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Investigation of physical characteristics and atomizing properties of coal-water slurry fuel from the sludge of Shubarkul coal

The article presents the technology of combustion of coal-water fuel (CWF), produced from coal slurries Shubarkul. The process of liquid fuel-spraying with the aerodynamic processes during combustion of coal-water fuel. Calculated according to the diameter of the atomized droplets on the surface tension for different values of speed drop. The authors conducted laboratory studies on the incineration of coal-water fuel in a pilot plant.

Key words: Shubarkul coal, coal-water slurry, nozzle, surface tension, atomized fuel.

Stability and fuel combustion efficiency in combustion chamber are determined by dispersing degree in fuel chamber and by aerodynamic efficiency of gas flow in the chamber. These qualities provide secure environment for torch ignition and stabilization, safe fuel mixing with oxidant and temperature distribution as well as optimal conditions for fuel combustion throughout all the volume of the chamber. The dispersing quality of coal-water slurry combustion chamber depends on the efficiency of atomizing device construction and fuel properties.

The scientists as G.N.Delyagin, V.G.Nekrassov and others studied dispersing processes in coal-water slurry. According to these studies, the crushing of coal-water slurry in dispersing essentially depends on fuel humidity. The lower the humidity of fuel (humidity from 45–50 %), the higher its viscosity and the worse spraying device characteristics [1].

Processes of liquid dispersion are described by criterion equation as:

$$n \cdot \frac{d_{cp}}{D} = F\left(\frac{V^2 \rho_г D}{\sigma}, \frac{D\rho_{ж}\sigma}{\mu_{ж}^2}, \frac{\rho_г}{\rho_{ж}}, \frac{\mu_г}{\mu_{ж}}\right), \tag{1}$$

n — constant distribution; d_{cp} — average drop size; D — character linear dimension; V — relative velocity; σ — the coefficient of surface tension of the liquid; $\rho_{ж}, \rho_г$ — density of atomizing liquid and gas medium; $\mu_{ж}, \mu_г$ — the coefficient of dynamic viscosity of a liquid and gas medium.

From equation (1), it is clear that to consider dispersing process we need to know the properties of dispersing environment as: density, viscosity and its surface tension. The surface tension, in turn, depends on the type of coal. According to the studies of G.N.Delyagin, as concentration of coal and coal-water fuel (CWF) increases to a certain critical value of concentration, the surface tension values slightly differs from the value for water, increasing with concentration growth modestly and this dependence is linear [2, 3]. Starting from critical concentration, the surface tension sharply increases. The limiting value of surface tension meets the condition of densely packed particles. For different types of coal, the concentration value and the limiting value of surface tension for coal-water fuel are different, their values increase with increasing the degree of coal metamorphism. As for lignite, critical concentration is in the range of 35–40 %, the limiting value of surface tension is 0.3–0.4 N/m, for black coal these values are higher, respectively — 50 % and 3.3 N/m.

Combustion of coal-water fuel essentially differs from the similar process using dust coal. The impact of rank of coal and its ash content on ignition temperature and combustion stability is insignificant. However, the results of practical application show that combustion of coal-water fuel made from high metamorphic coal and anthracite, requires higher initial heating of the combustion chamber to launch the process of fuel combustion. Similar phenomena was reported when using CWF made from high-ash coal sludge. All these show that ignition model and combustion of coal-water fuel proposed by G.N.Delyagin and other authors should be corrected.

It is assumed that spraying of coal-water fuel makes a stream of polydisperse drops (particles), containing only of clean coal particles, «freed» of liquid phase due to high speed, and the drops of coal-water fuel, consisting of the fines coal particles and a liquid phase. At the same time, depending on grain-size composition of coal in CWF, the number of clean coal particles can reach 25–30 % [4].

In our opinion, the process of atomization coal-water fuel by air or by stream is carried out in two stages. When coal-water fuel and dispersing agent are mixed in a sprayer, it leads to a stream crush of coal-water fuel due to the kinetic energy of the last. At the second stage, in fuel dispersing, the crush is carried out by resisting force influenced by gas medium, the speed of which is many times less than the speed of drops. The generated impact results in drop flattening and breaking into smaller ones.

Let's consider the crushing mechanism of drops of coal-water fuel from the sludge of Shubarkul coal by analogy with reduced fuel oil.

Pressure P_1 of the gas medium onto moving drop is determined by the impact of frictional force F on the frontal area of drop S_k:

$$P_1 = \frac{F_{mp}}{S_k}. \quad (2)$$

Disregarding gravity and considering only gas medium, we found that frictional force equals to:

$$F_{mp} = \psi \cdot S_{\kappa} \cdot \rho \cdot V_r^2, \quad (3)$$

ψ, ρ — the coefficient of resistance and density of gas medium; V_r — relative drop velocity to the gas medium.

Substituting (3) to equation (2), we obtain:

$$P_1 = \psi \cdot \rho \cdot V_r^2.$$

On the other hand, pressure put on the drop, due to surface tension force, is:

$$P_2 = \frac{2\sigma}{r_k}, \quad (4)$$

where σ — the coefficient of surface tension; r_k — radius of the drop.

It is assumed that drop will breakup into smaller ones, if

$$P_1 \rangle P_2. \quad (5)$$

In this case, maximum drop size is obtained, if $P_1 = P_2$, i.e.

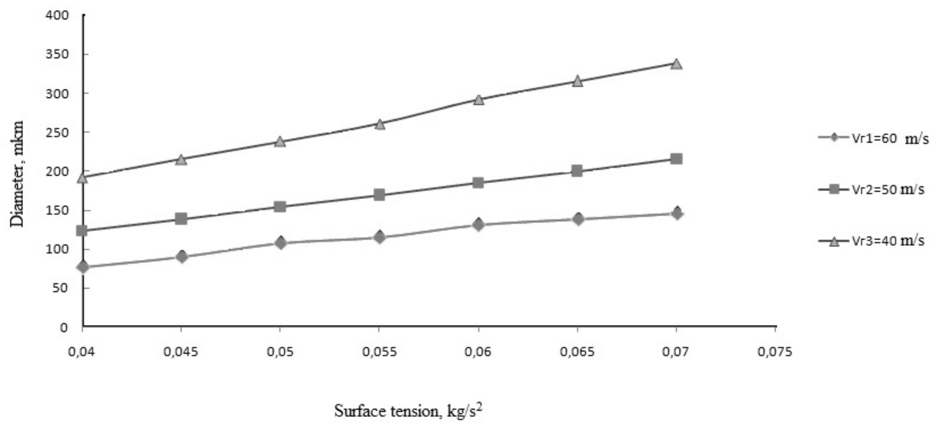
$$\psi \cdot \rho \cdot V_r^2 = \frac{2\sigma}{r_k}. \quad (6)$$

From expression (6), we find that:

$$r_k = \frac{2\sigma}{\psi \rho V_r^2}. \quad (7)$$

From equation (7), we see that drop diameter of CWF significantly depends on surface tension, medium density and relative drop velocity. Temperature rise at decreasing viscosity and increase in flow speed results in increase of the degree of fineness of liquid fuel spray.

Figure 1 show the calculated dependence of diameter of atomized drops on surface tension at different drop velocity. The calculations were made for values V_k = 40–60 m/s, ψ = 0,2, ρ = 1,29 kg/m^3.



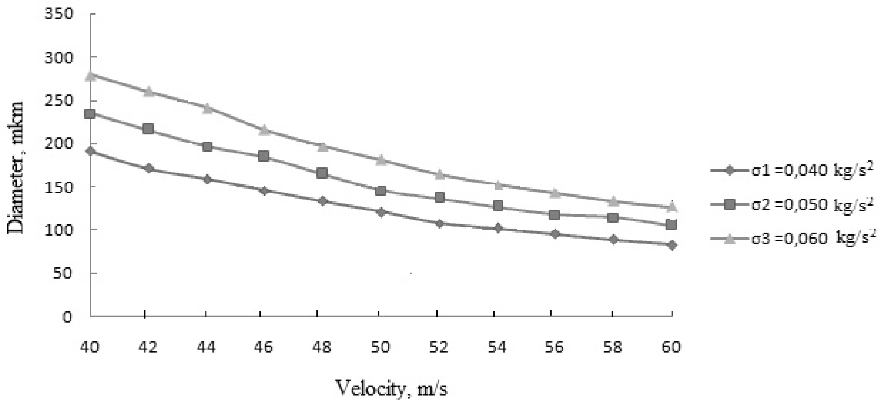
Drop velocity, V_r: *1* — 40; *2* — 50; 3 — 60 m/s;

Figure 1. Dependence of diameter of atomized drops on surface tension

From Figure 1, we see that the degree of fineness of liquid fuel increases as surface tension decreases.

Figure 2 show the calculated dependence of diameter of atomized drop of CWF on their velocity at different values of σ = 0,040–0,060 kg/s^2, ψ = 0,2, ρ = 1,29 kg/m^3.

Thus, if velocity of atomized drop spread from the nozzle of sprayer equals to 40–60 mps, then maximum diameter of drop will be in the range between 100 and 300 microns.

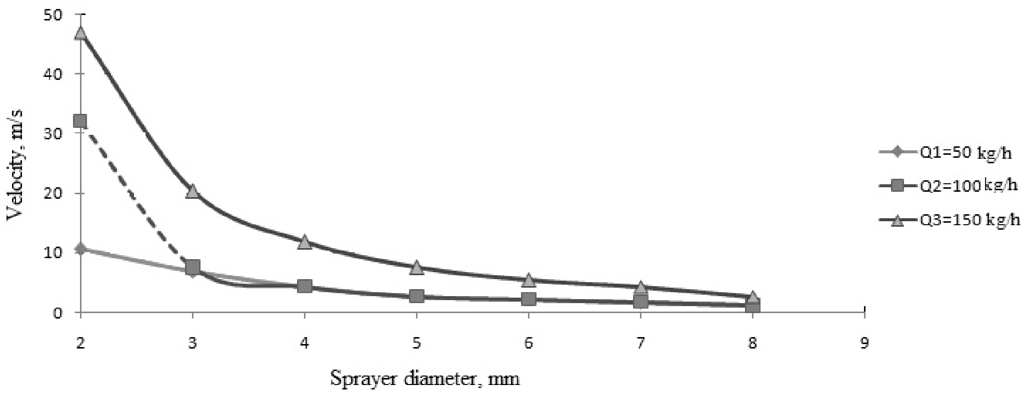


σ: *1* — 0,040; *2* — 0,050; *3* — 0,060 kg/s^2

Figure 2. Dependence of diameter of atomized drops on their velocity

As we can see from Figure 2, the higher relative speed, the smaller maximum diameter of the formed drops.

It is possible to get higher velocity value of fuel, using pneumomechanical sprayers due to reducing diameter of sprayer's nozzle. However, reducing the diameter of nozzle leads to increased risk of clogging the sprayer with large coal particles. In practice, the nozzles with diameter less than 3 mm are used very rarely because elimination of particles of initial coal-water fuel larger than 0,5–1 mm is rather a complicated problem. Thus, spraying quality significantly depends on the nozzle diameter of pneumomechanical sprayer (fig. 3).



Flow rate of fuel, Q: 1 — 50; 2 — 100; 3 — 150 kg/h

Figure 3. Dependence of velocity value of atomized fuel on sprayer diameter

The analysis of calculated dependence (Fig. 3) show that as the diameter of nozzle of sprayer decreases, the velocity value of atomized fuel increases. Moreover, the higher flow rates of fuel and the smaller the diameter of nozzle of sprayer, the higher the velocity value of atomized fuel.

Both, coal water drops, containing of the fineness particles of coal and liquid phase, and clean coal particles («drop-particles» larger than 80–100 microns) are obtained by atomizing CWF, the liquid layer with the fineness particles are torn off from them due to the hydrodynamic friction force.

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Шұбаркөл көмірінің қалдықтарынан алынған сулы-көмірлі отынның шашырату ерекшелігін және физикалық қасиетін зерттеу

Мақалада Шұбаркөл көмірінің қалдықтарынан алынған сулы-көмірлі отынды жағудың технологиясы келтірілген. Сулы-көмірлі отынды жағу кезіндегі аэродинамикалық үдеріс есебінен сұйық отынды шашыратудың үдерісі қарастырылған. Тамшы жылдамдығының әр түрлі мәні кезінде беттік керілуден шашыратылатын тамшы диаметрдің есептік тәуелділігі алынған. Авторлармен тәжірибелік қондырғыда сулы-көмірлі отынды жағу бойынша зертханалық зерттеу жүргізілген.

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Исследование физических свойств и особенности распыления водоугольного топлива, полученного из шламов шубаркульских углей

В статье приведена технология сжигания водоугольного топлива, полученного из шламов шубаркульских углей. Рассматривается процесс вспрыскивания жидкого топлива с учетом аэродинамических процессов при горении водоугольного топлива. Получены расчетные зависимости диаметра распыленных капель от поверхностного натяжения при различных значениях скорости капли. Авторами проведены лабораторные исследования по сжиганию водоугольного топлива на опытной установке.

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