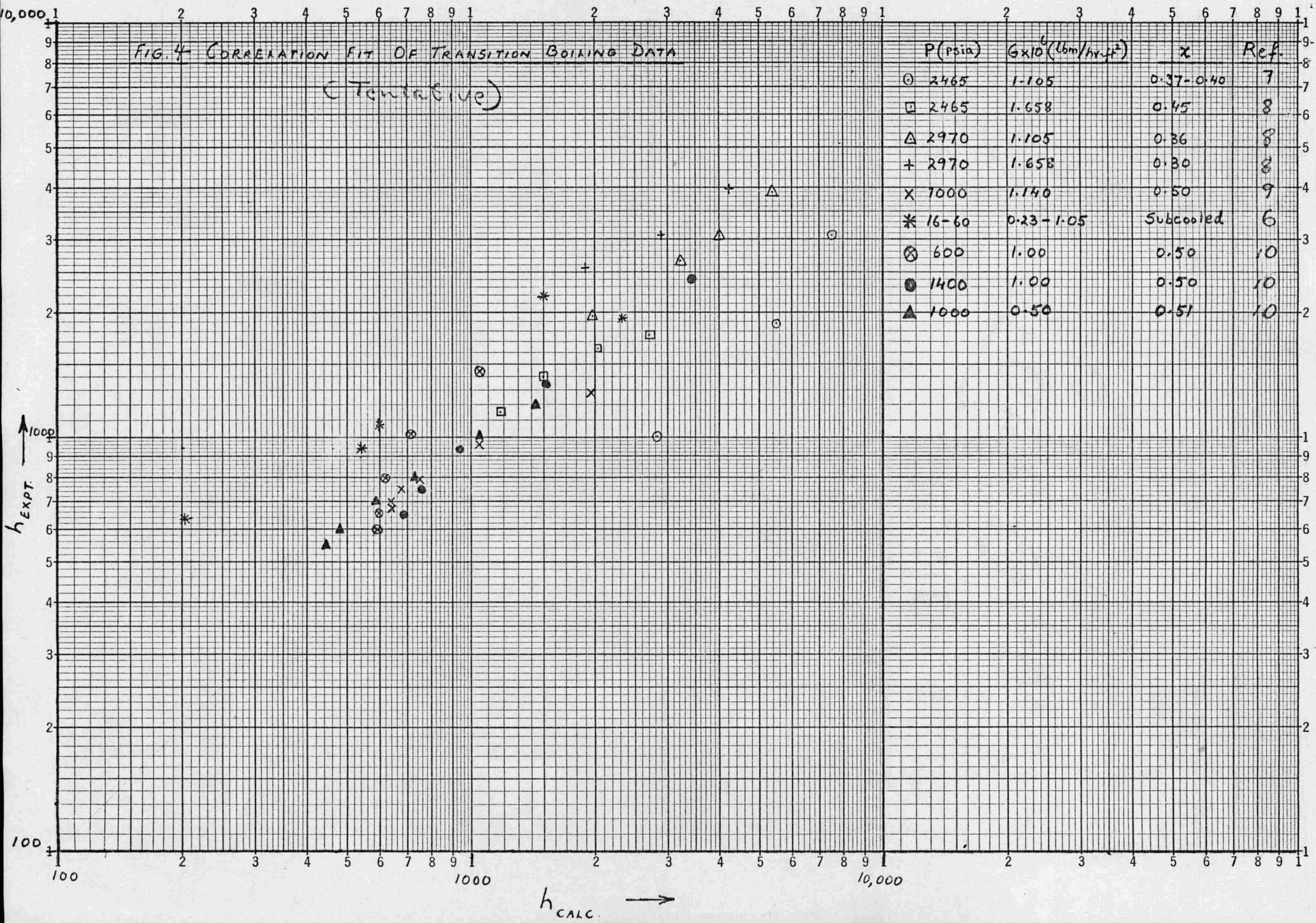


Fig 3
 Friction Loss
 Coefficients for
 Sudden
 Contractions



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