PREPARATION OF COAL-WATER SLURRY USING A HIGH-SPEED MIXER-DISPERSER

Aleksandrs Polyakovs
Corvus Company Ltd.
e-mail: poluakov@corvus.lv
Viktors Mironovs
Riga Technical University, Faculty of Civil Engineering,
Laboratory of Powder Materials.
e-mail: viktors.mironovs@gmail.com
Aleksandrs Korjakins
Riga Technical University, Faculty of Civil Engineering,
Chair of Building materials and Products
e-mail: aleks@latnet.lv
Andrej Shishkin
Riga Technical University, Faculty of Civil Engineering
e-mail: andrej.shishkin@gmail.com
Janis Baronins
Riga Technical University, Faculty of Civil Engineering
e-mail: jbaronins@gmail.com

ABSTRACT

The present article describes a method of preparation coal-water slurry using a high speed mixer-disperser (HSMD).The method is based on the multiple impacts in a liquid media by dispersing elements in the appearance of cavitation effects. Considering the design features of a high-speed mixer-disperser it was found that the processing of coal-water slurry increases their stability due to particle size deceasing.

Key words: mixer-disperser, cavitation, water-coal slurry, water-coal fuel.

INTRODUCTION

Water-coal slurry (WCS) technology was developed during the worldwide oil crisis of the 1970's to produce a novel and clean fluid fuel as a substitute for petroleum. The slurry is prepared as a mixture of 60–70% fine coal, 29–39% water, and about 1% additives (dispersants involved) determined specifically for each different type of coal (Yun et al., 2011),(Zhu et al., 2012). Creation of fine WCS during mixing is difficult because of bad distribution of coal particles in water. To solve this problem, special surfactants (Zhou et al., 2007),(Zhou et al., 2012), various mixers and disperser are used, for example, the propeller mixers, rotary pulsation devices, etc. (Sidenko, 1977). In works (Knapp et al., 1970), (Polyakov et al., 2008) it is found that with increasing the speed disperser elements can have simultaneously occurring effects as high-speed shock wave, ultrasonic vibration, cavitation process and as a result hydraulic impacts in a liquid medium.

The particular interest is in the cavitation process - generation in fluid cavitation bubbles (cavities) by local reduction of pressure in the fluid. In the initial phase of fluid cavitation small size bubbles are allocated. When cavities get to the area of high pressure, the steam bubbles collapse. Thus, there is a hydraulic shock (Knapp et al., 1970). Destruction of cavitation bubbles generates shock waves that destroy firm particles and mix them, forming thus a stable suspension.

Kinetic stability in dispersed systems, ability of a dispersed system to maintain an even distribution of particles throughout the entire volume of the dispersed phase, are characterized by the Stokes' law. The Stokes' law is derived by solving the Stokes' flow limit for small Reynold numbers of the Navier–Stokes' equations number (1) (Batchelor, 1967).

$$F_d = 6\pi\mu R v_s \qquad (1)$$

where:

F_d – frictional force – known as Stokes' drag – acting on the interface between the fluid and the particle (N),

μ – dynamic viscosity (N s/m^2),

R – radius of the spherical object (m)

v_s – particle settling velocity (m/s).

If the particles are falling in the viscous fluid by their own weight due to gravity, then a terminal velocity, also known as the settling velocity, is reached when this frictional force combined with the buoyant force exactly balances the gravitational force. The resulting settling velocity (or terminal velocity) is given by (Venkatalaxmi et al., 2004) equation number (2):

$$v_s = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} gR^2 \qquad (2)$$

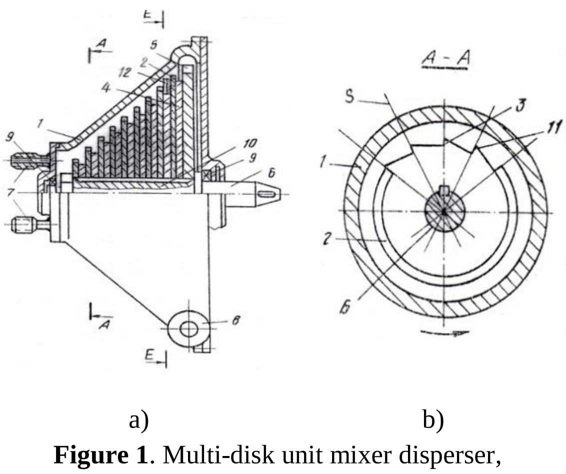
where:
v_s – particle settling velocity (m/s) (vertically downwards if $\rho_p > \rho_f$, upwards if $\rho_p < \rho_f$),
g – gravitational acceleration (m/s^2),
ρ_p – mass density of the particles (kg/m^3), and
ρ_f – density of the fluid (kg/m^3).

Based on equation number (2), the sedimentation rate is directly proportional to the square of the radius of the particles, and the difference in density between the solid and the liquid medium, and inversely proportional to the viscosity of media. Therefore, reducing the rate of sedimentation the sedimentation stability is increasing, the following methods can be used:
- To reduce the initial size of the particles;
- To pick up the dispersive environment with a density close to the substance density.

MATERIALS AND METHODS

Features of preparation of the high-speed mixer-disperser

For experimental studies we have proposed the construction of a high-speed multi-disc mixer-disperser (Polykov et al., 2008), (Polykov et al., 2007), which is presented in Fig 1. It comprises of the body 1, working disks 2 with teeth 3 and the intermediate washers 4, impeller 5, shaft 6. The shaft, working disks, washers and the impeller make up the rotor in the form of a truncated cone. The body 1 has two inlet mouths 7 and one outlet mouth 8. The rotor shaft rotates in bearings 9. The disks form a conical rotor 10. The working surface 11 of the teeth 3 is directed towards rotation and lies in the plane S, passing through the axis of a disk 2.



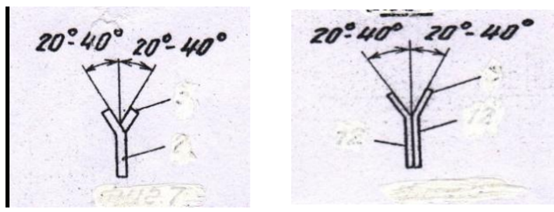
a) b)

Figure 1. Multi-disk unit mixer disperser,
a) longitudinal sections; b) transverse sections

With the motor the rotor shaft rotates at 9000 rpm. The travel speed of the work items is 70-80 m/s. In the zone of influence of the work item in the liquid medium at the same time there are several phenomena: impact, vibration and cavitation. The device operates as follows. Through connections to the mixer 7-dispersant serves subjected to mixing environment passing through the mixer mixed environments, including large broken up into small micron size.

With the motor the rotor shaft rotates at 3000 rpm. Thus, in the zone of influence of the working elements in the liquid medium there are some phenomena at the same time: impact, transonic fluctuations and cavitation. The device works as follows: through the inlet mouth 7 in the mixer environments are subject to mixture movement, passing through the mixer of the environment mix up, large inclusions are breaking in small to the micron size.

In the main scheme the disks are executed flat as it is presented in Fig.1. It is rather simple at production. However, overall performance of a mixer can be raised if the teeth of a disk are unbent from the plane of flange on 20° - 40° (Fig. 2). And each subsequent tooth should be unbent aside opposite the previous (Fig. 2a). The disks can be also executed from two plates, and their teeth are unbent to the opposite sides (Fig. 2b).



a) b)

Figure 2. Design of disperser disk with curved teeth

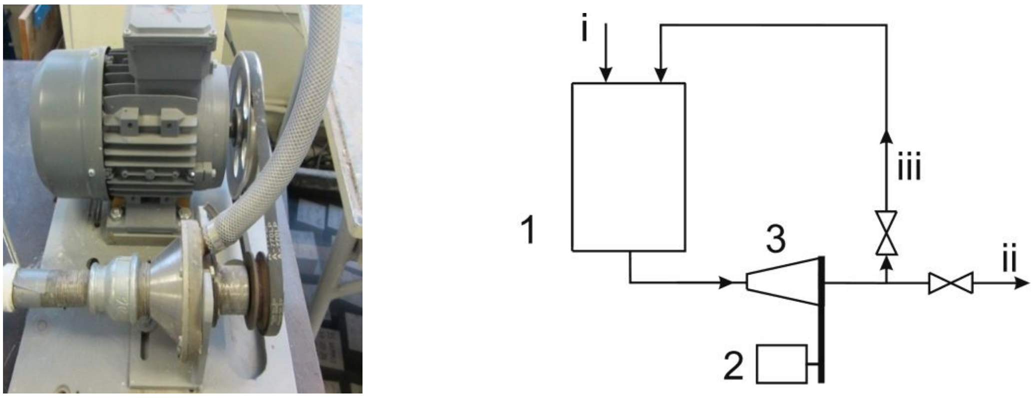
Experimental: water-coal slurry

It is known that WCS is used as fuel. Burning coal in coal-water slurry has a number of economic, environmental and operational advantages more than pulverized and especially fluid bed firing (Tillman et al., 2004), (Farag et al., 1989), (Kijo–Kleczkowska, 2011). This fuel has been on a substantial scale approved on a number of power objects. Works on burning mazut coal and water coal fuel were carried out by V. Kustov (Kustov, 1942). In a fire chamber coal particles have to burn down without ceding to speed combustion of fuel oil. The usual size of the particles of coal that used for coal fuel oil producing reaches 60-80 microns. It is established that it is expedient to apply a quantity of liquid non-flammable environment – water. However, coal-water slurry coal particles adhere to each other only when they are added stabilizers - surface active agents (SAA) – surfactants (Zhu et al., 2012), (Li et al., 2008). Water in such suspensions should not be more than 55%. The main way of mechanical dispersion of coal is wet milling in the rotating ball, rod or vibrating mills. Their drawback is inability to get fine suspension.

Preparation of water-coal slurry using a high-speed disperser

At the Riga Technical University (Latvia) a pilot plant based on the new high speed mixer-disperser for preparing water-coal and water-cement suspensions has been developed (Mironovs et al., 2011). The setup is shown in Fig. 5. It allows you to change the angular rotation speed from 0 to 9000 rpm continuously.

In conducting the studies long-flame grade coal D (volatile content - 39% or more, -76% carbon content, calorific value - 7500-8000 kcal/kg) was used. The maximum grain size is 200 μm. As the sample coal dust waste was used that produced during the production of coal briquettes (the company "EU Zeme", Riga, Latvia). Dust waste cannot be disposed of in its entirety for various reasons, and it accumulates, creating a significant environmental problem.



a) b)

Figure 5. Experimental setup for water WCS obtaining. General view (a) and scheme (b).
1 - container for suspension, 2 - motor, 3 - mixer-disperser; i - supply components to be mixed; ii - suspension output; iii - recycle stream

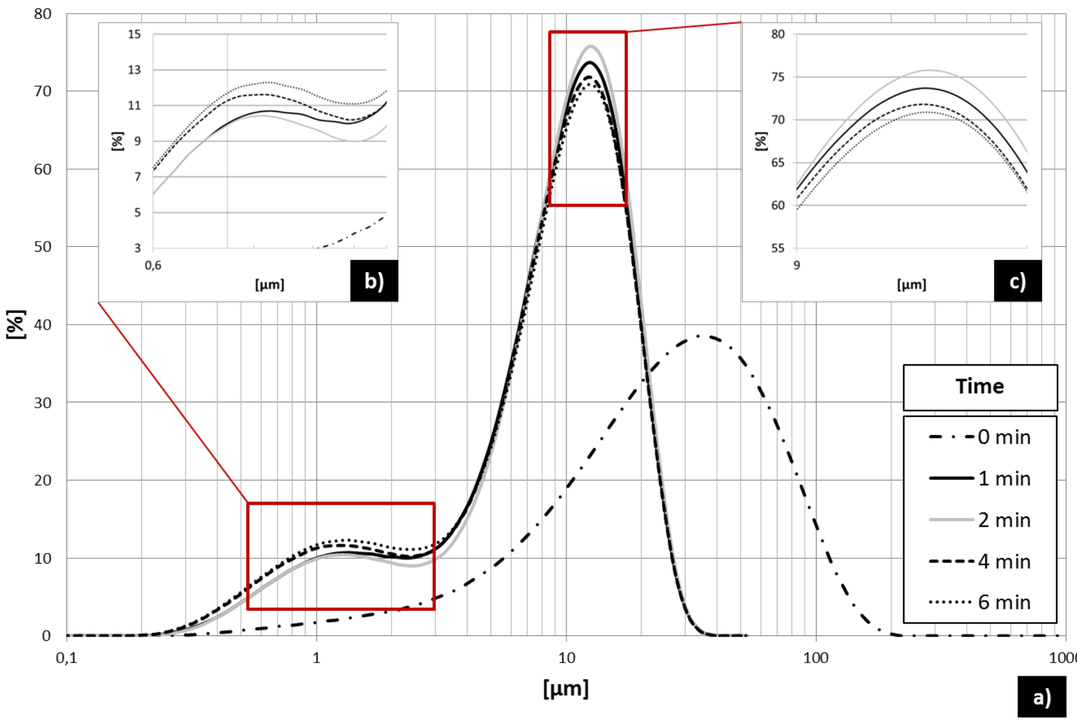


Figure 6. Particle size distribution of coal before and during treatment in HSMD

Dust-like coal waste is mixed with water and a surfactant in a ratio of: coal - 750.0 g, water - 1000.0 g, surfactant ((-)-Ethyl l-lactate by Fluka (now Sigma-Aldrich)) - 1.50 ml, till smooth. The received mass was poured into the container (1) for suspension of the high-speed mixer-disperser (3), given to rotation by the electric motor (2) Fig. 5(b). Treatment in high-speed mixer-disperser was carried out for 1 to 6 minutes at 9000 rpm of the rotor. During the process of dispersing (6 min), the temperature of the suspension increased from 17°C to 35°C.

Particle size distribution analysis

The size of the particles of coal after their processing in the disperser was defined by the method of granulometric laser diffraction on the device Analysette 22 Nano Tec (FRITSCH GmbH). The following parameters are used during the measurements.

Figure 7. High-speed mixer-disperser DRS10 (capacity -10 m^3/h, pressure - 0.2 MPa, motor power - 5,5 kW)

Measured media: distilled and deionized water (light refractive index: 1.3312). Optical properties: light reflection coefficient 1.8, the absorption coefficient 0.5 (both factors are taken due to that more exact values are not known), unless otherwise indicated. Ultrasound: is off. Water pump power: 30%. Direct laser beam hidden by 7 - 13%. The method of calculation: very broad. The measured particle size range: 0.1 to 50 μm.

RESULTS AND DISCUSSION

The resulting suspension remains stable for 4 days. During dispersing probes of WCS for particle size distribution are taken on 1-th, 2-d, 4-th, 6-th minutes. The results are presented in Fig. 6, which shows the curves of the particle size distribution: at baseline (0 minutes) and after treatment.

As seen in Fig. 6, after 1 min of treatment in HSMD the particle size decreases significantly: from one particle mode d_{50}=25 μm 2 modes d_{50}=13 μm and d_{50}=1.3 μm are formed. This fraction is almost absent in the source material. Apparently, this is the maximum possible range of grinding particles of coal, which provides the used mixer-disperser at the noted above conditions (rotation speed, water-coal rate, type of coal). The increase the dispersion time from 1 minute to 2 gives a small (from 73% to 76%) growth in the fraction d_{50}=13 μm. Due to increased processing time, the mode of d_{50}=13 μm reduced (Fig. 6 (b)), but the mode with d_{50}=1.3 μm increased, (Fig. 6 (c)). It can be concluded that long-term (more than 2 min) treatment is not practical because it does not contribute to the further significant refinement of the material.

The firm CORVUS Company (Latvia) started production of a high-speed mixer-disperser DRS10, which is shown in Fig. 7.

CONCLUSIONS

Using of the high-speed mixer-disperser stable water coal suspension with considerable fineness coal particles is prepared that will allow to increase the quality of burning water coal fuels in industrial boiler rooms and improve ecology in places of overload of coal.

Increasing processing time in HSMD more than for 2 min treatment is not practical, because it does not contribute to the further significant refinement of the material.

Coal dust short-time processing time for WCF obtaining is prospective for this technology in future implementation on commercial scale.

Increase a temperature of the environment during of preparation of water coal suspension evidences existence of the cavitation effect during the disperser work.

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