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EMULSION FLOW THROUGH SOME ELEMENTS OF HYDRAULIC SYSTEMS

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Abstract

This paper presents an experimental investigation of the characteristics of emulsion flows (oil in water) through some elements of hydraulic systems, such as; orifice meter, venturimeter, sudden enlargement and sudden contraction. The effects of oil concentration, Reynolds number, and locations of pressure tapping holes on the discharge and loss coefficients are studied. The results revealed that the location of the upstream and downstream tapping holes of sudden enlargement and sudden contraction has a significant effect on the loss coefficient. It is also shown that the discharge coefficient for the orifice and venturi meters are affected by the amount of oil in the mixture.

Nomenclature

A	Flow area	
C	Oil concentration (weight of oil/weight of water)	
C_d	Discharge coefficient	
C_L	Sudden enlargement loss coefficient	
C_n	Sudden contraction loss coefficient	
D	Pipe diameter	m
d_o	Orifice diameter	m
d_t	Venturimeter throat diameter	m
g	Gravitational acceleration	m/s^2
h	Pressure head	m.water
Δh	Differential pressure head across the orifice or across the convergent section of the venturi	m.water
Q	Volume flow rate	m^3/s
Re	Flow Reynolds number	
S	Specific gravity	
V	Mean velocity	m/s
x	Weight of oil/weight of mixture	
ρ	Density	Kg/m^3
μ	Dynamic viscosity	$N.S/m^2$

Subscripts

0	Orifice hole conditions
1	Upstream flow conditions
2	Downstream flow conditions
Hg	Mercury
LH	Homogeneous mixture flow
LO	Mixture flow is treated as pure water flow

mix	Mixture
oil	oil flow
t	Throat conditions
w	Water flow

1. Introduction

The oil in water emulsion flow through hydraulic systems has become of great importance to a wide range of technological applications in modern industry. To name a few of many possible examples; emulsion pipeline system for crude oil transport, water and oil collection systems, and chemical process systems.

Most of previous investigations in this field have been concerned with the flow of wet steam through ofifice plates, pipes and venturi contractions, [1-4]. Occasionally, the flow of non-Newtonian fluid through hydraulic components has been studied, [5-10]. Unlike the case of single phase flow, very little work has been published related to emulsion flow (oil in water) through such components. Considerable interest has been shown recently in developing techniques to reduce the pumping energy requirements, the heating requirements and the pipe size required to transport viscous crude oils in pipelines, [11 -13].

The aim of the present work is to determine the characteristics of emulsion flow through orifice meter, venturimeter, sudden enlargement and sudden contraction. Effects of oil concentration, Reynolds number and the location of pressure tapping holes on the loss coefficient are considered.

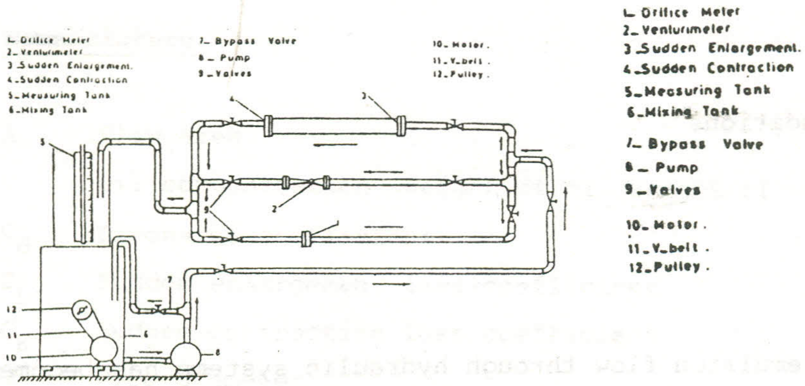
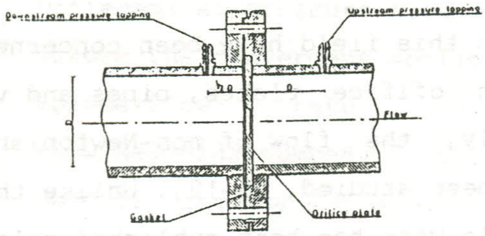
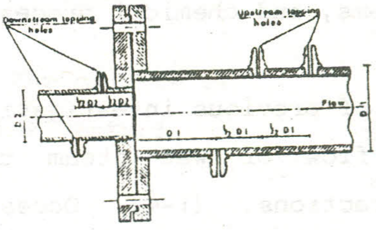


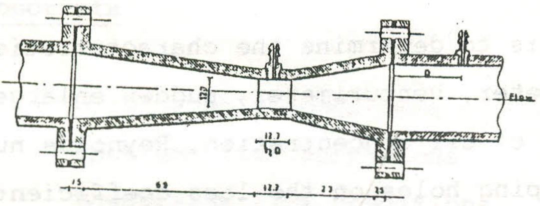
Fig (1) The Experimental Apparatus.



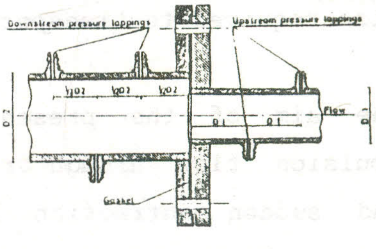
A- THE ORIFICE METER DETAILS



C- THE SUDDEN CONTRACTION SECTION



B- THE VENTURIMETER DETAILS



D- THE SUDDEN ENLARGEMENT SECTION

Fig(2) Test Elements

2. Experimental Set-Up And Measuring Devices

In order to study the behaviour of emulsion flow (oil in water) in some elements of hydraulic systems such as, orifice meter, venturimeter, sudden enlargement and sudden contraction, a testing apparatus was designed. Fig. (1) shows a schematic diagram of this apparatus. It consists of a test section, metering tank, supply or mixing tank, a pump and control valves. The main experimental block, representing the hydraulic circuit, comprises three branches. Each branch contains one of the hydraulic elements, orifice meter, venturi meter, sudden enlargement and sudden contraction. Fig. (2) shows details of these elements. The three branches have common inlet and outlet pipes. The common outlet pipe is directed to the metering tank. Oil was mixed with the main fluid (water) by a special propeller fixed on two opposite sides of the supply tank. The working fluid is supplied to the test section by a centrifugal pump. A bypass circuit is incorporated to control the flow through the main experimental block. The pump suction pipe was connected to the bottom of the supply tank. The working fluid (mixture of oil and water) returns back to the supply tank after passing through one of the main experimental lines or the test section.

Oil-in-water emulsions, made from refined mineral oil (suprex 50) and tap water, were prepared at different values of oil concentrations. Table (1) shows the concerned physical properties of this type of oil.

During the experimental program, the static pressure distribution, oil concentration, volume flow rate and fluid temperature were measured, Pressure tapping holes were drilled through the wall of the upstream and downstream pipes of each hydraulic element. The position of

Table (1) Physical properties of oil (suprex 50)

temperature	Specific gravity	Kinematic viscosity, (m^2/s)
25 °C	0.915	325×10^{-6}
30 °C	0.910	------
35 °C	0.907	250×10^{-6}
50 °C	0.90	124×10^{-6}

these holes are shown in Fig. (2). A multiple U-tube manometer system was used to measure the fluid pressure at different locations in the upstream and downstream pipes of each one of the hydraulic elements used. A collecting calibrated tank and stop watch were used to measure the flow rate. The fluid temperature was measured, during each experimental run, by using a mercury in glass thermometer. The oil viscosity was measured by using a viscometer. During each run the oil concentration (weight of oil/weight of water) was obtained.

The experiments were carried out with four different values of oil concentration, (c). These concentrations were 0.01, 0.02, 0.04 and 0.1.

3 Experimental Results

Figures (3 & 4) show the variation of discharge coefficient (C_d) with the flow Reynolds number (Re). The measurements were taken for

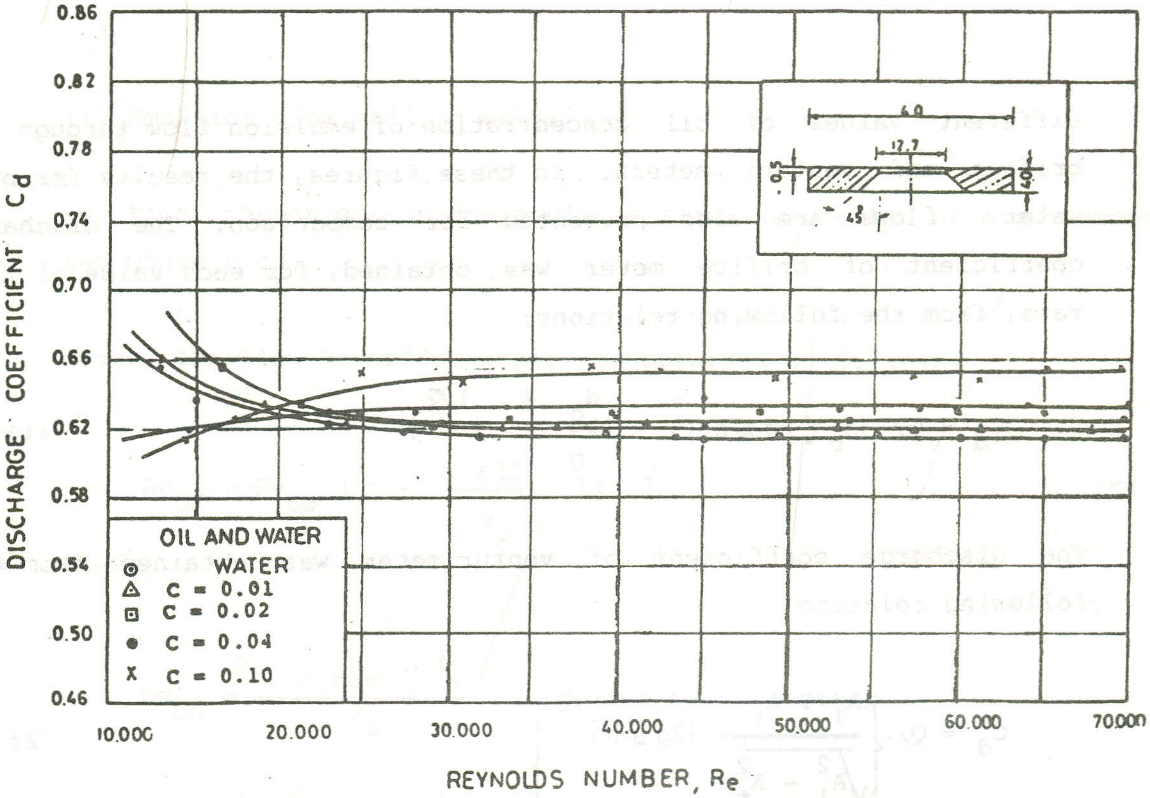


FIG (3)CALIBRATION DATA FOR ORIFICE

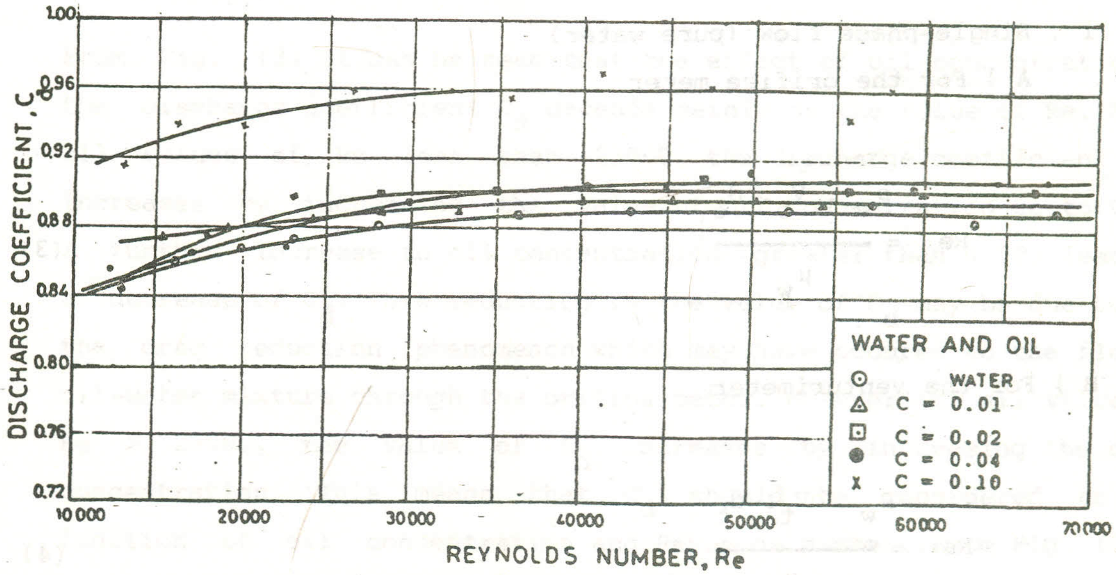


FIG. (4) CALIBRATION DATA FOR VENTURIMETER different values of oil concentration of emulsion flow through the orifice and venturi meters. In these figures, the results for pure water flows are also presented for comparison. The discharge coefficient of orifice meter was obtained, for each value of flow rate, from the following relations;

$$C_d = Q/ \{A_o [2g \Delta h/(1 - (\frac{d_o}{D})^4))]^{1/2} \} \qquad (1)$$

The discharge coefficient of venturimeter was obtained from the following relation;

$$C_d = Q/ \left\{ \frac{A_1 \cdot A_t}{\sqrt{A_1^2 - A_t^2}} [2g \Delta h]^{1/2} \right\} \qquad (2)$$

Flow Reynolds number was, however, calculated from the following relations;

i . Single-phase flow (pure water)

A) For the orifice meter

$$Re = \frac{\rho_w \cdot V_o \cdot d_o}{\mu_w} \qquad (3)$$

B) For the venturimeter

$$Re = \frac{\rho_w \cdot V_t \cdot d_t}{\mu_w} \qquad (4)$$

ii. Emulsion flow (oil in water)

In this investigation the emulsion flow was treated as a homogeneous two-phase flow.

Hence, the flow Reynolds number was obtained as follows;

$$Re_{LH} = Re_{Lo} \left[1 - \left(\frac{v_{oil}}{v_w} - 1 \right) x \right] \qquad (5)$$

where,

$$Re_{Lo} = \frac{\rho_w V_{o\,mix} \cdot d_o}{\mu_w} \quad \text{, for the orifice meter}$$

$$Re_{Lo} = \frac{\rho_w V_{t\,mix} \cdot d_t}{\mu_w} \quad \text{, for the venturimeter}$$

From Fig. (3) it can be seen that the effect of oil concentration on the discharge coefficient C_d depends mainly on the value of Re. For all values of Re less than 23000, the discharge coefficient C_d increases by increasing the value of oil concentration up to 0.02. A further increase in oil concentration (greater than 0.02) leads to a decrease of C_d. This reduction in the value of C_d may be due to the drag reduction phenomenon which may have occured to the flow of oil-water mixture through the orifice meter. However for all values of Re > 23000, the value of C_d increases by increasing the oil concentration. This means that C_d should be considered to be function of oil concentration and Reynolds number. From Fig. (3) it can also be seen that, for pure water and emulsion flows with low concentration of oil ($C = 0.01$ and $C = 0.02$), by increasing Re ($Re < 30000$) the discharge coefficient decreases. But for emulsion flow with higher values of oil concentration (0.04 and 0.1) the discharge coefficient increases by increasing Re.

It is observed from the curves shown in Fig. (4) that there is an increase in the discharge coefficient of venturimeter with the increase of the oil concentration at constant value of Re. This increase is believed to be due to the increase in the emulsion flow viscosity, which inturn increases the pressure drop through the venturi contraction. Also, it can be seen, for pure water flow and oil in water emulsion flow with different concentration, that by increasing the value of Re (up to 40000) the discharge coefficient increases. This is apparently due to the increase in flow inertia. For high Reynolds number ($Re > 40000$) the discharge coefficient approaches an almost a constant value.

The variation of loss coefficient C_L, through a sudden enlargement for pure water flow and different concentrations of emulsion flow was obtained for different values of flow Reynolds number. The results are shown in Figs. (5-9). In these figures the value of C_L was obtained from the following relation,

$$h_1 - h_2 = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + C_L \frac{(V_1 - V_2)^2}{2g} \qquad (6)$$

The values of h_1 and h_2 were obtained experimentally, for each value of flow rate.

It is observed from the curves shown in Figs. (5-7) that, for each value of Reynolds number the loss coefficient C_L increases by

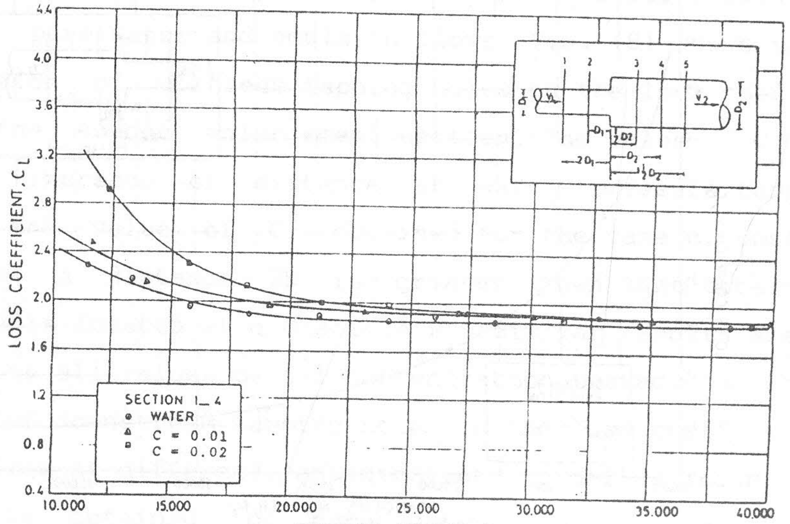


FIG (5) EFFECT OF THE CONCENTRATION OF OIL ON LOSS COEFFICIENT IN SUDDEN ENLARGEMENT

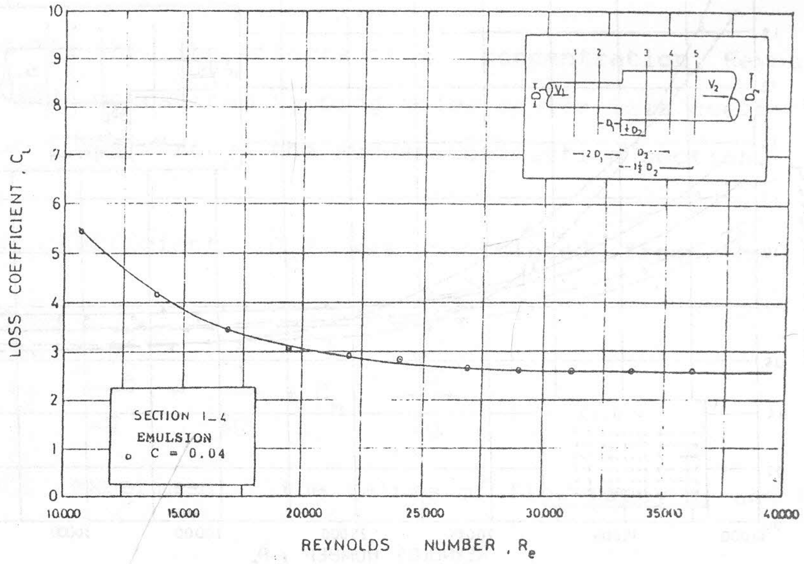


Fig (6) Effect of the concentration of oil on loss coefficient in sudden enlargement.

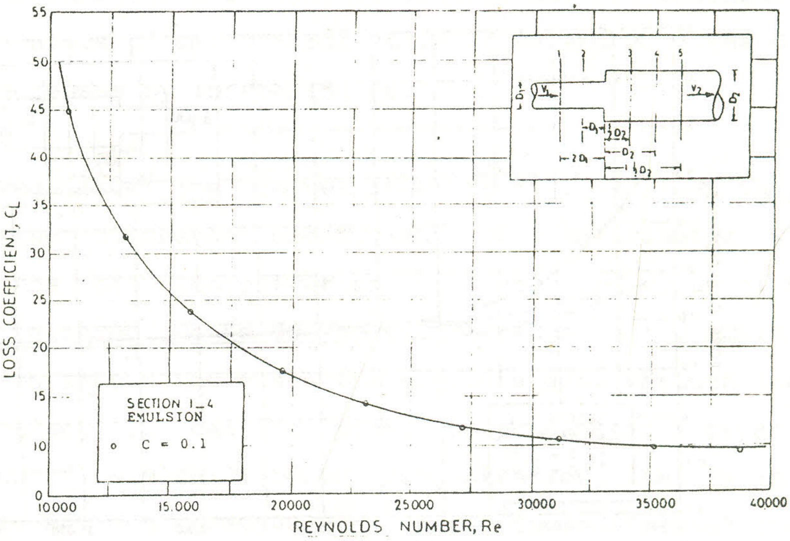


Fig (7) Effect of the Reynolds number on loss coefficient in sudden enlargement.

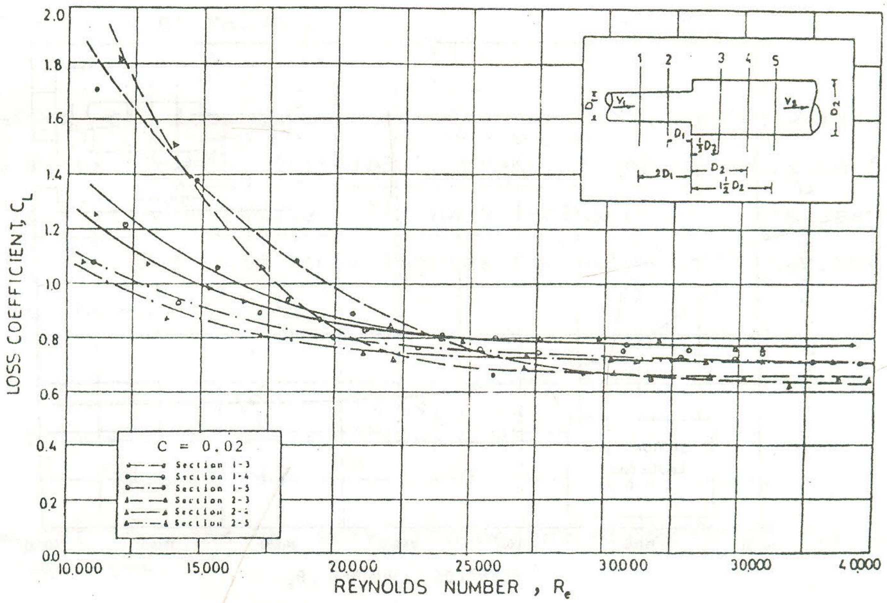


Fig (8) Effect of upstream tapping hole location on loss coefficient in sudden enlargement.

increasing the oil concentration. This is mostlikely to be due to an increase in the fluid viscosity. It is also observed that, by increasing the flow Reynolds number the loss coefficient decreases, for both pure water and emulsion flows. Fig. (8) shows the effect of the location of upstream tapping holes on the loss coefficient C_L through the sudden enlargement section. The value of C_L increases with the increase of distance at which pressure tapping hole is located, the value of C_L obtained for the case of upstream hole located at a distance 2D is greater than that obtained when the pressure hole located at a distance D_1. Similar results are, however observed for all values of oil concentration tested. The effect of the location of downstream tapping holes on the loss coefficient C_L for emulsion flow at different concentrations of oil is shown in Fig. (9). The results obtained for pure water flow are also plotted for comparison. The loss coefficient decreases by increasing the distance at which the downstream tapping hole is located.

Figs. (10-12) show the effects of oil concentration, Reynolds number, upstream and downstream tapping holes on the loss coefficient (C_n) of emulsion flows through the sudden contraction section.

The loss coefficient (C_n) was calculated from the following relation;

$$h_1 - h_2 = \frac{V_2^2}{2g} - \frac{V_1^2}{2g} + C_n \cdot \frac{V_2^2}{2g} \qquad (7)$$

During each experiment, the values of flow rate, h_1 and h_2 were measured.

The results illustrated in Fig. (10) indicate that, for lower values

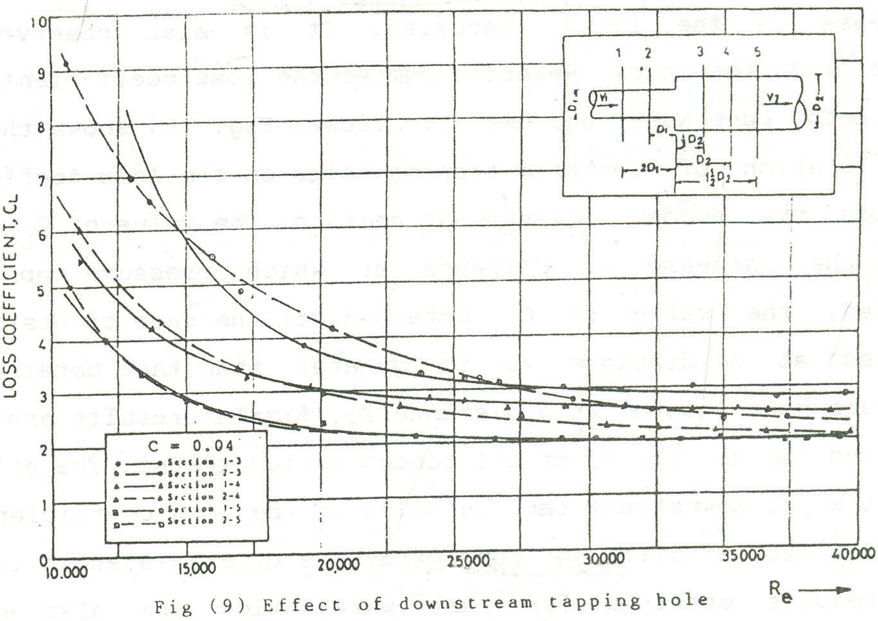


Fig (9) Effect of downstream tapping hole location on loss coefficient in sudden enlargement.

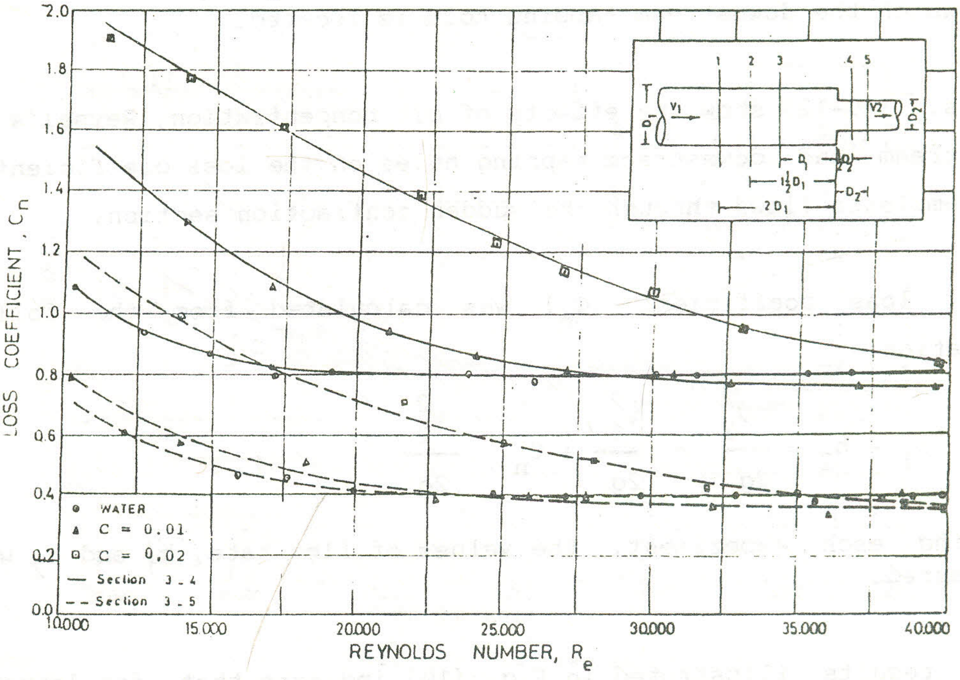


Fig (10) Effect of downstream tapping hole location and oil concentration on loss coefficient for sudden contraction.

of Reynolds number (Re < 25000), the loss coefficient C_n increases with the increase of oil concentration (c). For higher values of Reynolds number (Re > 25000), the effect of oil concentration on the value of C_n is, however different from that obtained at lower values of Re. This may be due to the drag reduction phenomenon which could be more pronounced in the present condition.

Concerning the effect of Reynolds number on the loss coefficient of emulsion flow through the sudden contraction section, the results illustrated in Figs (10-12) indicate that, the loss coefficient C_n decreases by increasing the flow Reynolds number.

The effect of the position of downstream tapping holes on the loss coefficient is quite clear in Figs (10 and 11). The results indicate that for all values of Re tested, the loss coefficient C_n obtained for the downstream tapping hole at a distance 1/2 D_2 has a higher value than that obtained from the down stream tapping hole mounted at a distance D_2. Also the difference between the value of C_n obtained from downstream tapping holes at points (4 and 5) and any one of the upstream tapping holes decreases with an increase in the distance in which upstream tapping hole is located.

From the results illustrated in Fig. (12), it can be seen that the value of C_n, at constant Re, increases by increasing the distance at which the upstream pressure tapping hole is located, i.e. the value of C_n obtained between points 1 and 4 is greater than that obtained between points 2 and 4 and so on. This is probably due to the flow separation which is usually associated with increase in turbulence activity.

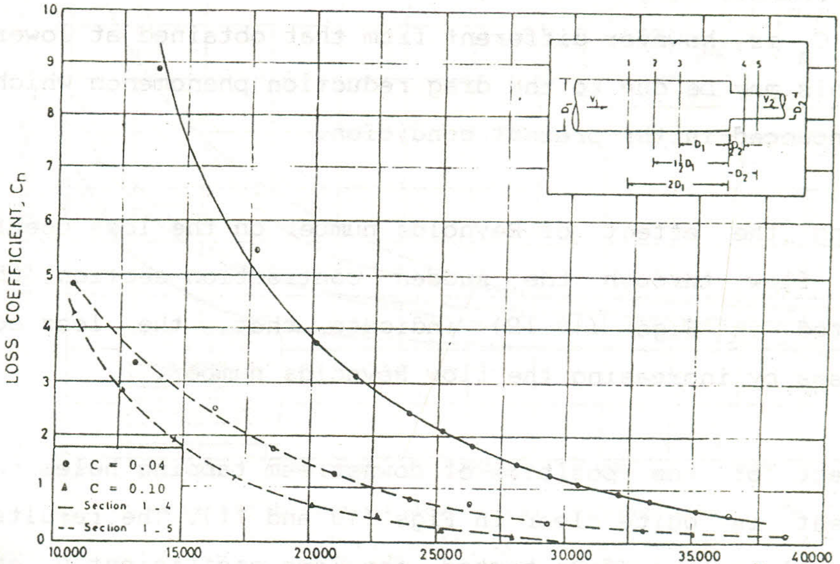


Fig (11) Effect of downstream tapping hole location and oil concentration on loss coefficient for sudden contraction.

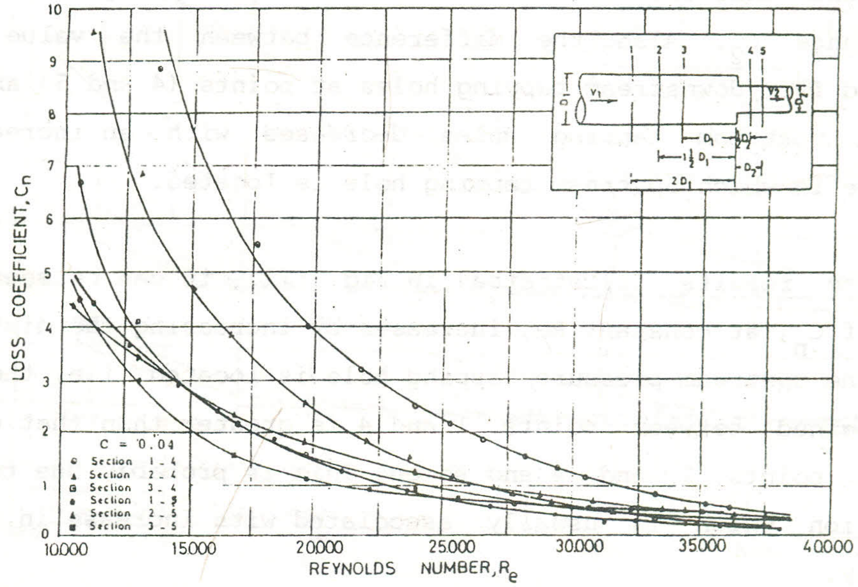


Fig (12) Effect of upstream hole location on loss coefficient for sudden contraction.

4. Conclusion

The main conclusions drown from this investigation (for the type of oil used, suprex 50, in water through the tested elements of hydraulic system) may be summerized as follows;

1. The discharge coefficient of the orifice meter is affect by the value of oil concentration. The orifice meters calibrated by pure water flow must however be recalibrated on the emulsion flow with different concentrations, otherwise errors in calibration could become pronounced.
2. The oil concentration has a significant effect on the discharge coefficient venturimeters. For all values of Reynolds number, the discharge coefficient increases with an increase of oil concentration; the calibration of a venturimeter using pure water flow gives an error of as much as 7% if it is used for an emulsion flow with oil concentration of 0.1
3. The loss coefficient of emulsion flow through a given sudden enlargement or sudden contraction section is mainly dependent on the value of oil concentration, flow Reynolds number and the location of the upstream or downstream pressure tapping hole.

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