UDC: 532.517.4

https://doi.org/10.59849/2409-4838.2024.3.20

STRUCTURE FORMATION IN OIL DISPERSED MEDIA

Vafa Imran Karimli*, Fatma Rashid Shikhieva
Institute of Catalysis and Inorganic Chemistry named after Murtuza Nagiyev,
Baku, Azerbaijan
*miracle1990@list.ru
Received: 22.04.2024
Accepted: 15.07.2024

A number of issues with crude oil production and transportation can arise from the presence of water dissolved in the oil as a water-in-oil emulsion. Issues related to transportation are demonstrated by the when water is present, the resulting fluids' viscosity increases. The effects of temperature, disperse phase droplet size, and disperse phase volume on the rheological characteristics of water-in-crude oil emulsions have been studied in order to better understand this undesired occurrence and to support demulsification research. The results obtained with various crude oils show that as the water content and water droplet size decrease, the viscosity of the water-in-light crude oil emulsions increases. The emulsions exhibit Newtonian behavior at low water contents, but deviate from it as water content increases. The results show how the rheological characteristics and dehydration of these emulsions are impacted by the precipitation of specific native surface active components in crude oil. Crude oil reservoirs are nearly invariably connected to gas and briny water. Therefore, it is highly possible that coproduction of water will also happen at some point during the production of crude oil. This often occurs as the reservoir gradually empties. The produced water may come from the reservoir's water-bearing portion or from water that has been injected for secondary or tertiary oil recovery. No matter what kind of water phase exists, as long as it is coproduced, shear and pressure drop at well-head chokes and valves will spread it out easily.

Keywords: *Rheological models, settling, drag coefficient, effective viscosity, structure formation*

INTRODUCTION

Ranges of experimental data are taken into consideration and rheological models of viscous-plastic heavy oils are created [15-18]. Numerous existing models can be made more universal by including new rheological models for viscous-plastic heavy oils. The criteria for the production of disordered structures in the majority of the oil flow are documented to determine the range of rheological models for heavy oils [1]. Based on the effective viscosity of the oil, pressure gradient, shear stress, and several other factors, a nonlinear equation for filtering in porous media is provided for heavy oils [3, 4, 6, 18]. This equation has an analytical solution that is suggested and agrees with the results of the experiment. A nonlinear equation for filtering in porous medium for heavy oils is provided, which depends on many parameters such as the oil's effective viscosity, pressure gradient, and shear stress. This equation has an analytical solution that is suggested and agrees with the experimental results. Proposed are models for the drag coefficient and settling rate of particles in heavy oils. In order to improve the rheological characteristics of heavy oil during processing as a result of developing a recirculation scheme at an operational oil refining unit, applied rheology difficulties are taken into consideration. The inclusion of naturally occurring surfactants from crude oil stabilizes the resulting water-in-oil emulsions by adsorbing at the oil-water interface and creating an interfacial skin around each water droplet. The physical barrier that prevents coalescence is what leads to the overall high stability of emulsions of water in crude oil [2, 7, 17, 21]. The addition of tiny, solid wax particles has been shown to enhance this skin when combined with specific crude oils. Water-in-crude-oil emulsions can cause a number of issues, such as: the cost of pumping or transporting the saline water by tanker or pipeline; corrosion of downstream overhead distillation columns and production equipment; the need for additional production equipment to provide export-quality crude oil; and poisoning of refinery catalysts. Therefore, it is evident that the removal of this emulsified water early in the production scheme is justified for both operational and commercial reasons. However, in other situations, such as when producing crude oil from autonomous offshore platforms or satellite wells, it is not feasible to resolve emulsions before pipeline transmission. Then, the presence of emulsified water droplets in cooling crude oil causes a rise in viscosity, which is the immediate production issue rather than the removal of the water. The current work aims to tackle this topic by concentrating on how the addition of water in an emulsified form alters the rheological characteristics of crude oil. To suggest the appropriate placement of facilities for pumping the generated water-in-oil emulsion, the design engineer must have a thorough understanding of the rheological behavior of the emulsion. In fact, the outcomes might affect whether or not the oil needs to be dehydrated before being transported. We will thus demonstrate how several factors affect the rheological characteristics of water-in-crude oil emulsions, including temperature, disperse phase volume, and water droplet size. Next, we will create a theme that illustrates how the bulk rheology of the emulsions can be impacted by the presence or absence of fine particulates at the crude oil-water interface. There have been several presentations of preliminary evidence for this. The current research has been expanded to allow us to examine the potential effects of other oil-native chemical species, such as asphaltenes, on the rheological characteristics of emulsions made with various types of crude oil [15, 16]. Lastly, we will show how the resolution of water-in-crude oil emulsions corresponds with the observed rheological behavior. Our goal is to draw attention to the significance of emulsion rheology in relation to the extraction and transportation of crude oil, a subject that hasn't gotten much attention up to this point.

A family of dispersion systems called emulsions is made up of two immiscible liquids [9-12]. In a liquid medium, the liquid droplets (the dispersion phase) are distributed (the continuous phase). Different classes can be identified: water with oil in it (O/W), both oil-in-oil (O/O) and water-in-oil (W/O) exist. An emulsion made of polar oil (propylene glycol, for example) dispersed in nonpolar oil (paraffinic oil) and vice versa can serve as an example of the latter kind. One needs the emulsifier, a third ingredient, to disperse two immiscible liquids. For the emulsion to form and remain stable over time, the emulsifier selection is essential [13, 14].Emulsions can be categorized based on the system's structure or the type of emulsifier used. Table 1. gives an illustration of this.

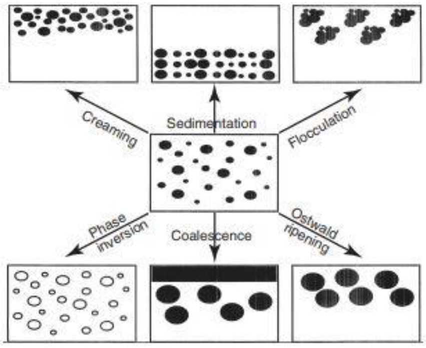

Table 1. Schematic representation of the various breakdown processes in emulsions

It is required to find solutions to a variety of, occasionally contradictory issues in order to regulate the structural and mechanical features of oil dispersion systems in the processes of oil production, transportation, refining, and petroleum product consumption. A high concentration of dispersed particles (water droplets, gas bubbles, and solid particles), along with asphalt-resin and paraffin particles dissolved in heavy oil, are considered the rheological properties of oil dispersed systems. These properties also include the ability of the particles to form different structures as a result of their physical interactions with one another. Particle size, shape, concentration, and characteristics all play a significant part in the creation of structures and the building of rheological models of non-Newtonian fluids. Many rheological models with distinct features that represent the flow of oils from diverse fields are provided in publications [3, 21].The core of rheological study is, as is well known, the nature of the relationship between shear stress τ, shear strain $\dot{\gamma}$, and their changes in time dτ/dt and $d\dot{\gamma}/dt$ [19, 20]. Heavy processing products and high viscosity viscous plastic oils are categorized using rheological properties as a criterion. After the system under study's limiting shear stress, τ_0 is overcome, a series of actions of breakage and restoration of links between scattered particles comprise the mechanism of plastic flow. The core of rheological study is, as is well known, the nature of the relationship between shear stress τ, shear strain γ_, and their changes in time dτ=dt and dγ_=dt [3, 5, 8]. Heavy processing products and high viscosity viscous plastic oils are categorized using rheological properties as a criterion. After the system under study's limiting shear stress, τ0, is overcome, a series of actions of breakage and restoration of links between scattered particles comprise the mechanism of plastic flow. When the shear stress exceeds the elastic limit stress, τ > >τ0, the structure breaks down and the viscosity rapidly decreases. It is possible to assess the basic characteristics of the systems themselves using rheological models of oil dispersed systems. These models are primarily empirical or semiempirical in character since they lack a shared mechanism of flow and deformation. There are several empirical rheological models of structured dispersal systems, but as of yet, no qualitative or quantitative theories exist that relate the structure parameters to the rheological characteristics of the system. This might be the result of the flow, distortion, and creation of an unorganized structure in each unique instance. As a result, the findings demonstrate that several empirical or semiempirical equations can accurately represent the same experimental investigation while maintaining model fidelity.

EXPERIMENTAL PART

Particles that have intermolecular connections with one another produce coagulation structures. If there are liquid interlayers between the particles, the strength of the coagulation structure is strongly influenced by the thickness of these interlayers. The variable state of the 2 Topics on Oil and Gas environment and changes in the physical characteristics of the particles that is, a shift in the size and volume of asphaltene particles as a result of their interaction, collision, coagulation, and crushing at a specific concentration in a closed volume are the hallmarks of aggregate unstable oil systems. A shift in the structure brought about by the creation and disintegration of aggregates from asphaltene particles in the presence of resins explains the relationship between the structure and viscosity of petroleum dispersed systems as well as the characteristics of their non-Newtonian flow. High molecular weight paraffin crystals, resins, and asphaltene particles combined with oil-structured materials form a chain or, in the worst case scenario, a continuous grid (framework) at very low laminar flow rates or without flow. Individual asphaltene nanoparticles coagulate or aggregate sequentially to create nanoaggregates and clusters of nanoaggregates, which ultimately forms a viscoelastic framework that gives heavy oils specific rheological characteristics. The study points out that two structural groups that differ in the kind of intermolecular interactions between particles in an oil-disperse medium are formed from the activation energies of real oil-dispersed systems. These groupings can be divided into two categories based on the amount of asphaltenes and resins they contain: immobile with a low asphaltene content and interactive with a high asphaltene content. The typical variations in activation energies for the two groups are displayed in Figure 1.

The following presumptions can serve as the foundation for the rheological model of the flow of oil dispersed systems [18].

- ✓ As a result of diffusion in laminar and turbulent shear flow and sedimentation (gravitational coagulation), asphaltene particles in structured oil systems can collide, coagulate, and aggregate, forming nanoaggregates. These aggregates can be deposited on the surface, forming a relatively thick layer of deposits on the walls of the porous oil reservoir. In addition, temperature-dependent pressure decreases during vigorous mixing or turbulent flow may cause precipitated asphaltene particles to dissolve or separate;
- ✓ Until they clash with asphaltene particles or other comparable aggregates, nanoaggregates travel as separate flow units;

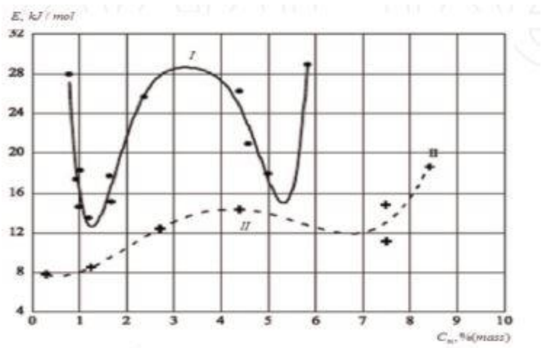

Fig. 1. For both the immobile group (I) and the interactive group (II), the activation energy is dependent on the asphaltene content [18].

Colliding nanoaggregates combine to form clusters, which in turn form a viscoelastic frame of a disordered structure with a loose coagulation structure and the maximum viscosity. The diameters of the channels (pores and pipes) that the flow passes through define the maximum size of the nanoaggregate structure. It is significant to remember that the variety of rheological models arises from the production of disordered structures in the oil volume;

Depending on the pressure gradient or flow rate, nanoaggregates can rotate in a gradient field and fracture due to tensile hydrodynamic forces;

The size of a single asphaltene particle to the largest possible cluster or disordered structure framework is the range of the linear dimensions of nanoaggregates;

Under the condition $\lim_{\tau\to\infty}(\tau_0/\tau) \to 0$, all aggregates are annihilated to individual particles in the limiting situation of infinite velocity, which causes the flow of a dispersed system to approach Newtonian;

RESULTS AND DISCUSSION

Asphaltenes dissolve readily in the presence of aromatic hydrocarbons, which inhibits the creation of structures such as clusters and viscoelastic frameworks. The solubility of asphaltenes is influenced by the existence of other compounds, like resins, in the oil.

Maxwell's viscoelastic fluid's rheological equation in considerable derivatives is expressed as follows:

$$\lambda\left(\frac{\partial\tau}{\partial t}+U\frac{\partial\tau}{\partial y}\right)+\tau=\eta_c\dot{\gamma}$$

$$t=0, \tau=\tau_0, \dot{\gamma}=0$$

where λ is the relaxation time.

The Eq. (1), presented in the form:

$$\lambda\left(\frac{\partial\tau}{\partial t}+U\frac{\partial\tau}{\partial y}\right)+\tau=0$$

The solution of Eq. (2) can be represented as:

$$\tau = C_1 f(y - Ut) exp\left(-\tau/_{\lambda}\right)$$

We get an identity by substituting this answer into Eq. (2). Here, $\lambda = \eta_c/G$ is the Maxwell relaxation time, U is the strain front movement velocity $f(y - Ut)$ is a function that determines the strain front in the frame, y is the coordinate, G is shear modulus, $\dot{\gamma} = d\gamma/dt$ is shear rate, γ is the shear gradient, τ_0 is the ultimate shear stress or yield strength. Moreover, if $\tau \leq \tau_0$, then $\dot{\gamma} = 0$. The complete solution of

Eq. (3) takes the form:

$$\tau = C_1 f(y - Ut)\exp(-t/_{\lambda})\, \tau_0$$

or this equation can be written in logarithmic form:

$$\ln \tau = \ln \tau_0 - 1/_{\lambda} + \ln(C_1\, f(y - Ut)), \tau_0 = \eta_c \dot{\gamma}$$

It's clear that the value t=λ in Eq. (5) describes the viscoelastic frame's deformation over time and that, when heavy oils flow, it depends on the pressure gradient or velocity, which, in an approximation, can be expressed as follows: $t/\lambda = t\dot{\gamma}\, /\, Wi \sim f[(grad\ P/(gradP)_0)^n]$

(where, $Wi = \lambda\dot{\gamma}$ is the Weissenberg number).

CONCLUSION

For viscous-plastic heavy oils, new rheological models are put forth, allowing for the generalization of numerous previous models. It is observed that the circumstances for the production of disordered structures in the majority of the oil flow dictate the range of rheological models for heavy oils. A nonlinear equation for filtering in porous medium for heavy oils is provided, which depends on many parameters such as the oil's effective viscosity, pressure gradient, and shear stress. This equation has an analytical solution that is suggested and agrees with the experimental results. Proposed are models for the drag coefficient and settling rate of particles in heavy oils. Rheological application issues focused on enhancing heavy oil's rheological characteristics during processing.

REFERENCES

1. Tadros, T. Applied Surfactants / T.Tadros. Wiley-VCH Verlag GmbH, Germany, − 2005. – 320 p.
2. Manafov, M.R. Study of the effect of asphaltene-resinous compounds on the separation of oil emulsions / M.R.Manafov, F.R.Shikhieva, K.I.Matiyev, V.I.Karimli // Azerbaijan Chemical Journal, − 2022. №2, − p. 18-27.
3. Kelbaliev, G.I., Manafov, M.R., Shikhieva, F.R. Rheology of a viscous-plastic liquid in a porous medium // Open Journal of Fluid Dynamics, − 2023, 13, − p. 16-31.
4. Qun, L. Influence of shear on rheology of the crude oil treated by flow improver / L.Qun , Z.Fusheng, G.Baoshan [et al.] // Energy Reports, − 2019, 5, − p. 1156-1162.
5. Manafov, M.R. Analysis of models of deposition of asphaltene-resin-paraffin deposits in vertical transport pipes / M.R.Manafov, G.I.Kelbaliev, F.R.Shikhieva // Azerbaijan Oil Industry, − 2021. №12, − p. 33-37.
6. Shadi, W. Hasan Heavy crude oil viscosity reduction and rheology for pipeline transportation / W. Hasan Shadi, T. Ghannam Mamdouh, Esmail Nabil // Fuel, – 2010, 89, – p. 1095-1100.
7. Langevin, D. Crude oil emulsion properties and their application to heavy oil transportation / D. Langevin, S. Poteau, I. Henaut, JF.Argillier // Oil Gas Science Technology Rev IFP, – 2004, 59 (5), – p. 511-521.
8. Shikhieva, F.R. Modeling of heavy component deposition of oil in horizontal and vertical pipes // Scientific works, – 2021. №1, – p. 142-148.

9. Anwarul Hasan MD. Rheology of Reconstituted Crude Oils: Artifacts and Asphaltenes / MD. Anwarul Hasan, John M. Shaw // Energy Fuels, – 2010, 24, – p. 6417-6427.
10. Muhammad, Waseem. Characterization of Crude Oil Emulsion Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Engineering (Hons)(Mechanical Engineering, – 2012. – 150 p.
11. Silva, P.H.L. Rheology Characterization Of Water-In-Oil Emulsions / P.H.L.Silva, M. F.Naccache, P.R.S.Mendes // Brazilian Journal Of Petroleum And Gas, – 2020, 14 (3), – p. 125-135.
12. https://doi.org/10.1016/j.proeng.2016.06.614
13. Келбалиев, Г.И. Осаждение частиц в неньютоновской нефти / Г.И. Келбалиев, С.Р Расулов, М.Р Манафов, Ф.Р Шыхыева // Оборудование и технологии для нефтегазового комплекса, − 2022. №2, − p. 45-51.
14. Келбалиев, Г.И. Реология структурированных нефтяных дисперсных систем / Г.И.Келбалиев, Д.Б.Тагиев, С.Р.Расулов [et al.] // Теоретические основы химической технологии, – 2017, 51 (5) , – с. 582-588.
15. Manafov, M.R. Analysis of the current state of researches of the deposition of asphalt-resinous substances, paraffin, and modeling methods. Review part II: wax deposition / M.R Manafov, G.S Aliyev, A.I Rustamova, V.I Kerimli // Azerbaijan Chemical Journal, − 2021. №2, − p. 13-23.
16. Kelbaliyev, G.I. Modeling of the processes of separation oil emulsions / G.I.Kelbaliyev, V.I.Karimli, G.N.Huseynov // Azerbaijan Chemical Journal, – 2019. №2, – p. 15-22.
17. doi: 10.5772/intechopen.105666
18. Kelbaliyev, G.I. Structurization and effective viscosity of a non-Newtonian oil / G.I. Kelbaliyev; D.B. Tagiyev; S.R. Rasulov // Journal of Engineering Physics and Thermophysics, – 2023, 96 (1), – p. 55-63.
19. Kelbaliyev, G.I. Kinetically and Aggregatively Unstable Oil Disperse Systems / G.I.Kelbaliyev, D.B.Tagiyev, M.R.Manafov [et al.] // Journal of Engineering Physics and Thermophysics, – 2023, 96, – p. 660-668.
20. Manafov, M.R. Evolution of the distribution function of drops in an oil emulsion / M.R.Manafov, S.R.Rasulov, F.R.Shikhieva, V.I.Kerimli // Azerbaijan Chemical Journal, – 2023. №3, – p. 61-69.

NEFT DİSPERS MÜHİTLƏRDƏ STRUKTURUN FORMALAŞMASI

V.İ. Kərimli, F.R. Şıxıyeva

Xam neftin hasilatı və nəqli ilə bağlı bir sıra problemlər neftdə su-neft emulsiyası kimi həll olunmuş suyun mövcudluğundan yarana bilər. Daşınma ilə bağlı problemlər suyun mövcud olduğu zaman yaranan mayelərin özlülüyünün artması ilə nümayiş olunur. Bu arzuolunmaz hadisəni daha yaxşı başa düşmək və demulsifikasiya tədqiqatlarını dəstəkləmək üçün temperaturun, dispers faza damcılarının ölçüsünün və dispers faza həcminin su-xam neft emulsiyalarının reoloji xüsusiyyətlərinə təsiri tədqiq edilmişdir. Müxtəlif xam neftlərlə əldə edilən nəticələr göstərir ki, suyun tərkibi və su damlacılarının ölçüsü azaldıqca, yüngül suda olan xam neft emulsiyalarının özlülüyü artır. Emulsiyalar aşağı su tərkibində Nyuton davranışını nümayiş etdirir, lakin suyun miqdarı artdıqca ondan kənara çıxır. Nəticələr bu emulsiyaların reoloji xüsusiyyətlərinə və dehidrasiyasına, xam neftdə spesifik yerli səthi aktiv komponentlərin çökməsinə necə təsir etdiyini göstərir. Xam neft rezervuarları demək olar ki, həmişə qaz və duzlu su ilə bağlıdır. Buna görə də, xam neft hasilatı zamanı nə vaxtsa suyun birgə istehsalının da baş verməsi çox mümkündür. Bu, tez-tez anbarın tədricən boşalması ilə baş verir. Lay suyu layın su tutan hissəsindən və ya ikinci və ya üçüncü dərəcəli neftin çıxarılması üçün vurulmuş sudan gələ bilər. Hansı növ su fazasının mövcud olmasından asılı olmayaraq, birgə istehsal olunduğu müddətcə quyu başındakı boğulma və klapanlarda kəsmə və təzyiq düşməsi onu asanlıqla yayacaq.

Açar sözlər: *Reoloji modellər, çökmə, sürtünmə əmsalı, effektiv özlülük, struktur formalaşması*

СТРУКТУРООБРАЗОВАНИЕ В НЕФТЕДИСПЕРСНЫХ СРЕДАХ

В.И. Керимли, Ф.Р. Шихиева

Ряд проблем при добыче и транспортировке сырой нефти может возникнуть из-за присутствия воды, растворенной в нефти в виде эмульсии «вода в нефти». Проблемы, связанные с транспортировкой, демонстрируются тем, что при наличии воды вязкость образующихся жидкостей увеличивается. Влияние температуры, размера капель дисперсной фазы и объема дисперсной фазы на реологические характеристики эмульсий «вода в сырой нефти» было изучено с целью лучшего понимания этого нежелательного явления и поддержки исследований по деэмульгации. Результаты, полученные с различными видами сырой нефти, показывают, что по мере уменьшения содержания воды и размера капель воды вязкость эмульсий «вода в легкой сырой нефти» увеличивается. Эмульсии демонстрируют ньютоновское поведение при низком содержании воды, но отклоняются от него по мере увеличения содержания воды. Результаты показывают, как осаждение специфических природных поверхностно-активных компонентов в сырой нефти влияет на реологические характеристики и обезвоживание этих эмульсий. Резервуары сырой нефти почти всегда связаны с газом и соленой водой. Поэтому вполне возможно, что совместное производство воды также произойдет в какой-то момент во время добычи сырой нефти. Это часто происходит по мере того, как резервуар постепенно опорожняется. Пластовая вода может поступать из водоносной части пласта или из воды, закачанной для вторичной или третичной добычи нефти. Независимо от того, какой тип водной фазы существует, пока она добывается совместно, сдвиг и перепад давления на устьевых штуцерах и клапанах будут легко распределять ее.

Ключевые слова: *реологические модели, оседание, коэффициент сопротивления, эффективная вязкость, структурообразование*.