U.P.B. Sci. Bull., Series C, Vol. 71, Iss. 3, 2009 ISSN 1454-234x

THE INFLUENCE OF DRAG-REDUCING ADDITIVES ON CRUDE OIL EMULSIONS IN PIPELINE FLOW

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În lucrarea de faţă sunt investigate două tipuri de emulsii ţiţei-apă, îmbogăţite cu aditivi, cu scopul de a determina pierderile de presiune în conducte, respectiv de a calcula coeficientul lui Darcy, λ. Experimentele sunt realizate în condiţiile unui debit constant, măsurându-se căderea de presiune între două secţiuni ale unei conducte liniare (diametrul d = 26 mm), cu ajutorul unui traductor de presiune foarte sensibil. Sunt investigate atât regimul staţionar, cât şi cel tranzitoriu, în funcţie de proprietăţile reologice ale fluidului. Pentru numere Reynolds aflate în domeniul 100 < Re < 10000, valorile experimentale ale coeficientului lui Darcy corespund predicţiilor teoretice şi pun în evidenţă influenţa aditivilor asupra pierderilor de presiune.

The present paper investigates two samples of crude oil – water emulsions, in presence of drag reduction surfactants, in order to determine the pressure loss in pipes, respectively to compute the Darcy coefficient, λ. The experiments are performed at constant flow rate and the corresponding pressure differences between two sections of a straight pipe (diameter d = 26 mm) are measured with a sensitive pressure transducer. Both stationary and transitory flow regimes are investigated, as function of the samples rheology. Experimental values of the Darcy coefficient in the domain 100 < Re < 10,000 fit the theoretical formulas and put in evidence the additive influence on pressure loss.

Keywords: emulsion, surfactant, pipe flow, pressure loss, Darcy coefficient, Reynolds number

1. Introduction

In the presence of surfactants, crude oil-water emulsions become rheologicaly complex fluids with remarkable viscoelastic and thixotropic behaviors. The macroscopic rheological properties of these fluids (viscosity and elasticity) are determined, for a given concentration, by the characteristics of the oil-water interface, i.e. the interfacial tension between the two liquids. The presence of surfactant (polymer) modifies the interfacial tensions, thus modifying the rheologic macroscopic properties of the emulsion.

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The rheological characteristics of crude oil-water emulsions were intensively studied as a function of the concentration of water, but less research has been done as a function of the type of surfactant, [1], [2], [3]. The influence of polymer adding on the flow properties of the oil-water emulsions is not explicitly presented in literature, probably due to their major economical implications of this method, [4], [5].

Surfactants are widely used and find a very large number of applications because of their remarkable ability to influence the rheological properties at surfaces and interfaces. Surfactants may be applied or encountered at all stages in the petroleum recovery and processing industry, from oil-well drilling, reservoir injection, and surface plant processes, to pipeline and seagoing transportation of petroleum based emulsions.

The unusual properties of aqueous surfactant solutions can be ascribed to the presence of a hydrophilic head group and a hydrophobic chain (or tail) in the molecule.

The conclusions one draws from studying the scientific literature on the subject:

(i) the type of crude oil (asphaltic or paraffinic) dramatically influences the rheology of the mixture;

(ii) the crude oil – water emulsions generally exhibit a thixotropic behavior (due to the irreversible changes of the interfacial tensions during flow under shearing);

(iii) the rheological properties of these mixtures are different in oscillatory shear tests than in continuous shear tests (the low-amplitude shear oscillations do not affect the interfacial tensions; continuous shear on the other hand, produces remarkable changes in the molecular bonds).

The rheology of crude oil – water emulsion is presented in [2].

Transport of crude oil – water emulsions in pipes is a major application of rheology in petroleum industry. One main problem to be solved is the decreasing of pressure loss. The procedure is based on the change of interface properties between oil and water by adding a surfactant, so called *drag reducer*.

The linear pressure loss in pipes depends on the flow mean velocity (V), pipe length (L) and diameter (d), fluid mass density ρ, and a friction factor, λ (so called the Darcy coefficient); the pressure loss formula is given by, [3],

$$\Delta p = \lambda \frac{\rho L}{d} \frac{V^2}{2} \tag{1}$$

The Darcy coefficient λ depends on the flow - if it is laminar, transient or turbulent, respectively on the Reynolds numbers and, in some cases, on the relative roughness of the tube wall.

The objective of the present research is to measure the linear pressure loss during the transport in pipes of the crude oil – water emulsions and to determine the Darcy coefficient as function of the additivated drag reduction polymer in different concentrations. The rheology of the samples was described elsewhere [8].

2. Experimental

Two samples of crude oil were used:

(i) PA: a water-in-asphaltic oil emulsion (30% water, density of ρ =935 kgm^{-3});

(ii) PB: a water-in-paraffinic oil emulsion (6% water, ρ =842 kgm^{-3}).

The tests were made in presence of the following additives and concentrations:

PA – additive NFS3 C0 = 0%, C1 = 1000g/tone of crude oil, C2 = 2C1, C3 = 4C1;

PB – additive AF C0 = 0%, C1 = 500g/tone of crude oil, C2 = 2C1, C3 = 3C1;

PB – additive SFP C0 = 0%, C1 = 1000g/tone of crude oil, C2 = 2C1, C3 = 3C1.

The experimental setup is a closed-circuit installation. The characteristics of the installation are: (i) volume of fluid – 30 l; (ii) length of the working pipe – 3.5 m; (iii) inner diameter of the pipe – d = 26 mm; (iv) distance between pressure gauges – L = 1.4 m. The emulsion is transported by a volumic pump with internal gears, Varisco V30-2 ST5WGY, at a constant flow rate – Q =70 l/min. The pressure difference is measured with a differential pressure transducer, Sensotec A5: pressure range 0 – 170 kPa, operating temperature 0 – 90°C.

There were measured no significant changes on fluid temperature during one measurement ($\Delta\theta < 0.5$°C, reference temperature being of 20^{o}C); the viscosity of each sample being measured for the testing temperature and the shear rate:

$$\dot{\gamma} = \frac{8\,\mathrm{V}}{\mathrm{d}} \cong 700\ \mathrm{s}^{-1}. \tag{2}$$

(mean velocity corresponding to the nominal flow rate is V = 2.2 m/s). We have mention here that the expression of the shear rate (2) is accurate only for a Newtonian fluid. The characteristic Reynolds number of the flow is calculated according to:

$$Re = \frac{\rho \mathrm{V d}}{\eta_*} \tag{3}$$

where η_* is the viscosity of the sample at testing temperature and shear rate (2). Detailed investigations of the samples rheology is presented in [2]. The samples viscosity functions are represented in Fig. 1 for samples PA and in Fig. 2a and Fig. 2b for samples PB.

The measurements were performed in laminar and transitory flow regimes, with Reynolds numbers similar to those from practical applications, i.e. $Re < 8{,}000$.

For the calculus of the Darcy coefficient, the following formulas were used:

$$\lambda = \frac{64}{Re}, \tag{4}$$

for the laminar regime ($Re < 2300$), respectively

$$\lambda = \frac{1}{\sqrt[4]{100\,Re}}, \tag{5}$$

the Blasius formula, for $Re > 2300$ (the flow regime is considered smooth), see [3].

In Fig. 3 are shown the measured and the theoretically computed values for the Darcy coefficient. Obviously, there is a great consistency between the experimental and the theoretic data.

One can observe that, despite the non-Newtonian behavior of the samples, the formulas (4) and (5) are able to predict correctly the measured values of Darcy coefficients.

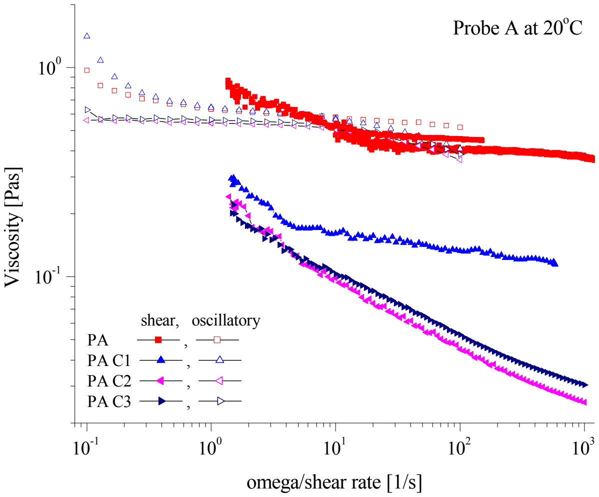

Fig. 1. Viscosity functions for samples based on PA emulsion.

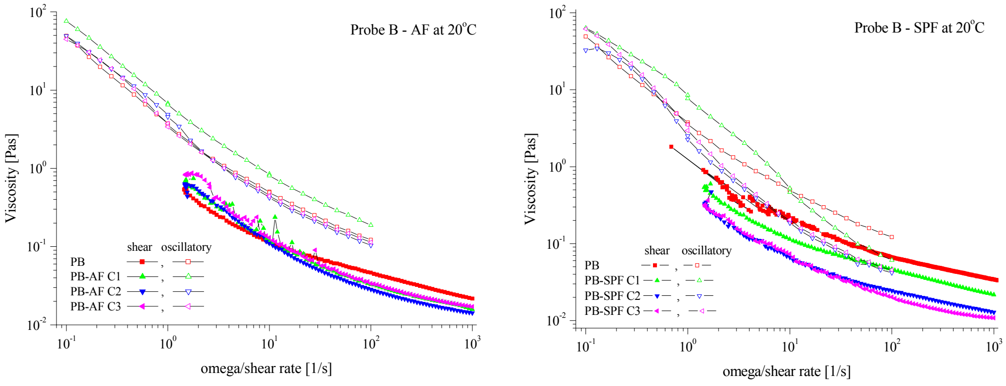

Fig. 2**.** a)Viscosity function for samples based on PB emulsion and additive AF;
b) Viscosity function for samples based on PB emulsion and additive SFP

The influence of drag reducer is very positive for PA sample, i.e. λ is reduced by the presence of polymeric additive, due to reduction of viscosity, which determines the increasing of Reynolds number, without to change the flow regime from laminar to transitory or turbulence, see relation (4).

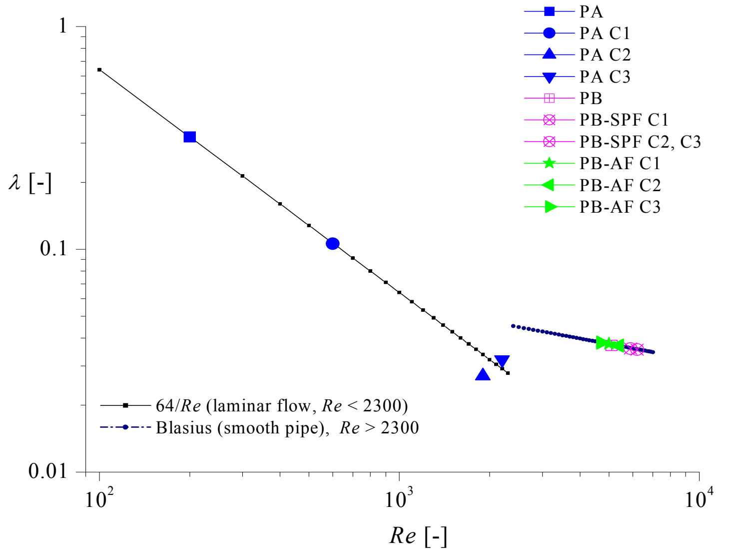

Fig. 3. Dependency $\lambda(Re)$ for the performed tests. The presence of additives in PB samples does not bring relevant influences on the Darcy coefficient, since the flow remains always in the transitory flow regime, i.e. Re > 3000

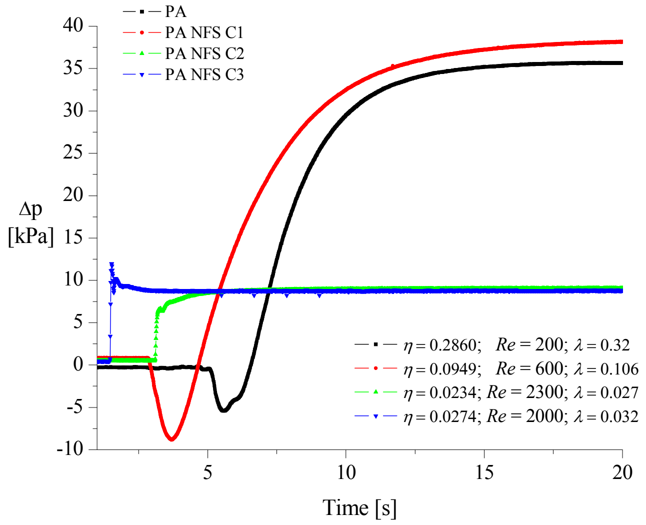

Fig. 4. Pressure variation for PA samples during the non-stationary flow regime

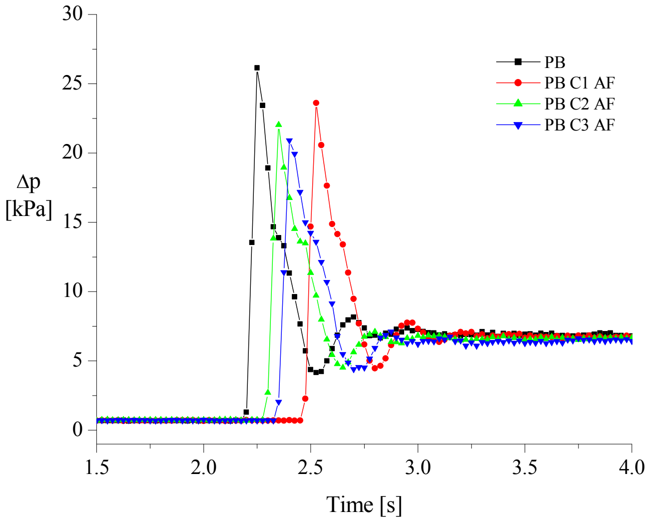

Fig. 5. Pressure variation for PB sample in presence of AF additive

The time variation of the measured pressure differences for a step-signal of Q = 70 l/min are shown in Fig. 4 (sample PA), Fig. 5 and Fig. 6 for samples PB, respectively. The pressures drop in Fig. 4 converges to stationary value after a period of approximately 30 s for PA and PA-C1. We also notice a dramatic fall of the pressure drop for PA-C2 and PA-C3 samples. There were observed no influences of the additives on the measured pressure differences for PB samples.

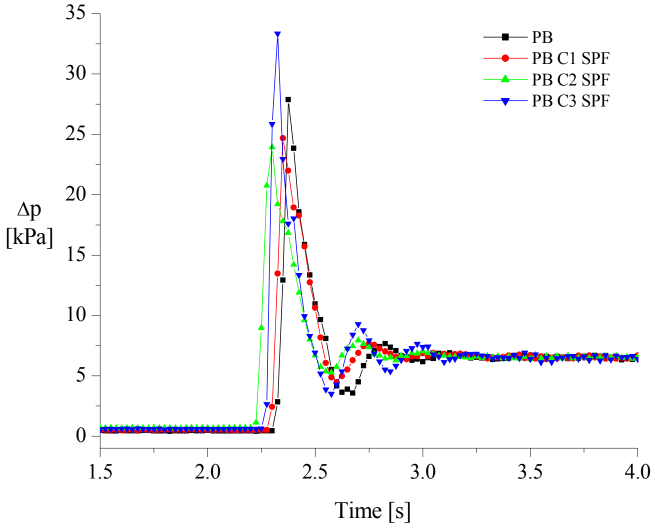

Fig. 6. Pressure variation for PB sample in presence of SPF additive.

3. Conclusions

The samples exhibit a rheologic behavior that is characteristic to emulsions: (a) the increased viscosity of the mixture compared to that of the main fluid (crude oil); (b) the shear viscosity is smaller than the complex viscosity (given by the oscillatory tests); (c) shear thinning rheologic of emulsions is remarkable; (d) viscoelastic behavior of the samples in presence of additives.

These properties are more evident for the PA sample, due to the higher concentration of water and the composition of the crude oil. The PB sample on the other hand, exhibits remarkable thixotropic properties, the rheological properties being thus strongly influenced by the shear and flow history of the material.

From the analysis of the experimental data at medium and high shear rates results a minimum shear viscosity for all tested samples at the concentration C2 of polymeric additives; simultaneously, the value of the Darcy coefficient reaches its minimum around this concentration, see Table 1. Our results are important for practical applications and offer solutions to improve the transport of petroleum emulsions, respectively to reduce the pressure loss due friction of liquids in pipes.

Table 1

Darcy coefficient for the investigated samples, as function of additive concentration

Sample	C0	C1	C2	C3
PA + NFS3	0.32	0.106	0.027	0.032
PB + AF	0.037	0.037	0.0368	0.038
PB + SPF	0.037	0.036	0.0355	0.035

The investigations show the influence of the polymeric additives on the rheology of crude oil – water emulsions. The drag reduction is remarkable only if the flow is kept in the laminar regime after the additivation. Therefore, the mechanism of drag reduction revealed in this study is based on increasing Reynolds number, at the same flow rate, due decreasing of viscosity. It is different from the investigations of the polymer influence on the turbulent flows in pipes, where drag reduction is based on the decreasing of turbulence intensity in vicinity of the wall due the polymer presence (viscosity of the fluid being practically unchanged).

Acknowledgement The author is very thankful to Prof. Corneliu Bălan for his advises and permanent support during the present work.

R E F E R E N C E S

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