STUDY OF WATER-OIL EMULSION AND COAL DUST-WATER SUSPENSION STABILITY

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INTRODUCTION

One of the main directions of research in preparation for burning fuel, refer to decrease their pollutant potential and the development of alternative fuel production technologies.

In this direction in industrially developed countries has been tested with positive results a new type of artificial fuel - water-oil emulsion (WOE) or coal dust-water suspension (CDWS), prepared by emulsification of fuel oil, coal dust that mixed with water.

Of features of WOE, that CDWS as a artificial fuel interested, primarily, physical properties that affects storage, transportation and spraying it (the degree of dispersion, viscosity, stability, density and freezing temperature) and secondly, the energy characteristics, such as mass heat, thermal conductivity, heat of combustion, flammability and ignition temperatures.

In the present study is presented WOE or CDWS stability.

1. GENERAL CHARACTERIZATION OF STABILITY

Stability is an important feature for storage and transport of WOE and CDWS.

As a parameter characterizing emulsion stability is adopted the time when the water concentration in the top layer of WOE or CDWS will be reduced twice.

In accordance with Stokes's formula [1], sedimentation velocity of a drop of *a* radius in the continuous phase,

$$v_s = \frac{2}{9} \cdot \frac{\rho_2 - \rho_1}{\rho_1 \cdot \nu_1} \cdot g \cdot a^2 \ , \qquad (1)$$

where, ρ_1 and ρ_2 is the density of continuous phase (the fuel) that the dispersed phase (water), $[kg/m^3]$; ν_1 - kinematic coefficient of viscosity of continuous phase, $[m^2/s]$; $g = 9{,}81 m/s^2$ - the gravitational acceleration.

Formula (1) shows that the sedimentation of water droplets of WOE or CDWS and the stabilization of the aqueous phase of fuel are influenced by three main factors: the difference between densities of water and fuel oil, $\rho_2 - \rho_1$, the viscosity of heavy oil, ν_1 and water droplets size in WOE or CDWS, *a*. Because water and droplet densities are practically equal ($\rho_2 \approx \rho_1$) and density of fuel oil with high viscosity may even exceed the density of water, practically the first factor will not influence the sedimentation of water droplets in WOE or CDWS, but to a greater extent will promote emulsion stability.

Variation of viscosity is limited by storage temperatures and techno-economic and security considerations. Therefore, practically the only factor that can influence the sedimentation and coalescence processes of droplets is their size, *a* which depends on the technology of preparation of WOE or CDWS.

2. WOE OR CDWS PARTICLE SEDIMENTATION AT THE FLOW THROUGH A HORIZONTAL PIPE

We will consider the sedimentation of particles dispersed phase of a monodisperse emulsions or suspensions flowing with the speed $\vec{u}$ through a horizontal pipe (Fig. 1, a) with a rectangular section with height H and width b (Fig. 1, b) or with circular section by diameter D (Fig. 1, c). To determine the effectiveness of the sedimentation process will first determine how varying the concentration of particles in the sedimentation process [1].

Given that the WOE or CDWS are incompressible, $div\, \vec{u} = 0$ therefore

$$\frac{Dn}{Dt} = -n \cdot B \cdot div\, \vec{F} \ , \qquad (2)$$

where $\frac{Dn}{Dt}$ is the total derivative of the concentration of particles along their trajectories, B is the particle mobility ($B = 1/6\pi\mu_2 a$), $[s/kg]$; $\vec{F}$ - the external force under the action of that sedimentation occurs, [N].

Formula (2) shows that in a solenoid force field $\frac{Dn}{Dt} = 0$ and particle concentration along the trajectory remains constant.

Effectiveness or efficiency of the sedimentation process of particles is calculated as:

$$\eta_s = \frac{n_0 v_s S_s}{n_0 \vec{u} S_c} = \frac{v_s S_s}{\vec{u} S_c}, \qquad (3)$$

where S_s and S_c are respectively the surface areas of sedimentation and cross-section of the pipeline, $[m^2]$.

For pipe with rectangular section, equation (3) is explicitly written as:

$$\eta_{s1} = \frac{n_0 \int_{-b/2}^{b/2} dx \int_0^L v_s dz}{n_0 \int_{-b/2}^{b/2} dx \int_0^H u_s dy}, \qquad (4)$$

If a pipe with circular cross section,

$$\eta_{s2} = \frac{n_0}{n_0 \pi \int_0^{D/2} u \cdot r \cdot dr}, \qquad (5)$$

To determine the dependence of the initial coordinates (x_0 and y_0, Figure 1, *b*; r_0 and x_0, Figure 1, *c*) of a particle P arbitrarily taken in the inlet section of pipe by the particle distance L along the z-axis travels to the sedimentation pipe wall (Figure 1, *a*) we'll write the equations of motion of the particle assuming neinertial motion of it:

$$\frac{dz}{dt} = u \quad \text{and} \quad \frac{dy}{dt} = v_s, \qquad (6)$$

and the equation of connection between Cartesian coordinates x_0 and y_0 cylindrical r_0 coordinates:

$$r_0^2 = x_0^2 + y_0^2, \qquad (7)$$

We obtain the correlation between yield η_s and length of sedimentation process of sedimentation, *L*.

$$\eta_{s1} = \frac{L_1 v_s}{H \vec{u}} = \gamma_1, \qquad (8)$$

Thus, if a pipe with rectangular section,

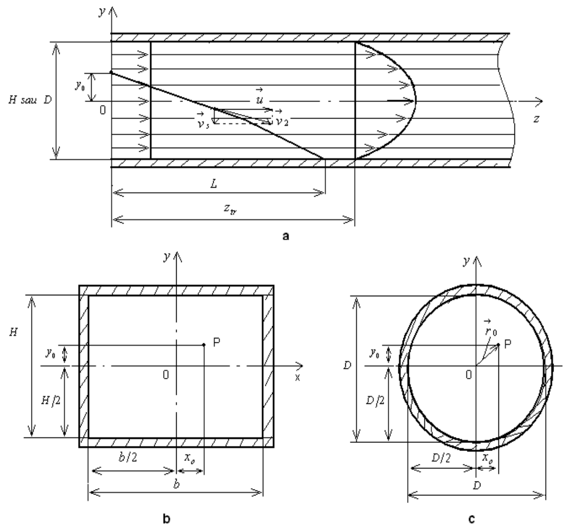

Figure 1. Scheme for calculating the sedimentation process of particles dispersed phase of WOE or CDWS flowing through a horizontal pipe: ______ *power lines;* -------

and for pipe with circular cross section the dimensionless parameter has the form:

$$\gamma_2 = \frac{3}{4} \cdot \frac{L_2 v_2}{D \vec{u}}, \qquad (9)$$

Theoretical dependences $\eta_{s1}(\gamma_1)$ and $\eta_{s2}(\gamma_2)$ are shown in Figure 2.

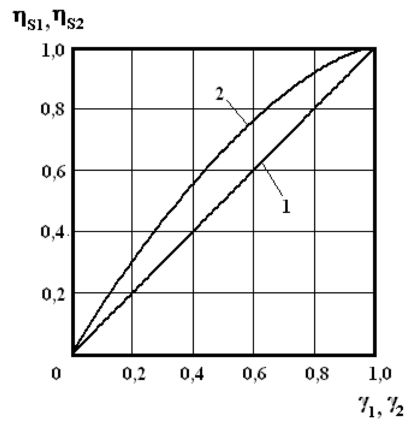

Figure 2. Theoretical dependencies $\eta_{s1}(\gamma_1)$ and $\eta_{s2}(\gamma_2)$.

3. METHODOLOGY FOR DETERMINING THE WOE OR CDWS STABILITY

With the use of water-oil emulsion is not possible wide variation of γ_1 and γ_2 parameters in equations (8) and (9) in order to obtain sufficient experimental data to validate these relationships.

For this reason it was chosen a model emulsion - droplets water in transformer oil that permits this even at room temperature.

Layout process to study sedimentation of water droplets transformer oil-water emulsion is shown in Figure 3.

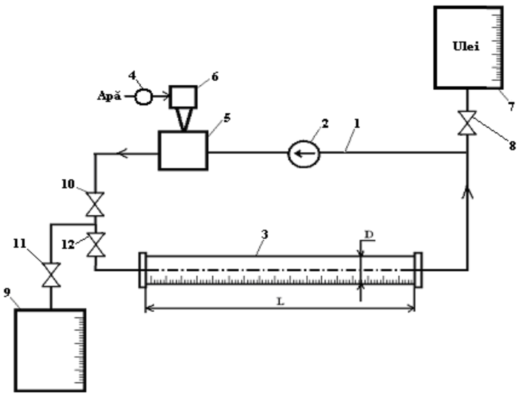

Figure 3. Experimental layout for the study of the sedimentation process of water droplets in the emulsion in laminar and turbulent flow: *1 - closed contour, 2 - pump, 3 - graded pipeline, 4 – water meter; 5 – emulsifying chamber, 6 - water injector, 7 - transformer oil tank, 8, 11, 12-valve, 9 - beaker, 10 - flow control valve*

The installation is carried out as a closed outline1, which, with a pump 2, is circulated studied emulsion. The process of sedimentation of water particles occurs in graduated horizontal pipe 3, by circular or rectangular cross-section diameter D (height H) and length L. Emulsion formation occurs in the emulsifying chamber 5, where, with the injector 6, in the oil transformer taken from tank7, sprayed water droplets in a wide range of $1\ \mu m \le a \le 1\ mm$ sizes. The flow regime of emulsion through the pipe 3 is fixed by adjusting valve 10.

Emulsion flow adjusted with valve 10, to the fully open valve 12 and the valve closed position 11, is measured using beaker 9. For this purpose, the valve 12 closes and opens valve 11. Using a stopwatch we determine the period of time τ to fill a emulsion volume V measured with beaker 9. Thus the flow of emulsion will be determined by the formula:

$$\dot{V} = \frac{V}{\tau}\ ,\ \left[\frac{m^3}{s}\right]. \qquad (10)$$

At the closing of the valve 11 and opening valve 12, speed emulsion through graded pipeline 3 is calculated by the formula:

$$u = \frac{4 \cdot \dot{V}}{\pi \cdot D^2}\ ,\ \left[\frac{m}{s}\right], \qquad (11)$$

if circular pipeline, or

$$u = \frac{\dot{V}}{b \cdot H}\ ,\ \left[\frac{m}{s}\right], \qquad (12)$$

for pipe with a rectangular section, where b is the width cross section of the pipeline.

Measurement methodology is as follows.

Contour 1, by opening the valve 8 (valves 10 and 12 open, valve 11 is closed), is filled with transformer oil in the tank 7. On the scale of the tank 7 we measure the volume of oil V_u wich filled contour 1. Valve 8 closes and oil pump 2 is put into operation. The air is discharged from the system through a special connector (not shown in Figure 3). After removing air, with injector 6 water is sprayed in the oil in the emulsifying chamber. The volume of sprayed water V_{H_2O} registers with water meter 4. It is determined by the volumic fraction of water α_{VW} in the emulsion to provide the desired value α_{VW}:

$$V_{H_2O} = \frac{\alpha_{VW}}{1-\alpha_{VW}} V_u \qquad (13)$$

The range of values of the fraction α_{VW} is $0 \le \alpha_{VW} \le 0{,}2$, that it starts from the minimum value, for example $\alpha_{VW} = 0{,}05$.

With the valve 10 is set velocity value u of the emulsion through the graded pipeline 3, which is calculated by formula (11).

After the emulsion circulation within 1-5 min using a magnifying glass to determine the diameters of water droplets $2a_i$ sedimented at the bottom of the wall pipe 3 and the distance L_i from that drop to the inlet section of the emulsion in the pipeline 3. The formula (1) is calculated sedimentation rate v_{si} of each drop of water.

Thus, sedimentation dimensionless parameter is calculated by the formula:

$$\gamma_{1i} = \frac{L_i \cdot v_{si}}{H \cdot u}, \tag{14}$$

for rectangular section pipe and

$$\gamma_{2i} = \frac{3 \cdot L_i \cdot v_{si}}{4 \cdot D \cdot u}, \tag{15}$$

for circular pipeline.

Sedimentation process yield is calculated as:

$$\eta_S = \frac{v_S \cdot S_S}{u \cdot S_C} \tag{16}$$

where S_S is the surface area of wall pipe 3, covered with drops, [m^2] ; S_C - cross-sectional area of the pipe ($S_C = \pi D^2/4$ - for circular pipeline and $S_C = H \cdot b$ - for rectangular section pipe).

In this way, varying speed emulsion u and concentration of droplets in the emulsion which depends on α_{VW}, are determined the experimental dependences $\eta_{S1}(\gamma_1)$ and $\eta_{S2}(\gamma_2)$ [2].

At α_{VW} variation starts from the minimum and calculating additions of water is determined the increasing values of α_{VW}. Each time, after the determination of emulsion flow through beaker 9 by fitting to eliminate the air quantity of emulsion is placed in a closed contour circuit.

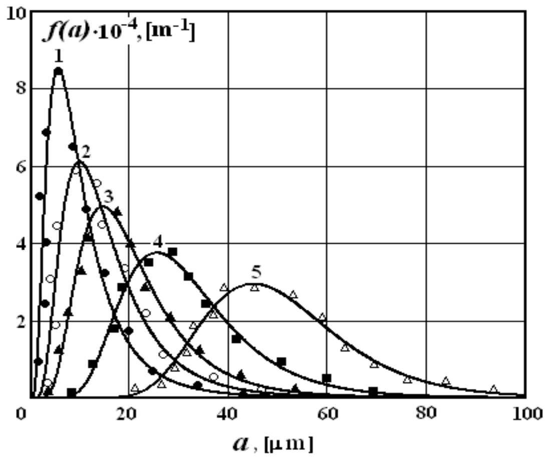

Figure 4. Distribution functions $f(a)$ of water droplets from WOE on ray:
$\bar{a}$, [μm]: 1- 11; 2- 16; 3- 21; 4- 32; 5- 51.
σ_a^2,[m^2]: 1- 8,123· 10^{-6}; 2- 9,719· 10^{-6}; 3- 1,092· 10^{-5}; 4- 1,284· 10^{-5}; 5- 1,506· 10^{-5}

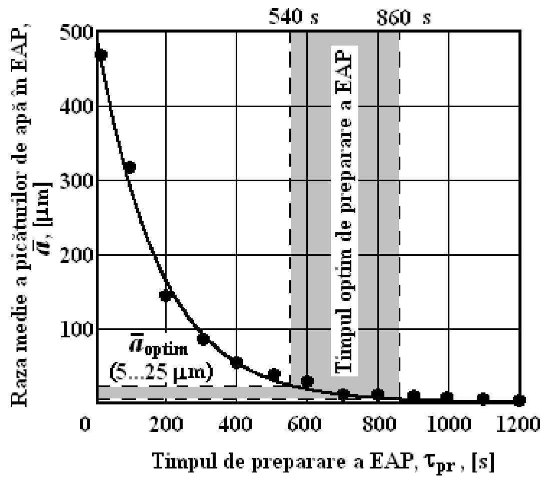

Figure 5. The dependence of the average radius of water droplets in WOE, $\bar{a}$ on WOE.

4. EXPERIMENTAL RESULTS

WOE stability largely depends on the size distribution of water droplets. Distribution functions $f(a)$ of water droplets from the WOE on rays are shown in Figure 4. The analysis of these functions results in two aspects:

1) distribution functions $f(a)$ are log-normal type;

2) With increasing time of preparation of the emulsion, the average radius of water droplets moves in the small size area.

Figures 5 and 6 are presented the dependences of the distributions of statistical parameters $f(a)$, average radius, $\bar{a}$ and dispersion, σ_a^2 of preparation time τ_{pr}.

With increasing time of preparation of emulsion, τ_{pr} average radius, $\bar{a}$ decreases, asymptotically approaching its minimum value. And dispersion distribution σ_a^2 is reduced with increasing τ_{pr}.

Therefore, in the cavitational process of mixing water with fuel oil occurs reducing the size of water particles that leads to increased WOE stability.

Dependences of yield sedimentation process of WOE water droplets on dimensionless parameters (4) and (5) for a circular and rectangular pipeline section are presented in Figures 7 and 8. The solid lines are drawn theoretical graphs calculated with relations (4) and (5). There is a satisfactory agreement with the experimental and theoretical data, which validate the process model of sedimentation of water droplets of an emulsion flowing through a horizontal pipe, described in paragraph 3.

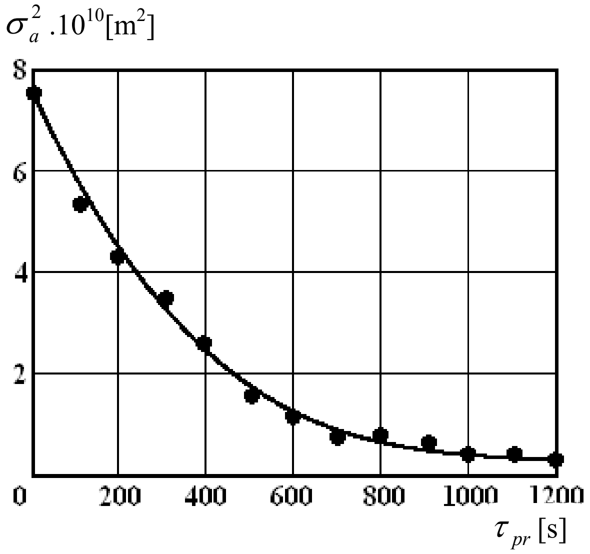

Figure 6. Dependence of distribution dispersion of water droplets in WOE, σ_a^2 on WOE preparation time, τ_{pr}

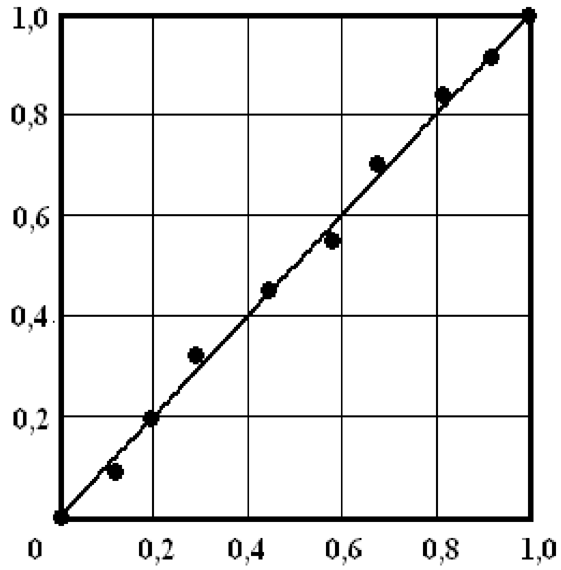

Figure 7. Dependence of sedimentation efficiency η_{S1} of water droplets in WOE on a dimensionless parameter γ_1 for rectangular section pipe.

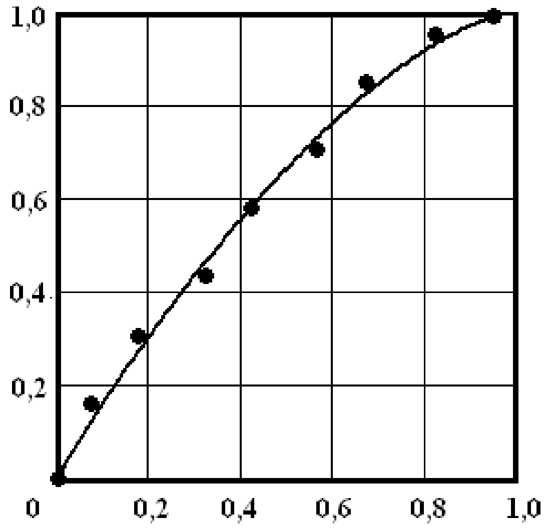

Figure 8. Dependence of sedimentation efficiency η_{S2} of water droplets in WOE on dimensionless parameter γ_2 for circular section pipe.

5. CONCLUSIONS

1. Were presented some general features about the stability of emulsions and modeling particle sedimentation process at the flow of WOE or CDWS through a horizontal pipe.
2. A plant was presented and the methodology for determining the stability of WOE or CDWS.
3. The experimental results validates the theoretical equations and particle sedimentation model along the pipeline.

References

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