# BEHAVIOUR OF AIR_WATER_OIL MIXTURE FLOW THROUGH A CENTRIFUGAL PUMP

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## ABSTRACT

The behavior of air-water-oil mixture flow through a single stage radial flow type centrifugal pump has been studied experimentally. In this study effects of changing the oil concentration, the amount of air injected into the suction side and the oil viscosity on the pump performance under different operating conditions were considered. The results obtained from this study are useful for those who are working in chemical and petroleum industries. For certain operating conditions, the head generated by the pump, pump discharge, pump efficiency and the power required to drive the pump were mainly affected by the oil concentration, type of oil and the amount of air bubbles flowing through the pump impeller.

## 1-Introduction

The behavior of air-water-oil flow through dynamic pressure pumps has an increasingly important to a wide range of hydraulic systems. The name of few of many possible examples of this situation, pumps with emulsion pipeline systems for crude oil transport; pumps used in oil-water collection systems; waste treatment plant where sewage pump conduct air-water mixture flow and pumps used for pumping oil-gas-water mixture from deep oil well to the hydraulic systems in the oil field. The behavior of air-water flow through a pump has been investigated by several authors. Most of the previous investigations in this field have been concerned with the motion of air bubbles in a rotating pump impeller, [1-10]. They found that the motion of bubbles in an impeller is governed substantially by two forces, the drag force due to the surroundings water and the force due to the pressure gradient in the impeller. The bubbles moving near the suction side of the blades experience greater force and have larger flow velocities than those moving along the pressure side. They concluded also that the presence of air bubbles in the impeller blade channels has a great effect on the pump performance.

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## 2. Experimental Apparatus

The general arrangement of the experimental apparatus is shown in Fig (1).
A single stage radial type centrifugal pump operated in a closed system is used. The hydraulic system consists of (161)liter sump tank, a suction line and a delivery line.
The centrifugal pump was equipped with facilities for measuring the pump discharge, suction head, delivery head, pump speed and the pump torque. Oil was mixed with the main fluid (water) by two special propellers (7) fixed vertically on the sump tank (8), Fig (1). The propellers were connected directly to the three phase induction motors by means of steel shafts. Two types of oil are used in this investigation, the first one is a motor oil (Shell 20w/50) and the second type is a crude oil. In all our experiments, a fixed volume of water (132 lit) was used. The concentration was calculated according to the mass relation in particle per million (P.P.M)

$$\text{Concentration (C)} = (\text{Mass of Oil (kg)} / \text{Mass of Water (kg)}) \times 10^6$$

For each oil used the following properties were measured at 24°c and atmospheric pressure: density, specific gravity and kinematics viscosity. These properties are tabulated in table (1).

Table (1) properties for tested oil at 1 atm and 24°c

| Type of Oil | Motor Oil(Shell 20W/50) | Crude Oil |
|---|---|---|
| Density, $kg/m^3$ | 834 | 897 |
| Specific gravity | 0.8363 | 0.8995 |
| Kinematics viscosity, $m^2/s$ | $5.075 \times 10^{-4}$ | $3.288 \times 10^{-3}$ |

In order to observe the effect of the presence of the air bubbles in the emulsion flow through the pump impeller on the pump performance, the air was injected in the suction pipe. The injected air flow rate was measured by using a calibrated orifice meter (16). The pressure difference across the orifice meter was measured by an inclined manometer (11), Fig. (1). The suction and delivery pressures were measured by U-tube manometers (14) and (12), respectively. The pump torque was measured by a torque balance (19). The pump speed was measured by an electric tachometer. The mixture of oil and water discharge flow rate ($Q_t$) was measured by a calibrated collecting tank (3) and stopwatch.

The uncertainty in the measurements was calculated and considered as follows; in flow rate ± 1.16% in oil concentration ±2.4%, in pressure head ±1.25%; in pump torque ±1.2%, and pump speed ±1.3%.

## 3-Results and discussions

### 3.1.Effect of oil concentration

In order to study the effect of changing the concentration of oil on the pump performance, when the pump is operating with air-water-oil mixture flow, the pump was tested by using motor oil (shell 20W/50) in the mixture with different oil concentration. A representative selection of the results obtained is shown in Figs (2-4). The results were plotted in the dimensionless form corresponding to those obtained for pure water flow at a maximum pump efficiency. The results illustrated in Fig (2) indicate that when the concentration of oil increases the pump head decreases. This is due to the increasing value of fluid viscosity and also due to the increase of head degradation which occurs due to the presence of oil in the mixture and depends on the type of fluid flows through the pump impeller. A further increase of oil concentration leads to an increase in fluid consistency and hence the shear stresses near the wall of blade impeller channels are increased. Fig (3) shows the variation of the power required to drive the pump with oil-air-water flow discharge. The results indicate that at constant pump speed and constant amount of air injected, for a certain flow rate discharge the power increases as the oil concentration increases. This is due to the change of fluid viscosity and also is mainly due to the change of fluid properties which are affecting the load on the pump impeller The relation between the pump efficiency and the pump flow rate discharges is shown in Fig (4). This figure shows that the pump efficiency decreases as the oil-concentration increases. This decrease in efficiency is mainly due to the increase of hydraulic losses and also due to the increase of power required to drive the pump with increasing the oil concentration.

### 3.2.Effect of changing type of oil

The variation of head developed by the pump pumping oil-air-water mixture flow for two types of oil used at constant oil concentration and airflow rate is shown in Fig. (5). The results indicate that when the oil viscosity is increased (i.e. crude oil is used in the mixture), the head developed by the pump is less than that developed when the oil motor is used ($v = 5.075 \times 10^{-4} m^2/s$). Fig. (6) shows the variation of power required to drive the pump. For a certain flow rate discharge the power is increased when the crude oil is used. This is due to the increasing value of oil viscosity. The results illustrated in Fig. (7) indicate that for the same pump speed, the values of pump efficiency are smaller when the crude oil is used in the mixture ($v=3.228 \times 10^{-3} m^2/s$) than those obtained for oil motor. This is due to the increase of hydraulic losses.

### 3.3.Effect of air injection into emulsion flow

In order to investigate the effect of the presence of air bubbles in the emulsion flow through the pump impeller, the air was injected into the suction pump pipe with different flow rates. The experiments were carried out for mixture of air plus emulsion fluid (crude oil in water). A representative selection of the results is shown in Figs (8-10). The results indicated in Fig. (8) show that, for the same pump speed, when the air is injected into the suction pipe, the head decreases. This is due to the change of pumping fluid viscosity. When the amount of injected air increases to ( $Q_a$ =3.7 x $10^{-7}$ m³/s), the results illustrated in Figs (8 and 10) indicated that a drop in head and efficiency of the pump. Fig. (9) shows that, the power required is generally increased as the amount of air injected is increased. This is also due to the changing of fluid viscosity. For the same pump speed as the amount of air-injected increases the pump efficiency decreases, Fig. (10). In order to investigate the effect of increasing the amount of air injected into the suction pipe on the pump performance the results obtained were compared with those obtained for pure emulsion (oil in water) flow (when the pump is operating at maximum efficiency corresponding to the value of oil concentration). The comparison is shown in table (2).

Table (2) effect of air injected

| Operating Conditions | N = 2165 rpm<br>$H_o$=4.73 mw<br>$P_o$=63.438 w | C = 2x $10^4$ P.P.M.<br>$Q_t$= 65 l/min<br>$\eta_o$= 80% | |
|---|---|---|---|
| $Q_a$ x $10^{-7}$ m³/s | 1.8 | 2.9 | 3.7 |
| % Decrease in H | 4.4 | 7.0 | 10.4 |
| % Increase in power | 5.7 | 10.3 | 12.3 |
| % Decrease in η | 14.2 | 16.4 | 22.8 |

The results illustrated in Figs(8-10) and table(2) indicate that under such oil-water-air flow conditions, the centrifugal pump becomes unable to generate the same head as that produced in the case of emulsions flow. Therefore the air bubbles through the pump impeller play an important role in the head degradation mechanism. The head degradation is smaller for the reduced values of pump discharge and air flow rate and increases with the increase in pump discharge and air flow rate. The reasons for this may be three-fold; the first reason is related to possibility of cavitation, the second is due to the increase of the amount of air in the mixture and the third is due to the change of air flow density. Due to the difference of flow media densities between emulsion and air, the former is subjected to large external force (centrifugal force) than the latter. Consequently, the emulsion fluid at pump exit is accelerated slower than in the case of emulsion flow only, this acceleration of emulsion fluid contributes to the major part of head degradation.

## 4-Conclusions

The behavior of air-oil-water flow through a single stage, radial type centrifugal pump has been studied experimentally. The main conclusion may be summarized as follows;

1-The centrifugal pump operating with air present in the suction pipe becomes unable to generate the same head and maximum discharge as that obtained in the case of emulsion fluid flow (oil in water).

The amount of air injected, oil viscosity and the amount of oil in the mixture plays an important role in the head degradation.

2- the power required to drive the pump was found to depend on the amount of air injected oil concentration and oil viscosity.

3- for certain operating conditions, the pump discharge, pump head, overall pump efficiency and the required power to drive the pump were mainly affected by the oil concentration, oil viscosity (i.e. type of oil used) and the amount of injected air into the suction pipe.

## Nomenclature

C ; oil concentration, P.P.M.
H ; pressure head given by the pump, mw(meter water).
N ; pump speed, rpm.
P ; power required to drive the pump, Watts
Q ; pump discharge , $m^3/s$.
$\nu$ ; oil kinematic viscosity, $m^2/s$
$\eta$ ; pump overall efficiency.

Subscripts
a: Air flow
o: Results corresponding to the maximum efficiency of the pump at pure water
t: Emulsion flow

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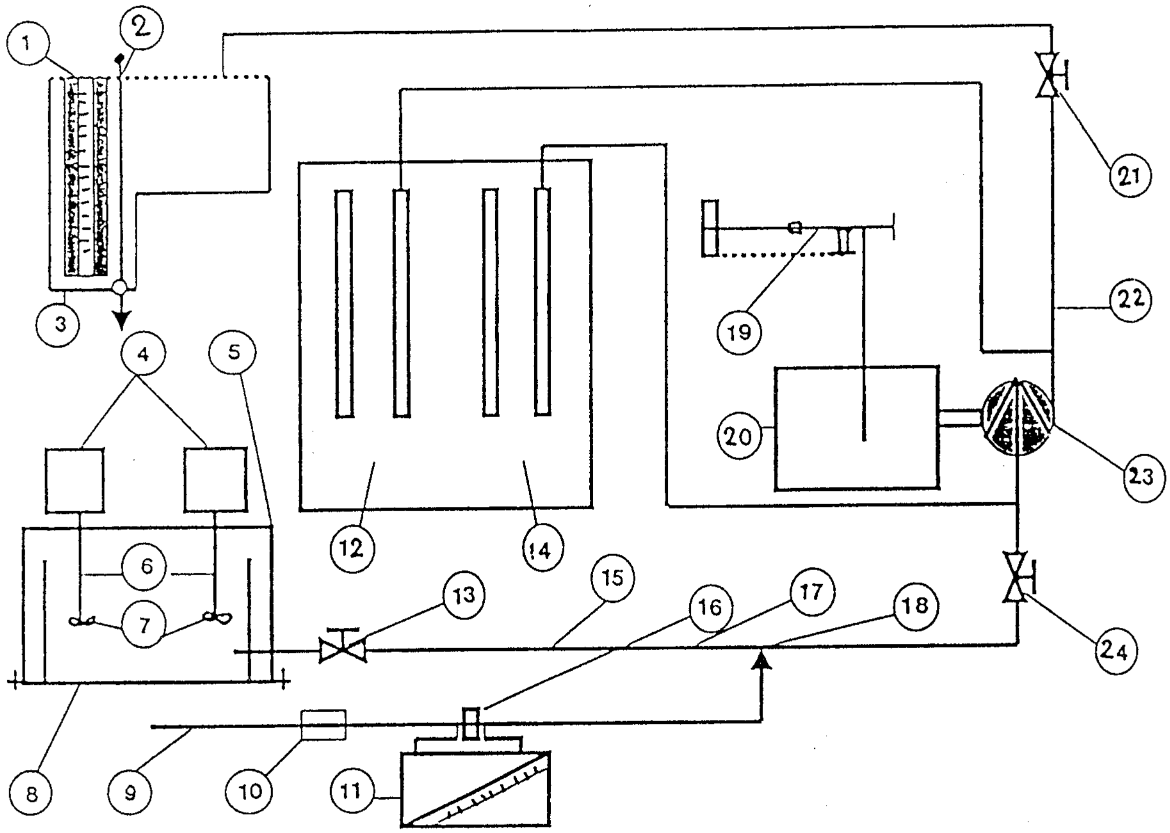
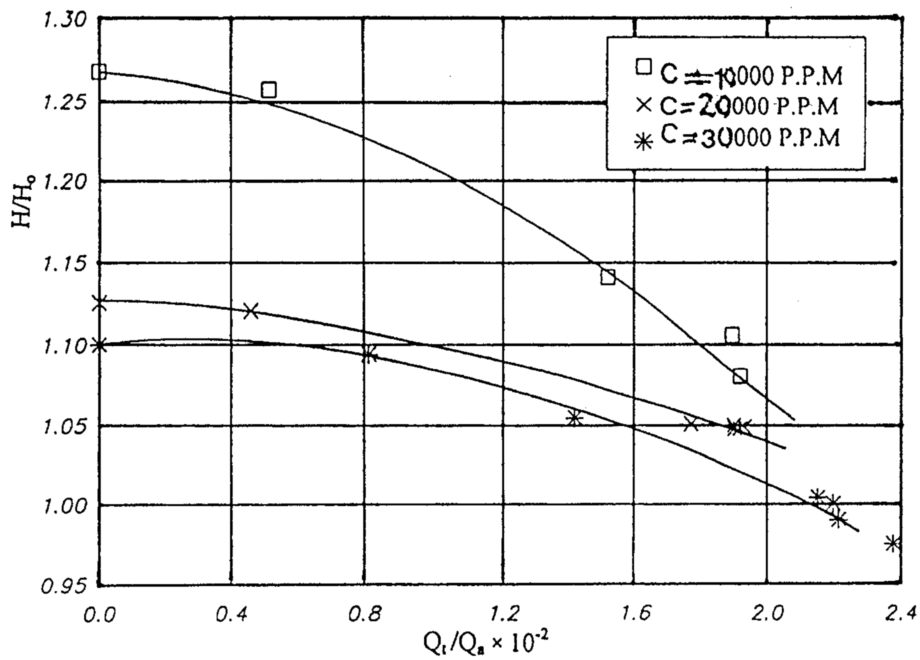


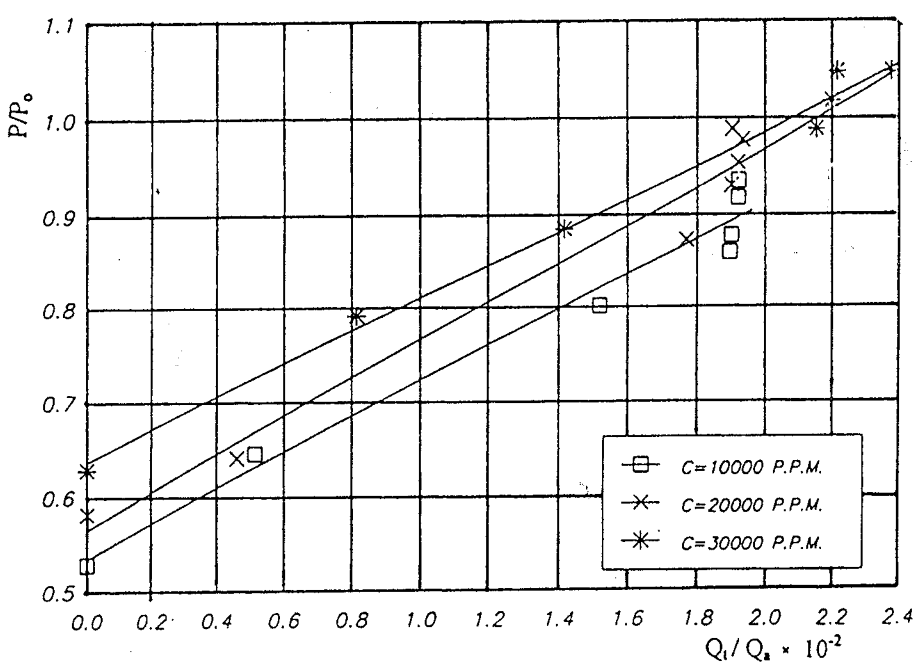

| | | | |
|---|---|---|---|
| 1 | Flow sight glass | 13 | Main flow valve |
| 2 | Dump valve | 14 | U-Tube manometer (suction) |
| 3 | Volumetric tank | 15 | Suction pipe |
| 4 | Electric driving motors | 16 | Orifice meter |
| 5 | Carrier Bracket | 17 | Pressure test pipe |
| 6 | Propellers driving shafts | 18 | Injection station |
| 7 | Propellers | 19 | Torque balance lever |
| 8 | Sump tank | 20 | Dynamometer motor |
| 9 | Main compressed air line | 21 | Flow control valve |
| 10 | Pressure regulating valve | 22 | Delivery pipe |
| 11 | Inclined manometer | 23 | Centrifugal pump |
| 12 | U-Tube manometer (delivery) | 24 | Suction regulating valve |

Fig. (1) General Layout of the Experimental Set-up.



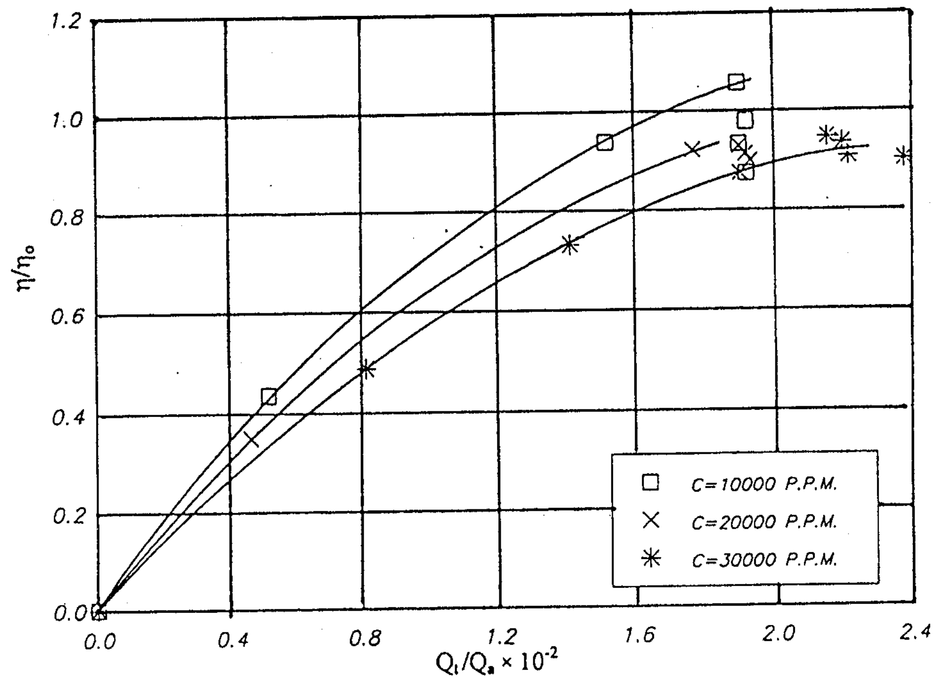

N = 1624 rev / min & $Q_a = 2.9 \times 10^{-7} m^3/s$

Fig ( 2 ) Effect of oil concentration on the pump head




N = 1624 rev / min & $Q_a = 2.9 \times 10^{-7} m^3/s$

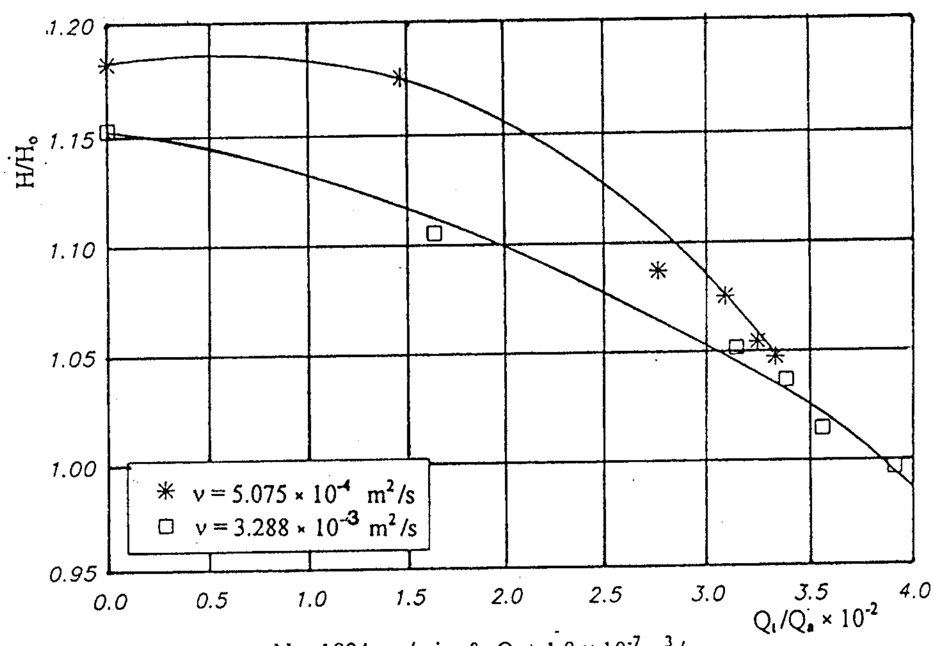
Fig ( 3) Effect of oil concentration on the pump input power




$Q_t/Q_a \times 10^{-2}$

N = 1624 rev / min & $Q_a = 2.9 \times 10^{-7}\ m^3/s$

Fig ( 4 ) Effect of oil concentration on the pump efficiency

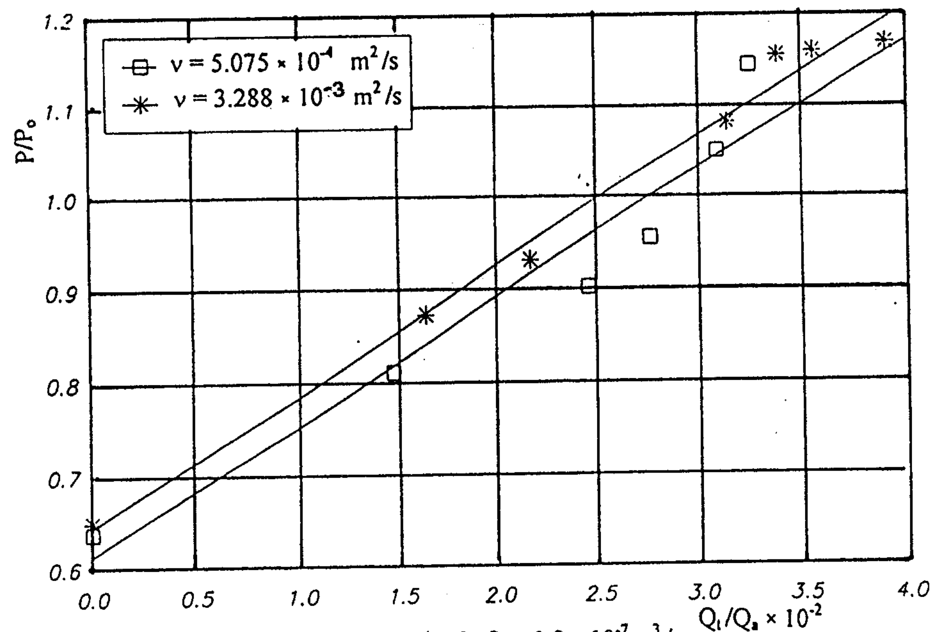



$Q_t/Q_a \times 10^{-2}$

N = 1894 rev/min & $Q_a = 1.8 \times 10^{-7}\ m^3/s$

C=20000 P.P.M

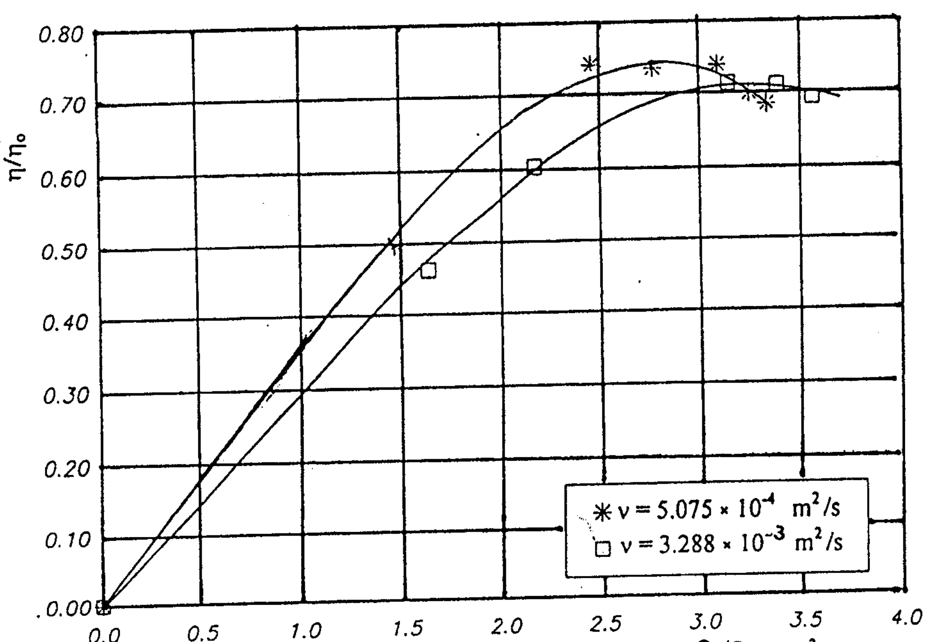
Fig ( 5 ) Effect of oil viscosity on the pump head




N = 1894 rev/min & $Q_a = 1.8 \times 10^{-7}\ m^3/s$

C = 20000 . P.P.M

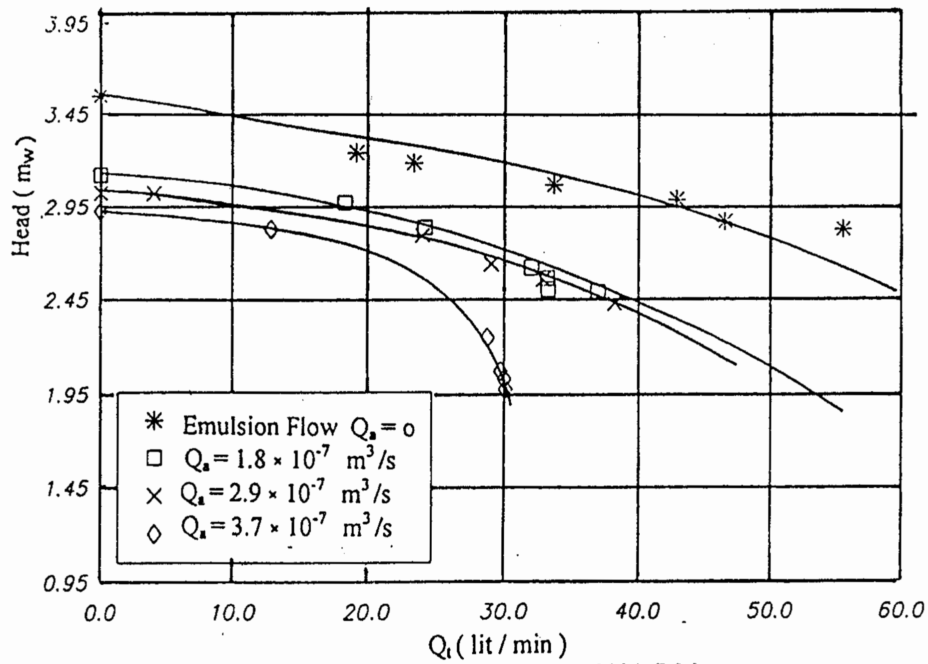
Fig ( 6 ) Effect of oil viscosity on the pump input power




N = 1894 rev/min & $Q_a = 1.8 \times 10^{-7}\ m^3/s$

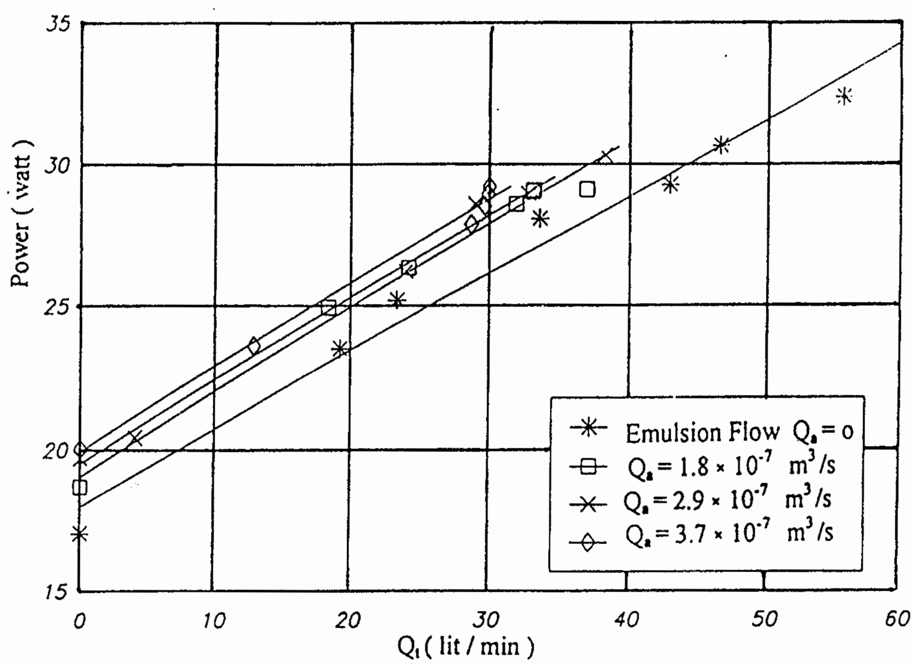
C = 20000 P. P.M

Fig ( 7 ) Effect of oil viscosity on the pump efficiency



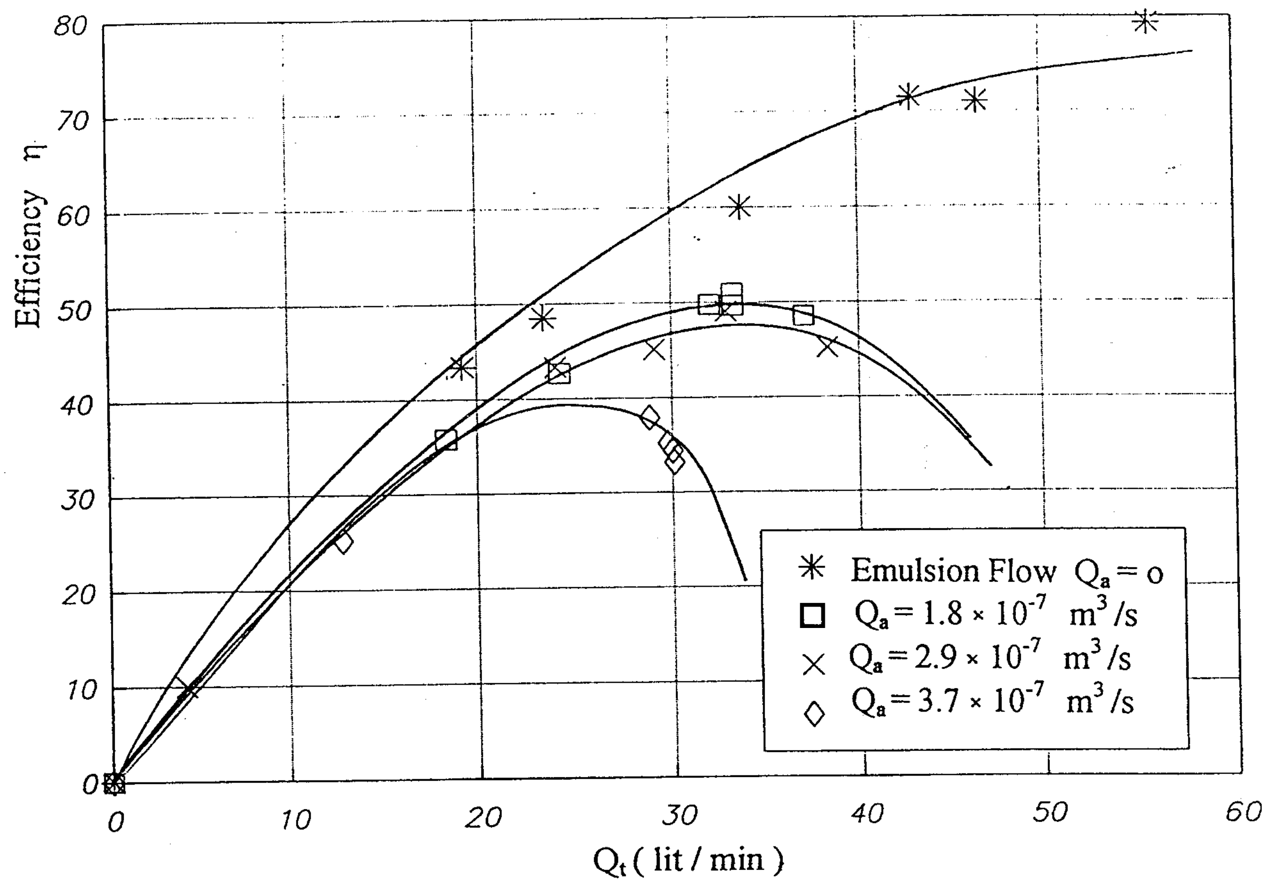

N = 1624 rev / min & C = 2000 P.P.M

Fig (8) Effect of the air flow rate on the pump head




N = 1624 rev / min & C = 2000 P.P.M

Fig (9) Effect of the air flow rate on the pump input power




N = 1624 rev / min & C = 2000 P.P.M

**Fig (10) Effect of the air flow rate on the pump efficiency**

# سريـــان خليـــط من المـــاء والزيـــت والهـــــواء
## خلال مضخة طرد مركزى

أ.د/ كمال عبدالعزيز إبراهيم ، د/ محمد عبدالمجيد القاضى

*ملخـــص :*

سلوك سريان خليط من الهواء والماء والزيت خلال مضخة طرد مركزى لها تطبيقات كثيرة فى المنظومات الهيدروليكية مثل منظومات نقل الزيوت – الخ. ودراسة سريان خليط من الماء والزيت او الماء والهواء قد تناولها كثير من الباحثين

ولاجراء هذه الدراسة فقد تم بنـاء جهاز معملى لاجراء التجارب المطلوبه واستعمل نوعين من الزيت زيوت الوقود الذى لزوجته الكيمانيتيكية ٥ر٠٧٥×١٠$^{-٤}$ م$^{٢}$/ث وزيوت ثقيلة (خام) لزوجته الكيناميتيكية ٣ر٢٢٨x١٠$^{-٣}$ م$^{٢}$/ث .

وقد تم إجراء التجارب وأخذ النتائج مع وضع المتغيرات المختلفة وتأثيرها على أداء المضخة.

مثل تأثير تركيز الزيت فى الماء وتأثير تغيير نوع الزيت وتأثير إضافة الهواء الى الخليط من الماء والزيت وتم تمثيل تلك النتائج على منحنيات الاداء للمضخة.

وقد إستخلص من النتائج الاتى :

١– عند تشغيل المضخة مع وجود هواء فى جهة السحب فإن المضخة لاتعطى نفس العلو لنفس معدل التصرف بالاضافة الى أن كمية الهواء المحقونة ولزوجة الزيت وكميته فى الخليط لهما دور مهم على إنخفاض العلو.

٢– القدرة المطلوبة لتشغيل المضخة تعتمد على كمية الهواء المحقونة ولزوجة الزيت وتركيزة.

٣– عند ظروف تشغيل معينه فإن معدل التصرف للمضخة والعلو والكفاءة والقدرة المطلوبة لتشغيل المضخة تتأثر كثيرا بدرجة تركيز الزيت فى الخليط ولزوجتة وكمية الهواء المحقونة للمضخة.