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Chemical engineering

RHEOLOGICAL MODEL FOR FLOWS OF NON-NEWTONIAN PETROLEUM

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This study researched the problems of filtration modeling of structured petroleum with anomaly characteristics in porous rock layers with respect to coagulation structuring. New rheological equation of fluids with Bingham flow model, the events of filtration in pores in oil reservoirs was established and presented. A relation was achieved regarding the changes in filtration velocity based on pressure gradient and shear stress in the new equation. It has been observed that the theoretical model demonstrated established good compliance with the experimental dates.

Keywords: non-Newtonian oil, rheological equations for liquids, porous rock strata, coagulation, filtration

Petroleum structured systems are composed of high molecular paraffin crystals and coagulation of asphaltene particles. These structures are mainly in reticulated form, which are chained or formed at the extreme boundary equilibrium [1,2]. These systems gain mobility only when this structure is collapsed ($\tau \gg \tau_0$), where τ_0 – is the critical shear stress. On the other hand, if the external stress applied is weak, it results in the deformation of the reticulum or the carcass. As demonstrated by this expression, with increasing petroleum viscosity, the collision frequency and formation probability of objects (clustering) formed at the result of the coagulation would decrease. The dimensions of the clustered asphaltene particles increase and the disintegration of the particles commence when they reach the maximum size that is the unstable structure. Among the particles of the clustered object under the effects of the hydrodynamic forces, when the stress reaches critical values, these objects divide into smaller objects. Clustered structures formed by paraffin and asphaltene have different specifications. These structures do not immediately disintegrate when pressure is applied for the flow of petroleum. When the shear rate increases in excess ($\tau \gg \tau_0$), objects could disintegrate until they form single particles. This type

of flow of petroleum and petroleum emulsions indicate the characteristics of non-Newtonian flow. Since effective viscosity $\eta(T, \text{grad } P)$ is dependent on temperature and shear rate (pressure gradient), additional energy expenditure is required for disintegration of the objects during the initial period of the petroleum flow. On the other hand, when the effect of the pressure is removed, the structure of the object returns to its initial state and viscosity reaches the maximum value. Thus, thixotropic property is observed. In such structures, disperse asphaltene particles are in coagulation and clustering activity and have structural instability. Characteristics of the anomaly petroleum are different than the characteristics of the petroleum that fit general specifications and their flow regimes determined by the laws of flow for non-Newtonian flows. Rheological characteristics of non-Newtonian specific petroleum change depending on the concentration of disperse mixture they contain as well. Elastic flow area is written according to Bingham equation as follows:

$$\tau = \tau_0 + \eta^* \dot{\gamma} \quad (1)$$

Darcy law for non-Newtonian petroleum is different from its traditional form and could be written as the following nonlinear form:

$$V = -\frac{k}{\eta(T, \text{grad } P)} \frac{\partial P}{\partial x} \quad (2)$$

When the Newton equation ($\eta = \frac{\tau}{\dot{\gamma}}$) is taken into consideration (1) could be written as follows:

$$\eta = \eta^* + \frac{\tau_0}{\dot{\gamma}} = \eta^* \left(\frac{\tau_0}{\eta^* \dot{\gamma}} + 1 \right) \quad (3)$$

Then the following basic statement is obtained for effective viscosity:

$$\eta = \eta^* + \frac{\tau_0}{\dot{\gamma}} = \eta^* \frac{\tau}{\tau - \tau_0} \quad (4)$$

In the limit approach ($\tau \gg \tau_0$), if $\tau_0/\tau \rightarrow 0$, yields $\eta \rightarrow \eta^*$. Thus, with effects of the increase in shear stress of the systems with structural framework, viscosity changes from the initial value of η_0 , to η_∞ value. When (4) is considered in equation(2), that modified Darcy equation for structural specific petroleum systems is obtained as follows[3]:

$$V = -\frac{k}{\eta^*} \left(1 - \frac{\tau_0}{\tau} \right) \frac{\partial P}{\partial x} \quad (5)$$

Evidently, it turns into the traditional Darcy equation for basic petroleum without structural characteristics when $\tau \gg \tau_0$. To implement this new equation (5) determining filtration of structural suspensions and anomaly petroleum, the relation of τ_0/τ ratio with the system parameters has to be established. According to the review of the results

of several experimental studies, (τ_0/τ) ratio in filtration of anomaly petroleum could be expressed as follows:

$$\ln \frac{\tau}{\tau_0} = \alpha \left(\frac{\text{grad } P}{(\text{grad } P)_0} \right)^n \quad (6)$$

Thus filtration velocity of petroleum, (τ_0/τ) ratio determined from equation(6), considering at equation(5) easily can be calculated. Using the experimental results [4] and considering equations(5) and (6), the petroleum filtration velocity could be written as below:

$$V = K_2(T) \left(1 - \exp \left(-\alpha_2(T) (z/z_0)^6 \right) \right) z \quad (7)$$

Here

$$\alpha_2 = 0.1422 \exp(-0.0247T),$$

$$K_2(T) = 1.4 \times 10^{-5} \exp(0.0364T),$$

$z = \text{grad } P$, $z_0 = (\text{grad } P)_0$, $K_2 = \frac{k}{\eta^*}$ is the mobility of petroleum.

Figure 1 demonstrates the comparison of experimental [4] and theoretical (7) results of filtration velocity of the anomaly petroleum drilled from different oil wells. The changes of the initial pressure gradient based on temperature written as below, $(\text{grad } P)_0 = \alpha_2 + \frac{b_2}{T}$ where $\alpha_2 = 2.197$, $b_2 = 0.3275$.

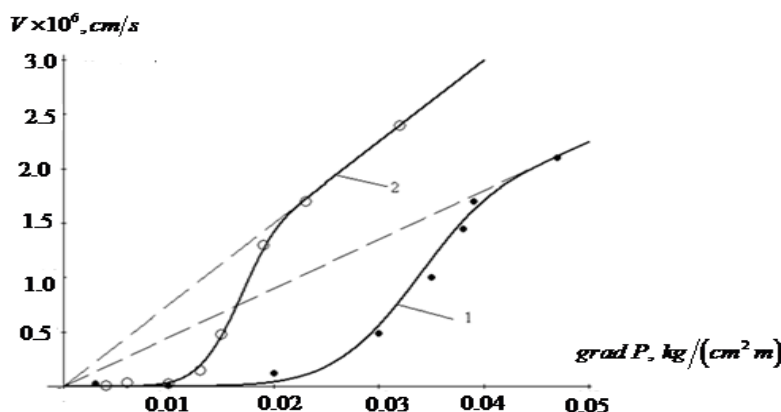


Fig. 1. The comparison of experimental and theoretical results of the change in filtration velocity of the petroleum for oil well based on temperature: 1. T=24°C; 2. T=50°C; 3. T=80°C

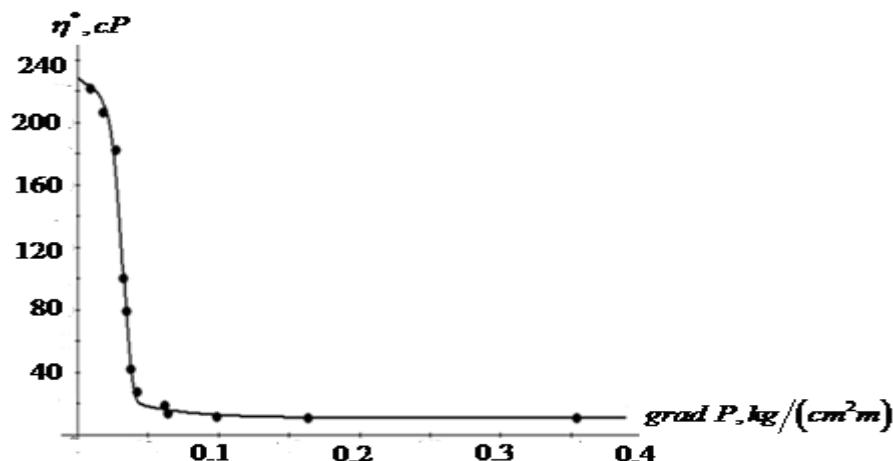


Fig. 2. The variation of effective viscosity based on the pressure gradient. Figure 6 indicates theoretical results for the change in shear stress relative to the pressure gradient calculated based on the formula,

Comparison of these equations clearly demonstrates that the form of the changes in the filtration equations for anomaly petroleum from different drillings indicated the same similarities. According to as results of experimental dates, the relation of plastic viscosity of anomaly petroleum with pressure gradient could be determined with the following empirical formula:

$$\eta^* = (\eta_0 - \eta_\infty) \exp(-30z^6) + 28 \exp(-26.65z) + \eta_\infty \quad (8)$$

Here, η_0, η_∞ is the initial ($\tau \ll \tau_0$) and final ($\tau \gg \tau_0$) viscosities of petroleum, respectively. Figure 2 indicates the comparison of the theoretical results of Eq. 10 and the experimental dates [4] in $T=24^\circ\text{C}$ temperature. Considering empirical results in literature [4] approximate relation of the variation of effective viscosity based on the pressure gradient for anomaly petroleum can determine. As could be observed in Figure 2, effective viscosity of anomaly petroleum in low flow velocity is effectively dependent on shear rate or pressure gradient.

$$\ln \tau = \ln \tau_0 - \exp \left(-\alpha \left(\frac{\text{grad } P}{(\text{grad } P)_0} \right)^6 \right) \quad (9)$$

Usually one of the factors affecting the effective viscosity of suspensions is various disperse mixtures they contain. Concentration of the particles asphaltenes, their shapes and dimensions affect significantly the effective viscosity of this type of systems.

The study presented the new form of Darcy equation, which takes into consideration the dependency of filtration velocity for Bingham rheological fluid flows to pressure gradient, and shear stress (Eq. 5). Semi-empirical equations that determine the mobility and efficient viscosity of petroleum based on volumetric density of particles and shear stress, are proposed. Properties and coagulation structures (formation and disintegration of objects) of rheological fluids change in time due to their unstable behavior.

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Institute of Catalysis and Inorganic Chemistry named after acad. M.F.Nagiyev

kudret.kelbaliev@mail.ru**QEYRİ-NYUTON NEFTLƏRİN AXINI ÜÇÜN REOLOJİ MODEL****Q.İ.Kəlbəliyev, S.R.Rəsulov, Ab.Q.Rzayev, G.Z.Süleymanov, D.B.Tağıyev**

İşdə anomal xüsusiyyətlərə malik neftlərin daşlaşmış məsaməli süxurlarda quruluş əmələgəlmə və koagullaşma zamanı süzülməsi problemləriylə əlaqədar tədqiqat işlərinin nəticələrinə baxılmışdır. Bu nəticələrə görə maye axını və “Bingham” modeli üçün yeni reoloji tənlik təklif edilmişdir ki, bu tənlik yataqlardan süzülən neftin həcm sürətini müəyyən etməyə imkan verir. Digər tərəfdən müəyyən edilmişdir ki, neftin həcmi süzülmə sürəti lay təzyiq əmsalından asılı olaraq dəyişir və nəzəri hesablamalarla eksperimental nəticələr üst-üstə düşür.

Açar sözlər: qeyri-nyuton neftlər, mayələr üçün reoloji tənliklər, daşlaşmış məsaməli laylar, koagullaşma, süzülmə

РЕОЛОГИЧЕСКАЯ МОДЕЛЬ ДЛЯ НЕОНЫУТОНОВСКИХ НЕФТЯНЫХ ПОТОКОВ**К.И.Келбалиев, С.Р.Расулов, Аб.К. Рзаев, Г.З.Сулейманов, Д.Б.Тагиев**

В работе исследовались проблемы моделирования фильтрации структурированной нефти с аномальными характеристиками в пористых каменных пластах в отношении к структурированию коагулирования. Установлены и представлены новые реологические уравнения жидкостей посредством проточной модели “Bingham” и явления фильтрации в порах нефтяных резервуаров. Установлены взаимосвязи в отношении изменений объемной скорости фильтрации на основе градиента давления и давления сдвига в новом уравнении. Выявлено, что теоретическая модель демонстрирует хорошее согласие с экспериментальными данными.

Ключевые слова: неоньютоновские нефти, реологические уравнения жидкостей, пористые каменные пласты, коагулирования, фильтрации