J. King Saud Univ., Vol. 5, *Eng. Sci.* (1), pp. 141 - 152 (A.H. 1413/1993)

SHORT COMMUNICATION

Flow of Saudi Oil Emulsions in Pipelines

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(Received 5/1/1991; Accepted for publication 7/8/1991)

Abstract. Flow characteristics of Saudi oil emulsions in pipelines were studied experimentally and described mathematically. The type of emulsions prepared were oil-in-water and their rheological properties were measured using HAAK viscometer at different temperatures and oil concentrations. The emulsifying agent (Triton X-100) was used to stablize the emulsions with a concentration of 0.5% by volume. Three rheological models were developed to relate the shear stress to shear rate, oil concentration and temperature. These models were used to describe the flow behavior of the emulsions in pipelines. The effects of oil concentration and temperature on the pressure required to pump such emulsions in pipelines under turbulent conditions were also studied.

Nomenclature

C	=	Oil concentration, % volume
D	=	Pipeline diameter, m
f	=	Friction factor
g	=	Acceleration factor, m/s^2
hs	=	Static head, m
k'	=	Metzner and Reed parameter, $Pa/s^{n'}$
n'	=	Metzner and Reed parameter
N_{Reg}	=	Generalized Reynolds number
N_{Rg}	=	Reynolds number defined by Clapp
N_{Rn}	=	Newtonian Reynolds number
P_f	=	Frictional pressure drop, Pa

P_t	=	Total pressure drop, Pa
T	=	Temperature, °K
V	=	Average velocity under turbulent conditions, m/s
V_l	=	Laminar velocity, m/s
γ	=	Specific weight, Pa/m
$\dot{\gamma}$	=	Shear rate, s^{-1}
ρ	=	Mass density of the fluid, kg/m^3
τ	=	shear stress, Pa
τ_w	=	Wall shear stress, Pa
μ	=	Newtonian viscosity, Pa s
μ_p	=	Plastic viscosity, Pa s.6

Introduction

An extensive study of the flow characteristics of oil emulsions is indispensable for lowering the energy consumption, and ensuring safety and cost effectiveness in pipeline transportation of such emulsions [1]. A change in the rheological characteristics of oil emulsions, due to thermal and shear histories and oil concentration, strongly affects the design calculations of pipelines handling these emuslions. Although, several studies had reported the effects of temperature and oil concentration on the oil emulsion viscosity, no agreement has emerged on a general correlation involving such effects for flow of emulsions in pipelines under turbulent conditions [2,3,4,5,6].

This study had two major objectives. The first objective was to develop correlations of shear stress versus shear rate, temperature and oil concentration that can be applied to pipeline design calculations. The second objective was to investigate the effects of temperature and oil concentration on the pressure required to pump the emuslions in Al-Jubail-Yanbu pipeline [7] under turbulent conditions.

Experimental Work

The rheological properties of Saudi oil and its emulsions were measured using HAAK viscometer (Model RV-12) at temperatures 5,10,15,20,25,30 and 35°C. The oil concentrations in the emuslions prepared were fixed at 10,20,30,40,50,60,70,80 and 90% by volume. The emulsifying agent (Triton X-100) was used to stabilize the emulsion with a concentration of 0.5% by volume. This emulsifier is a nonionic water soluble molecule (iso-pheoxypolyethoxy ethanol) with 9 to 10 ethylene oxide units.

In a typical experiment, the sample of the emulsion to be tested was placed in the viscometer cup and stirred at the specified test temperature for four hours before the measurements were recorded. This duplicates the aging time in flow equipment. The rotational speed was then increased and the corresponding shear stress and shear rate were recorded.

Results and Discussion

Rheological properties of Saudi oil and its emulsions are plotted in Figs 1 through 10. Figure 1 shows that the shear stress increases as the shear rate increases or temperature decreases. These data were correlated with Newton's law of viscosity [8] and were found to be Newtonian fluids. Data of Figs 2 and 3 exhibit Newtonian behavior at the test temperatures. At low oil concentration the droplets do not interfere with each other appreciably, but as more internal phase is introduced the droplets begin to collide more frequently. This causes a slight increase in the viscosity of the emulsion. At this range of oil concentrations (10-14%), the rheological properties mainly governed by the properties of the external phase.

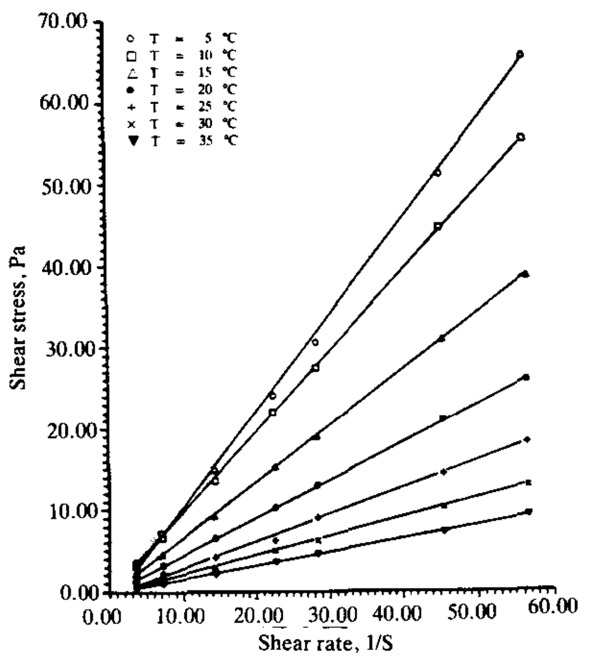

Fig. 1. Shear stress versus shear rate for Saudi Oil - 700 (Newtonian Fluid)

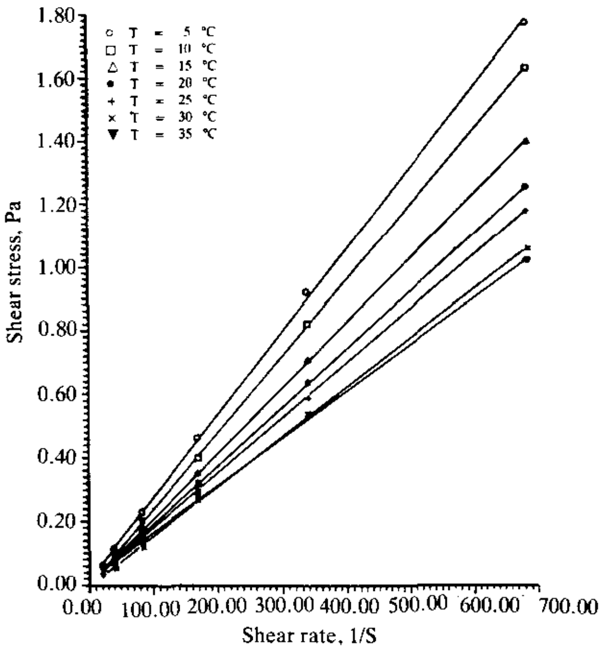

Fig. 2. Shear stress versus shear rate for 10% emulsion (Newtonian Fluid)

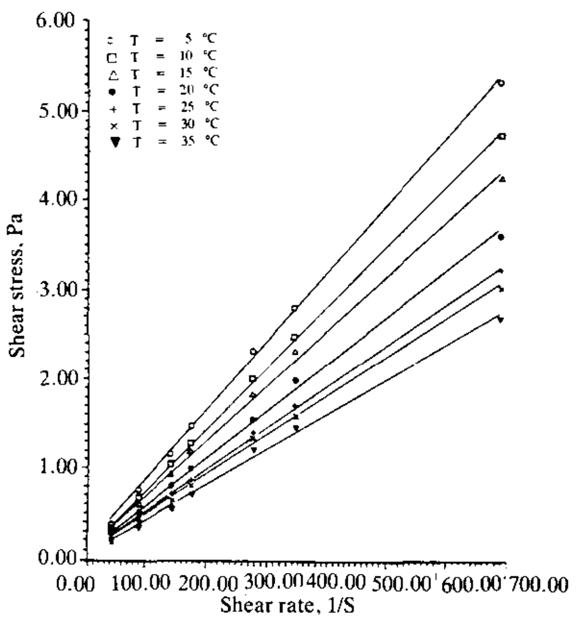

Fig. 3. Shear stress versus shear rate for 40% emulsion (Newtonian Fluid)

As the oil concentration increases above 40%, the droplets interfere with each other rather drastically, and the non-Newtonian behavior becomes remarkable with increase in viscosity. Data of 50 and 60% oil concentration (Figs. 4 and 5) show a pseudoplastic behavior at the test temperatures. A yield stress was observed for the emulsions of 70,80 and 90% oil concentration as shown in Figure 6. This rapid increase in viscosity is due to the change of the type of emulsions from oil-in-water to water-in-oil [1,6]. These emulsions were termed as yield-pseudoplastic fluids.

Applying the pseudo-analysis technique developed by Levenspiel [9] to the measured data, the following three rheological models were obtained.

For Newtonian emulsions (10% – 40% oil)

$$\tau = 2.422 \times 10^{-6}\,\mathrm{Exp}\,(1845.63/T + 0.03\,C)\,\dot{\gamma} \tag{1}$$

For pseudoplastic emulsions (50% – 60% oil)

$$\tau = 241822 \times 10^{-8}\,\mathrm{Exp}\,(2373.43/T + 0.125\,C)\,\dot{\gamma}^{0.835} \tag{2}$$

For yield-pseudoplastic emulsions (70% – 90% oil)

$$\tau = \tau_y + 4.627 \times 10^{-9}\,\mathrm{Exp}\,(2137.38/T + 0.166\,C)\,\dot{\gamma}^{0.507} \tag{3}$$

The correlation coefficients of Eqs 1,2 and 3 were found to be 0.965, 0.932 and 0.948 respectively. These values were accepted at confidence level of 95%.

Determining n' and k' for non-Newtonian emulsions

Flow behavior of the non-Newtonian emulsions in pipelines under turbulent conditions require the knowledge of the Metzner and reed [10] parameters (n' and k'). These parameters can be determined by substituting Eqs. 2 and 3 in Rabinowitsch and Mooney equation (8).

$$8V_l / D = (4 / \tau_w^3\, w) \int_0^{\tau_w} 2\dot{\gamma}\, d\tau \tag{4}$$

where n' and k' were defined by the following relations:

$$n' = d\,[\log \tau_w]/d\,[\log 8V_l / D] \tag{5}$$

$$k' = \tau_w / (8v_l / D)^{n'} \tag{6}$$

Substituting Eqs 2 and 3 in Eq. 4 and integrating the resulting equations, the following relations were obtained.

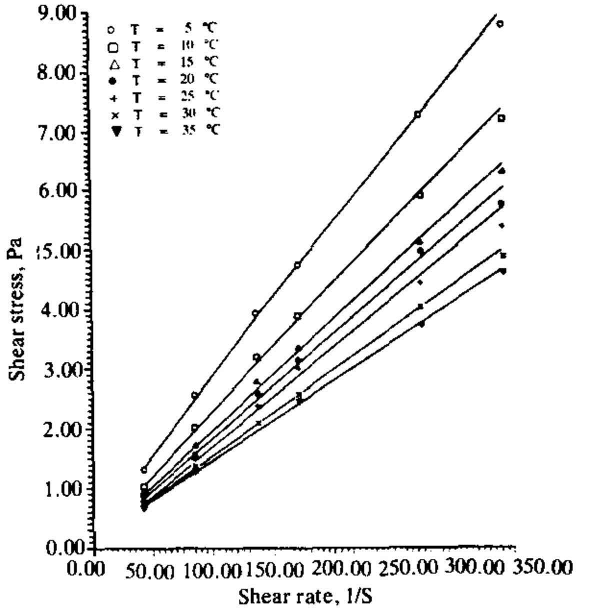

Fig. 4. Shear stress versus shear rate for 50% emulsion (Power Law Fluid)

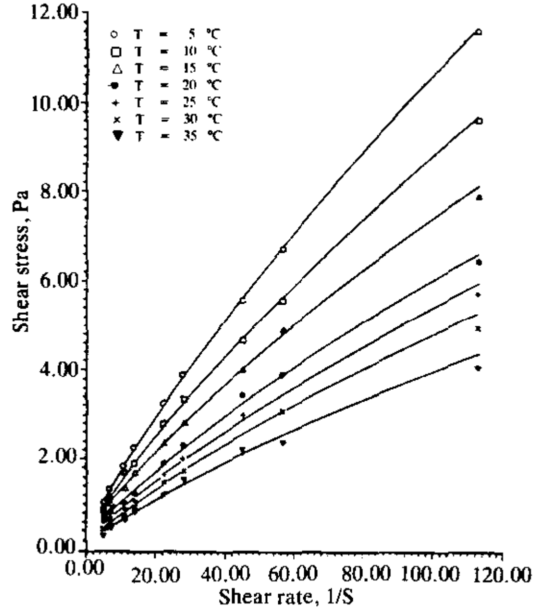

Fig. 5. Shear stress versus shear rate for 60% emulsion (Power Law Fluid)

For newtonian emulsions

$$n' = 1.0 \quad (7)$$

$$k' = 2.422 \times 10^{-6} \text{ Exp } (1845.63/T + 0.036\ C) \quad (8)$$

For pseudoplastic emulsions

$$n' = 0.835 \quad (9)$$

$$k' = 2.517 \times 10^{-8} \text{ Exp } (2373.43/T + 0.125\ C) \quad (10)$$

For yield-pseudoplastic emulsions

$$2V_l/D = \{^{\tau} W/[4.627 \times 10^{-4} \quad \text{Exp } (2137.38/T + 0.166C]\}^{1.972}$$

$$[0.2011\ (1 - X)^{4.972} + 0.507\ X\ (1 - X)^{3.972} + 0.336\ X^2\ (1 - X)^{2.972}] \quad (11)$$

where $X = \tau_y / \tau_w$

The values of n' and k' can be determsined from Eq. 11 at specified temperature and oil concentration by plotting (τ_w) versus ($8V_l$ / D) on log-log scale and applying Eqs 5 and 6.

Turbulent pipeline flow calculations

Pipeline flow calculations involve the determination of friction factor, frictional pressure loss and total pressure loss. These calculations were carried out for Newtonian, pseudoplastic and yield pseudoplastic emulsions. The friction factor for yield-pseudoplastic emulsions can be calculated from Torrance correlation [8].

$$1/\sqrt{f} = 4.53/n' \ [\log (1 - \tau_y / \tau_w) + \log (N_{Rg}\ f^{1-n'/2})\ ] + 0.45 - 2.75/n' \quad (12)$$

Flow Newtonian emulsions (τ_y = 0.0 and n' = 1.0), Eq. 12 becomes

$$1/\sqrt{f} = 4.53 \log (N_{Rn} \sqrt{f}) - 2.3 \quad (13)$$

For pseudoplastic emulsions (τ_y = 0.0), Eq. 12 becomes

$$1/\sqrt{f} = 4.53/n' \ [\log (N_{Reg}\ f^{1-n'/2})\ ] + 0.45 - 2.75/n' \quad (14)$$

Where R_{eg} is the generalized Reynolds number defined by Metzner and Reed [10] as follows:

$$N_{Reg} = D^{n'} V^{2-n'} \rho / (K' 8^{n'-1}) \quad (15)$$

The frictional pressure loss was calculated from Fanning equation (8).

$$P_f = 2f V^2 L \rho / D \quad (16)$$

The total pressure loss is equal to the pressures equivalent to the frictional, static and kinetic energy.

$$P_t = P_f + h_s \rho g/g_c + \frac{V^2}{2 g_c} \rho \quad (17)$$

Application to Al-Jubail-Yanbu pipeline Transportation

Equations 7 through 17 were used to calculate the pressure required to pump Saudi oil emulsions. (Newtonian, pseudoplastic and yield-pseudoplastic) in Al-Jubail-Yanbu pipeline. The diameter, thickness length and flow rate of the pipeline were 1.219 m, 0.0254 m and 1202.131 km 2.2 cu.m/s respectively. The type of flow in this pipeline was found to be turbulent. The results are plotted in Figs7 through9.

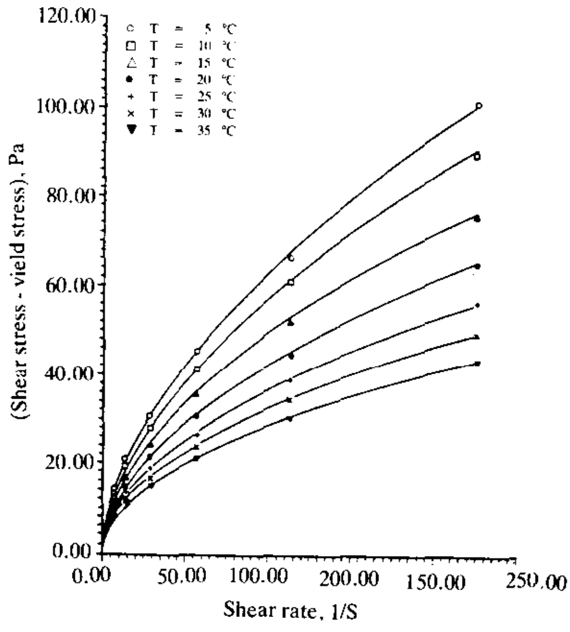

Fig. 6. Shear stress versus shear rate for 80% emulsion (Hershel - Bulkley Fluid)

These Figs. show that the pressure required to pump such emulsions increases as the oil concentration increases or temperature decreases. It can also observed that, the pumping pressure of yield-pseudoplastic emulsions are higher than those of Newtonian and pseudoplastic. This means that the suitable oil concentration for pumping Saudi oil in Al-Jubail-Yanbu pipleine as oil-in-water emuslion should be less than 70%.

Conclusions

1) Saudi oil emulsions exhibit Newtonian behavior at oil concentrations of 10-40%, pseudoplastic behavior at oil concentration of 50-60%, and yield-pseudoplastic behavior at oil concentration of 70-90%.

2) Saudi oil emulsions change from oil-in-water to water-in-oil at oil concentration greater than or equal to 70%.

3) The suitable oil concentration for transporting Saudi oil emulsions through Al-Jubail-Yanbu pipeline should be less than 70%.

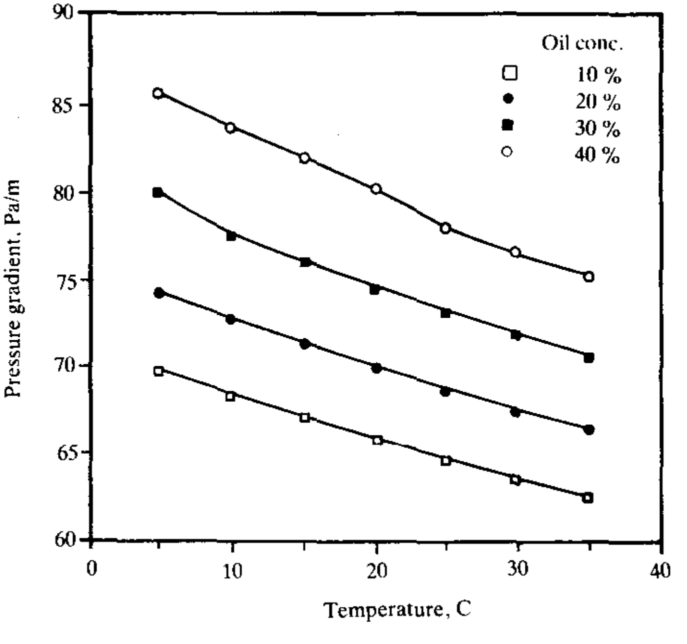

Fig. 7. Pumping pressure gradient of Newtonian oils in Al-Jubail - Yanbu pipeline

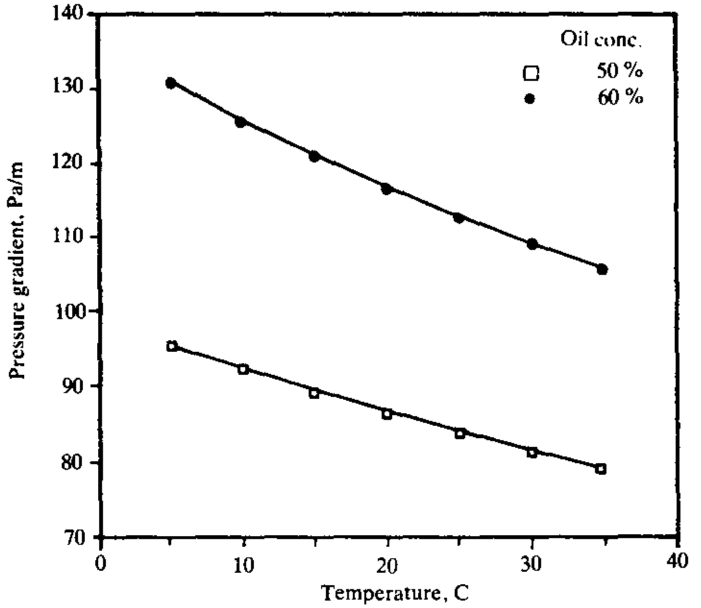

Fig. 8. Pumping pressure gradient of Pseudoplastic oils in Al-Jubail - Yanbu pipeline

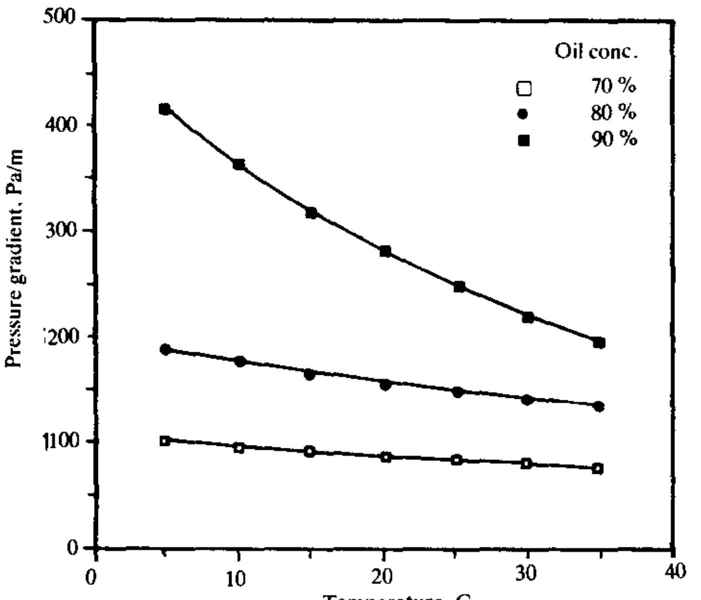

Fig. 9. Pumping pressure gradient of Yield-Pseudoplastic oils (X = 0.4) in Al-Jubail - Yanbu pipeline

References

[1] Wyslouzil, B.E.; Kessick, M.A. and Masliyah, J.H. "Pipeline Flow Behavior of Heavy Crude Oil Emulsions." *Can J. Chem. Eng.* 65 (June, 1987), 353-360.

[2] Marsden, S.S. Jr. and Rose, S.C. "Cold Emulsion Line Proposed for Arctic." *Oil & Gas J.* (Oct. 11, 1971), 100-106.

[3] Marsden, S.S. Jr. and Raghavan, R. "A System for Producing and Transporting Crude Oil as an Oil/Water Emulsion." *J. Inst. Pet.* (Nov., 1971), 373-378.

[4] Zakin, J.L.; Pinaire, R. and Borgmeyer, M.E. "Transport of Oil as Oil in Water Emulsion." *J. Fluids Eng.*, 101, No. 10, (1979).

[5] Alvarado, D.A. and Marsden, S.S. Jr. "Flow of Oil-in-Water Emulsions Through Tubes and Porous Media." *Soc. Pet. Eng. J.* (Dec., 1979), 369-377.

[6] Yildirim, E.; Rimmer, D.P.; Gregoli, M.A.; Hamshar, J.A. and Olah, A.M. "Water Continuous Emulsions for Heavy Crude Transportation." *Technical Report*, Canada: Technical University of Nova Scotia, 1988, 1-26.

[7] Al-Fariss, T. and Desouky, S.M. "Calculations Allow Program to Design Pipelines for Waxy Crude." *Oil & Gas J.*, 88, No. 2 (1990), 69-74.

[8] Govier, G.W. and Aziz, Kh. *The Flow of Complex Mixtures in Pipes*. New York: Van Nostrand Reinhold Co., 1982.

[9] Levenspiel, L.O. *Chemical Reaction Engineering*, 2nd ed. New York: J. Wiley & Sons, 1972.

[10] Metzner, A.B. and Reed, J.C. "Flow of Non-Newtonian Fluids Correlation of the Laminar, Transition and Turbulent Flow Regions." *Am. Chem. Eng. J.*, 1, No. 4 (1955), 434-440.

[11] Savins, J.; Wallick, G.C. and Foster, W.R. "The Differentiation Method in Rheology: I. Poiseuille-Type Flow." *SPE*, (September, 1962), 211-215.

[12] Martinez, A.E.; Shoham, S.A. and Brill, J.P. "Prediction of Dispersion Viscosity of Oil/Water Mixture Flow in Horizontal Pipes." Paper No. 18221, *Presented at 63rd Annual Tech. Conf., and Exhibition of SPE*, Houston, (October, 1988), 427-438.

سريان مستحلبات الخام السعودي في خطوط الأنابيب

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ملخص البحث. إن خواص سريان مستحلبات الخام السعودي في خطوط الأنابيب قد قيست معمليا باستخدام جهاز لقياس اللزوجة عند درجات حرارة وتركيزات مختلفة. وقد استخدم عامل الاستحلاب (Triton X-100) بتركيز ٠,٥٪ (بالحجم) لخلط الخام بالماء.

وقد وصفت خواص السريان للمستحلبات رياضيا باستخدام ثلاث معادلات ريولوجية، وهذه المعادلات الثلاثة تربط بين: الإجهاد، ومعدل القص، وتركيز الخام في المستحلب، ودرجة الحرارة. كما استخدمت هذه المعادلات في وصف سلوك سريان المستحلبات خلال خطوط الأنابيب، كما تمت دراسة تأثير كل من درجة الحرارة وتركيز الخام على الضغط اللازم لدفع هذه المستحلبات خلال خطوط الأنابيب تحت ظروف السريان الاضطرابي.