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DEPENDENCE OF WATER DROP SETTLING SPEED ON TURBULENT DIFFUSION COEFFICIENT IN OIL AND MODELING OF PHYSICAL PROCESSES

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Oil emulsions are a component of oil raw material extraction and refining processes. The presence of dispersed water, mineral salts and solid phase particles, as well as asphalt-resin and paraffin substances dissolved in it, significantly changes the physical properties and structure of the oil emulsion. As a rule, oil emulsion separation is carried out in two stages. First, large drops are quickly deposited (surfaced) and undergo coalescence. Very small drops remain in the form of "fog" and are deposited for a long time by forming an intermediate layer in the apparatus. The rate of stratification in most cases determines the productivity of the extraction process.

The emulsion formed when oil is mixed with reservoir water should be considered as a mechanical mixture of two insoluble liquids (oil and water). At this time, one of the liquids is distributed in the form of drops of different sizes in the volume of the other.

Due to the presence of water in the oil, the increase in the volume and viscosity of the transported liquid, the transportation cost becomes more expensive. Water solutions containing mineral salts cause wear and tear of oil-transporting devices and oil-refining equipment. The presence of even 0.1% water in the oil causes intense foaming of the oil in the rectification cylinders of oil refineries, which causes a violation of the processing regime and, in addition, contamination of condensation devices.

Keywords: *oil drops, coalescence, destruction of drops, turbulent diffusion coefficient, turbulent flow*

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INTRODUCTION

Oil freed from gases are kept in special tanks for a certain period of time to separate it from mechanical mixtures [1-3]. Under these conditions, those mixtures sink to the bottom of the tanks and are separated from the oil. At this time, most of the water in the crude oil gradually separates by itself. However, oil often contains a certain amount of small microscopic water droplets, which are difficult to separate. When water and oil are in the form of an emulsion, they are relatively difficult to separate. Water remains suspended inside the oil in the form of small droplets. In this work, we have analyzed the effect of the turbulent diffusion coefficient of these droplets on oil deposition [4-6].

In practice, centrifugal forces are used to intensify phase separation, and various structures and fillings placed in precipitators are applied. In some cases, the electric field of the high-voltage direct current created inside the device also enables stratification [7]. The structure of the pulsating interlayer is determined by the density and size of the droplets, which obey the dynamic equilibrium conditions and ensure the continuity of precipitation, as well as the velocity of the main flow [8-11].

According to its structure, the intermediate layer formed in precipitation devices is compressed, expanded, stratified according to its size and height, densified, moved, etc. It is analogous to the "hot layer" of drops with its properties. Let us assume the following conditions to describe the motion of the droplets [12]:

a) drops are only spherical and this is determined by the small value of the Weber number: $W_e \ll 1$; $W_e=\rho_m U^2 a/\sigma_m$;

b) the washing of drops in the intermediate layer has a viscous character and is obtained from the condition of a small value of the Reynolds number:

$$Re_d = \frac{\Delta U a}{\nu_m} < 1, \left(\Delta U = \left|U - V_p\right|\right), \quad (1)$$

Here U - flow rate, V_p - velocity of drops in turbulent flow, a- the size of the drop, ν_m - kinematic viscosity of the medium.

c) There are no electrostatic, thermo- and diffusiophoretic and non-hydrodynamic effects in the flow. Droplet transfer by efficient diffusion and deposition is an exception. In this case, deposition effects for Stokes drops $\tau_r = \frac{1}{18}\frac{\rho_d a^2}{\eta_m}$, for large size drops $\tau_r = \frac{\rho_d a^2}{18\eta_c\left(1+Re_d{}^{2/3}/6\right)}$ is expressed. Here, ρ_d is the density of the drops, η_m is the dynamic viscosity of the medium, τ_r is the relaxation time of the drop, and a is the size of the drop[13, 14].

It should be noted that the turbulent diffusion coefficient plays an important role in the processes of droplet coalescence and destruction in isotropic turbulent flow, and its value is determined according to (2.) for the range of different values of the turbulent pulsation scale λ.

$$\lambda>\lambda_0, \; D_T = \alpha_0(\varepsilon_R\lambda)^{1/3}\lambda \; (2)$$

$$\lambda<\lambda_0, \; D_T = \alpha_0(\varepsilon_R\lambda)^{1/2}\lambda^2$$

MATERIAL AND METHODS

The movement of suspended particles in a turbulent flow of a liquid differs in complexity and intensity in all directions compared to laminar flows. In dispersed systems, small-sized particles will be completely involved in turbulent pulsations and will move along complex trajectories in fluids. With the increase in the size of the particles, they will lag behind the fluid movement, and in this case, the turbulent pulsation of the particles will decrease. It should be noted that the turbulent diffusion coefficient for large particles in a turbulent flow will be determined not only by the flow speed, but also by the precipitation speed of the particles. The turbulent diffusion coefficient of particles during the turbulent flow of dispersed systems is calculated as follows [15].

$D_{TR} \approx \mu^2 D_T$, where D_{TR} is the turbulent diffusion coefficient of particles, D_T is the turbulent diffusion coefficient of the liquid, μ^2 is the degree of attraction of particles by the pulsating medium, which depends on the size of the particles. In a broader sense, empirical formulas were proposed for determining the diffusion coefficients of particles depending on the dynamic speed of the flow, settling speed, etc.

$$\mu^2 = \frac{1}{1+\omega^2\tau_R^2} \; (3)$$

Here ω- turbulent pulsation frequency, τ_R- is the relaxation time of the particles. The value of μ varies between $0 \le \mu \le 1$. For small-sized particles, the value of μ is zero, and for large-sized particles, μ approaches unity.

For the degree of attraction of finely dispersed particles

$$\mu = \frac{1}{\left[1+\left(\frac{\rho_d a^2 \omega}{18\eta_c}\right)\right]^{1/2}} \quad (4)$$

RESULTS AND DISCUSSION

To estimate the turbulent diffusion coefficient in turbulent flow, a number of empirical dependences for vertical and horizontal channels can be obtained using various experimental studies, e.g.

$$D_{TR}/D_T = \mu^2 = 0{,}023\Psi\,(U_D)\left(\frac{U_D^3}{V_S}\right)^{1/4} \quad (5)$$

$$Re_d = \frac{V_S a}{\nu} \leq 5$$

Here V_S - droplet settling velocity, $\Psi\,(U_D) = 1 + 0{,}786 \cdot 10^{-6} U_D^4$, $U_D = \frac{0{,}2U_s}{Re^{1/8}}$ - dynamic flow rate, U_s - is the mean velocity of the turbulent flow. If $Re_d > 5$, then we get the following expression

$$D_{TR}/D_T = \mu^2 = 0{,}054\left(\frac{U_D^3}{V_S}\right)^{1/4} \quad (6)$$

From these equations, it can be seen that the turbulent diffusion coefficient of particles when flowing through vertical channels is directly proportional to the dynamic speed of the flow and inversely proportional to the precipitation speed of the particles. The following table 1 shows the comparison of the calculated and experimental values of the turbulent diffusion coefficient of particles.

Table 1.

Turbulent diffusion coefficient of particles during liquid flow in a vertical channel [16]

U_s, m/sec	U_d, sm/sec	a, mkm	V_S , sm/sec	D_T, sm^2/ sec	D_{TR}, sm^2/ sec	D_{TR}/D_T	μ^2	Re_d
1,55	9,0	80	17	6,3	0,370	0,059	0,059	< 5
3,44	18,0	80	17	12,6	1,35	0,107	0,107	< 5
7,60	36,0	80	17	25,2	10,1	0,400	0,386	< 5
1,55	9,0	150	50	6,3	0,26	0,042	0,045	$= 5$
3,44	18,0	150	50	12,6	1,05	0,083	0,082	$= 5$
7,60	36,0	150	50	25,2	6,20	0,246	0,295	$= 5$
1,55	9,0	200	69	6,3	0,20	0,032	0,032	> 5
3,44	18,0	200	69	12,6	0,44	0,035	0,038	> 5
7,60	36,0	200	69	25,2	1,22	0,048	0,046	> 5

For horizontal ducts, the following corrections for the turbulent diffusion coefficient were obtained using experimental evidence of the movement of solid particles and oil droplets in the air flow.

$$\frac{D_{TR}}{D_T} = \mu^2 = 0{,}24\left(\frac{V_s}{U_D^8}\right)^{1/4}, Re_d \geq 2{,}5 \quad (7)$$

$$\frac{D_{TR}}{D_T} = \mu^2 = k(V_S)\left(\frac{V_S}{U_D}\right)^{1/4}, Re_d < 2 \quad (8.)$$

Here $k(V_S)$ is a parameter whose value is $k(V_S) = \frac{2{,}16}{V_S^{1/8}}$. As can be seen from the expression, in contrast to vertical channels, the turbulent diffusion coefficient in horizontal channels is directly proportional to the settling velocity and inversely proportional to the dynamic velocity. Thus, the diffusion coefficient for both horizontal and vertical channels depends on the settling velocity, and this dependence increases as the particle size increases. The dependence of the turbulent diffusion coefficient of particles on the precipitation rate shows the influence of the particle mass on the diffusion coefficient. If the increase in the mass of particles in vertical channels mainly causes the particle to lag behind the speed of the main medium, then the increase in the mass of particles in horizontal channels directly affects their diffusion coefficient. The following table 3 show the comparison of the calculation and experimental values of the turbulent diffusion coefficient (Figure 1) in horizontal channels.

Table 2.

Experimental evidence and calculated values of the turbulent diffusion coefficient of solid particles in air (a=100-200 mm, Red>2.5) in a square channel with a cross section of 76x76mm [17]

U_S, m/san	U_D, sm/san	V_S, sm/san	D_T, sm^2/san	D_{TR}, sm^2/san	D_{TR}/D_T	μ^2
7,6	40,7	41	23,5	0,9	0,038	0,038
16,7	81,0	41	63,7	1,5	0,024	0,023
25,9	119,0	41	103,0	1,8	0,017	0,017
7,6	40,7	104	23,5	1,36	0,056	0,048

Based on the indicators shown in Table 2, the dependence between the calculated values of the turbulent diffusion coefficient and the experimental indicators was obtained:

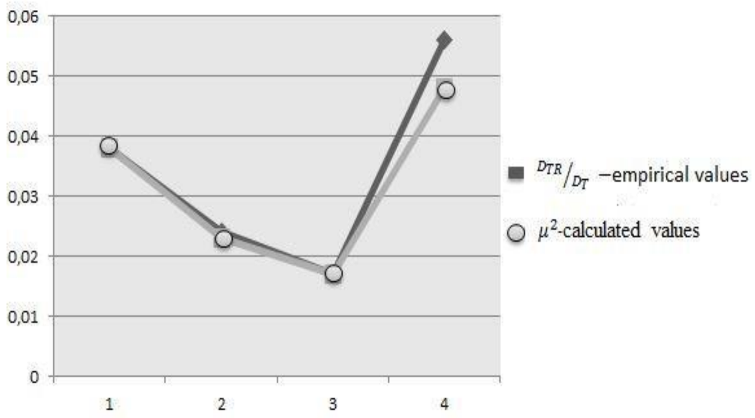

Fig. 1. Calculated and experimental values of the turbulent diffusion coefficient

Table 3.

Experimental evidence and calculated values of the turbulent diffusion coefficient for oil drops (a=45µm, Red>2.5) in a horizontal pipe (D=152mm, Vs= 3.5cm/sec) [18]

U_s, m/sec	U_D, sm/sec	D_T, sm^2/sec	D_{TR}, sm^2/sec	D_{TR}/D_T	μ^2
58	241	358	229	0,640	0,641
87,2	344	511	298	0,583	0,585
122	461	686	386	0,563	0,545
148	546	812	460	0,566	0,522

Despite the fact that dispersed systems (emulsions, suspensions) are characterized by polydispersity of particles, the sizes of which vary mainly in the wide range of 1-200 µm, there are larger colloidal particles in the flow [19]. In general, the state of dispersed flow, which determines the structure of the dispersion spectrum, its aggregative resistance to size change and precipitation resistance to precipitation, is characterized by the minimum and maximum particle sizes. It should be noted that the processes occurring in dispersed systems are accompanied not only by collisions and the enlargement of colliding drops, but also by the opposite phenomena - fragmentation, which is the division of particles in a mixed effect or the ability to maintain a continuous state, as well as spontaneously or their external accompanied by disintegration under any impact on the surface. Thus, in dispersed systems, there is such a size of the drop, amax, that the drop is unstable, deformed and quickly disintegrated at sizes higher than this; and the minimum amino size indicates the lowest droplet durability limit, or rather, drops that have reached this size under certain flow conditions cannot be crushed any more. The maximum size of the particles characterizes the discontinuity of the droplets, and this dispersed environment depends on the hydrodynamic conditions of the flow, so that the turbulent flow is accompanied by a tendency to break up and break up individual drops under certain conditions.

CONCLUSION

Expressions for the turbulent diffusion coefficient are given using experimental studies to explain the movement of solid particles and oil droplets in vertical and horizontal channels. As can be seen from the expressions, in contrast to vertical channels, the turbulent diffusion coefficient in horizontal channels is directly proportional to the settling velocity and inversely proportional to the dynamic velocity. Thus, the diffusion coefficient for both horizontal and vertical channels depends on the settling velocity, and this dependence increases as the particle size increases. The dependence of the turbulent diffusion coefficient of particles on the precipitation rate shows the influence of the particle mass on the diffusion coefficient. If the increase in the mass of particles in vertical channels mainly causes the particle to lag behind the speed of the main medium, then the increase in the mass of particles in horizontal channels directly affects their diffusion coefficient.

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NEFTDƏ SU DAMLALARININ ÇÖKMƏ SÜRƏTİNİN TURBULENT DİFFUZİYA ƏMSALINDAN ASILILIĞI VƏ FİZİKİ PROSESLƏRİN MODELLƏŞDİRİLMƏSİ

V.İ. Kərimli, F.R. Şıxıyeva

Neft emulsiyaları neft xammalının çıxarılması və emalı proseslərinin tərkib hissəsidir. Tərkibində dispers su, mineral duzlar və bərk faza hissəcikləri, eləcə də orada həll olunan asfalt-qətranlı və parafin maddələrinin olması, neft emulsiyasının fiziki xassələrini və strukturunu əhəmiyyətli dərəcədə dəyişir. Neft emulsiyanın ayrılması bir qayda olaraq iki mərhələdə həyata keçirilir. Əvvəlcə iri damlalar tez çökdürülür (üzə çıxır) və koalessensiyaya məruz qalır. Çox kiçik damlalar “duman” şəklində qalır və aparatda aralıq təbəqə əmələ gətirməklə uzun müddət çökdürülür. Təbəqələnmə sürəti əksər hallarda ekstraksiya prosesinin məhsuldarlığını müəyyən edir.

Neft lay suları ilə qarışığını çıxaran zaman yaranan emulsiya iki bir-birində həll olmayan mayenin (neft və su) mexaniki qarışığı kimi baxılmalıdır. Bu zaman mayelərdən biri digərinin digərinin həcmində müxtəlif ölçülü damlalar şəklində paylanılır.

Neftin tərkibində suyun olması, nəql olunan mayenin həcminin və özlülüyünün artması səbəbindən nəql posesi bahalaşır. Tərkibində mineral duzların olduğu su məhlulları, nefti nəql edən qurğların və neft emalı avadanlıqlarının aşınmasına, tez sırada çıxmaına səbəb olur. Neftin tərkibində hətta 0,1 % suyun olması, neft emalı zavodlarının rektifikasiya kalonlarında, neftin intensiv köpüklənməsinə səbəb olur ki, bu da emal rejiminin pozulmasına və əlavə olaraq kondensasiya cihazlarının çirklənməsinə səbəb olur.

Açar sözlər: *neft damlaları, koalessensiya, damlaların parçalanması, turbulent diffuziya əmsalı, turbulent axın*

ЗАВИСИМОСТЬ СКОРОСТИ ОСЕДАНИЯ КАПЕЛЬ ВОДЫ ОТ КОЭФФИЦИЕНТА ТУРБУЛЕНТНОЙ ДИФФУЗИИ В НЕФТИ И МОДЕЛИРОВАНИЕ ФИЗИЧЕСКИХ ПРОЦЕССОВ

В.И. Керимли, Ф.Р. Шихиева

Нефтяные эмульсии являются составной частью процессов добычи и переработки нефтяного сырья. Наличие диспергированной воды, минеральных солей и частиц твердой фазы, а также растворенных в ней асфальтосмолистых и парафиновых веществ существенно изменяет физические свойства и структуру нефтяной эмульсии. Как правило, разделение масляной эмульсии проводят в две стадии. Во-первых, крупные капли быстро осаждаются (всплывают) и подвергаются слиянию. Очень мелкие капли остаются в виде «тумана» и длительное время оседают, образуя в аппарате промежуточный слой. Скорость расслоения в большинстве случаев определяет производительность экстракционного процесса.

Эмульсию, образующуюся при смешении нефти с пластовой водой, следует рассматривать как механическую смесь двух нерастворимых жидкостей (нефти и воды). В это время одна из жидкостей распределяется в виде капель разного размера в объеме другой.

Из-за наличия воды в масле, увеличения объема и вязкости транспортируемой жидкости стоимость транспортировки удорожается. Водные растворы, содержащие минеральные соли, вызывают износ нефтетранспортирующих устройств и нефтеперерабаты-вающего оборудования. Наличие даже 0,1 % воды в масле вызывает интенсивное вспенивание масла в ректификационных цилиндрах нефтеперерабатывающих заводов, что вызывает нарушение режима обработки и, кроме того, загрязнение конденсационных устройств.

Ключевые слова: *капли нефти, коалесценция, разрушение капель, коэффициент турбулентной диффузии, турбулентное течение*