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PRODUCTION OF HIGH-CALORIC COAL BRIQUETTES FROM THE EKIBASTUZ COAL DEPOSIT

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The article provides information on the coal briquetting process, the briquetting process, and establishes the mechanism of coal briquettes structure formation taking into account the physicochemical and structural-rheological properties of coal. Of great importance is the uniform distribution of elementary size classes in the briquette charge. It is achieved by choosing a coal classification process flow chart and appropriate equipment. The coal size determines the total surface area of the briquetting mass particles. The more developed this surface area is, the greater the number of particle contacts inside the briquettes and the more intense the action of molecular adhesion forces. The increase in the total surface area of the grains can be achieved by crushing. The main factors influencing the coal briquetting process are: coal moisture and moisture distribution in individual classes, coal size, distribution of elementary size classes in the briquette charge, granulometric composition, pressure, pressing duration and temperature, water content.

Keywords: coal, ash content, briquetting, raw material quality management, combustion heat, coal size.

ЕКІБАСТҰЗ КЕН ОРНЫНЫҢ КӨМІРІНЕН ЖОҒАРЫ КАЛОРИЯЛЫ КӨМІР БРИКЕТТЕРІН АЛУ

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Мақалада көмірді брикеттеу процесі, брикеттеу процесі туралы мәліметтер келтірілген, көмірдің физикалық-химиялық және құрылымдық-реологиялық қасиеттерін ескере отырып, көмір брикеттерінің құрылымдық түзілу механизмі анықталған. Брикет шихтасындағы қарапайым кластардың біркелкі таралуы маңызды. Оған көмірді жіктеудің технологиялық схемасын таңдау және тиісті аппараттық дизайн арқылы қол жеткізіледі. Көмірдің мөлшері брикеттелген масса бөлшектерінің жалпы бетін анықтайды. Бұл бет неғұрлым дамыған болса, брикеттер ішіндегі бөлшектердің байланыс саны соғұрлым көп болады және молекулалық байланыс күштерінің әсері күшейеді. Дәндердің жалпы бетінің ұлғаюына ұсақтау арқылы қол жеткізуге болады. Көмірді брикеттеу процесіне әсер ететін негізгі факторлар: көмірдің ылғалдылығы және жекелеген кластардағы ылғалдың таралуы, көмірдің үлкендігі, брикет шихтасындағы үлкендіктің қарапайым кластарының таралуы, гранулометриялық құрамы, қысымы, престеу ұзақтығы мен температурасы, судың мөлшері.

Түйін сөздер: көмір, күл, брикеттеу, шикізат сапасын басқару, жану жылуы, көмірдің мөлшері.

ПОЛУЧЕНИЕ ВЫСОКОКАЛОРИЙНЫХ УГОЛЬНЫХ БРИКЕТОВ ИЗ УГЛЯ ЭКИБАСТУЗСКОГО МЕСТОРОЖДЕНИЯ

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В статье приведены сведения о процессе брикетирования угля, процесса брикетирования, установлен механизм структурообразования угольных брикетов с учетом физико-химических и структурно-реологических свойств угля. Важное значение имеет равномерное распределение элементарных классов крупности в брикетной шихте. Оно достигается выбором технологической схемы классификации угля и соответствующим аппаратурным оформлением. Крупность угля определяет суммарную поверхность частиц брикетируемой массы. Чем более развита эта поверхность, тем больше число контактов частиц внутри брикетов и интенсивней действие молекулярных сил сцепления. Увеличение суммарной поверхности зерен может быть достигнуто дроблением. Основными факторами, влияющими на процесс брикетирования углей, являются: влажность угля и распределение влаги в отдельных классах, крупность угля, распределение элементарных классов крупности в брикетной шихте, гранулометрический состав, давление, продолжительность и температура прессования, содержание воды.

Ключевые слова: уголь, зольность, брикетирование, управление качеством сырья, теплота сгорания, крупность угля.

Introduction. Coal briquetting is the process of converting fine fractions and coal dust into durable, compact briquettes that are convenient for transportation, storage and use. This method not only allows for the rational use of coal waste, but also improves its calorific properties, reducing dust formation during combustion. [1-2].

The briquetting process includes several key stages:

- preparation of raw materials - coal is crushed to the required fraction and, if necessary, dried to achieve the optimal moisture level;

- mixing with binders - to increase the strength and integrity of the briquettes, binders such as petroleum bitumen, lignosulfonates, molasses, liquid glass or cement are added to the coal mass6 The choice of binder depends on the type of coal and the requirements for the final product;

- forming briquette - the prepared mixture is fed into a press, where briquettes of a given shape and size are formed under high pressure;

- drying and cooling - after pressing, the briquettes are dried to remove excess moisture and increase strength, and then cooled to room temperature [3-5].

This method provides more efficient use of coal raw materials and reduces the negative impact on the environment. Figure 1 shows briquetted coal.

To organize the briquetting process, specialized production lines are used, which include:

- crushers - designed to crush coal to a given fraction.

- mixers - ensure uniform distribution of binders in the coal mass.

- briquette presses - form briquettes under high pressure, giving them the required density and shape.

- drying units - remove excess moisture, increasing the strength and stability of the finished briquettes.

The combination of these elements allows for high process efficiency and a high-quality final product [6-9]. Coal briquetting plants are shown in Figure 2.

The advantages of coal briquettes are:

- high calorific value: briquetted coal has a calorific value of at least 6000 kcal/kg;

- ease of transportation and storage: briquettes have a uniform shape and density, which facilitates their transportation and storage.

- environmental friendliness: when burning, high-quality briquettes emit less smoke and harmful gases, burn out completely, leaving a minimum amount of ash.

Fig. 1 - Briquetted coal

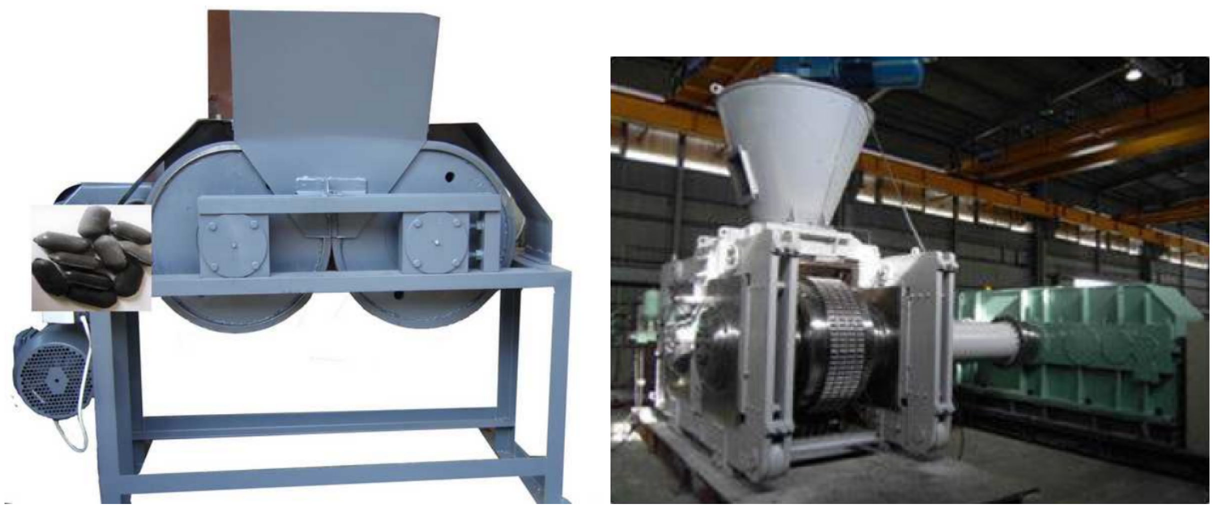


Fig. 2 - Coal briquetting plants

In the work [10] within the framework of the work performed on the use of coal enrichment waste, their experimental combustion was carried out, technologies for granulation and further use were developed. For the preparation of granules, the following are used: coal enrichment waste, marble chips for binding sulfur oxides, and for the formation of granules in order to prevent ”smearing” of dust preparation equipment, bitumen emulsion is added.

In the work [11] modern technologies for obtaining coal-water fuel from coal enrichment waste are considered and are being developed mainly in three directions: using wet grinding vibratory mills, using cavitation devices, hydraulic shock technologies based on disintegrators and rotary pulse devices.

The work [12] presents studies that the company OJSC Irkutskenergo is currently developing in the areas of using waste from enriching Cheremkhovo coals. One of the promising areas is the preparation and combustion of water-coal fuel.

In the work [13] a computer modeling of

coal combustion technology in an oxygen-enriched environment is presented. Determination of the degree of burnout, volatile substances and NO formation. A computer model CFD (Computational Fluid Dynamic) of oxy-coal combustion technology has been developed to study the process of coal combustion in an oxygen-enriched environment.

The work [14] shows the development of the structure of a vacuum-technological line for the production of environmentally friendly, energy-efficient fuel obtained from raw materials of organic origin, in particular, peat and coal.

A review of the work shows that insufficient attention has been paid to issues of involving substandard coal fines in production, including through enrichment and briquetting, which demonstrates the relevance of this area.

Materials and Methods. The coals of the Ekibastuz basin were selected for the study. Six coal seams of working capacity have been identified in the Ekibastuz basin, of which seams 6 and 5 are confined to the Ashlyarik suite, and the rest are confined to the Ekibastuz. The seams of the Ekibastuz suite are industrial and under development. The coals of the basin are hard, humus, highly mineralized, and are characterized by a complex substance-mineralogical composition. The ash content of the coals is very high and reaches 40-49%.

The Ekibastuz coal basin is developed by an open-pit method, which in turn has a negative impact on the environmental situation in the region. Polluting factors here are stripping operations and waste dumps after them. One of the most severe polluting factors is the wind blowing of coal dust and fines from open-pit coal mines and waste dumps. The essence of the idea is to obtain briquettes from fine coal and dust of high-ash coals of the Ekibastuz deposit with the possibility of subsequent coking by increasing the carbon content, i.e. the calorific value. One of the problems of briquetting at the moment is the impossibility of obtaining briquettes without adding non-combustible binders, which, in turn, will again increase the already high ash content of the briquettes. As a solution, the possibility of obtaining processed organic waste products of cattle or some by-products of oil distillation as a binder, which are combustible substances and will not reduce the percentage of the calorific value of the briquette, is being considered.

Coals can be considered as a specific hydrated amorphous polymer of irregular structure. Its properties are largely determined by colloidal swelling processes. Briquetting of such substances should be presented as a complex multi-stage process of forming a strong autohesive complex due to high pressing pressures. There are several hypotheses about the mechanism of coal briquettes formation.

Colloid hypothesis. According to this hypothesis, the briquetting of coals is estimated from the position of molecular forces. The basis is the mechanism of interaction between coal particles in the presence of water and without it. According to this hypothesis, the formation of briquettes is explained by the action of cohesive forces.

Bitumen hypothesis. According to the bitumen hypothesis, coal briquetting is presented as a process similar to briquetting of minerals with a binder. It is believed that the role of binders is played by bitumens contained in coals. Coal bitumens are products of the decomposition of resins, waxes and fatty acids. They consist of a mixture of hydrocarbons, alcohols, acids and ethers. The bitumen content in young coals is 10–20%. Bitumens melt at a temperature close to 90 °C. In the molten state, bitumens have good adhesive properties. When cooled, they solidify and acquire a fairly high strength.

The total surface area (cm^2) of crushed grains in one briquette can be calculated as follows:

$$S_v = Sa, \tag{1}$$

where S - surface of particles obtained from crushing one grain, cm^2; a - number of grains in a briquette.

$$S = \frac{\pi D^3}{d} \tag{2}$$

where **D –** average grain size before crushing, cm;

d – average grain size after crushing, cm.

$$a = \frac{6M}{\pi D^3 \gamma} \quad (3)$$

where *M* – briquette weight, g;

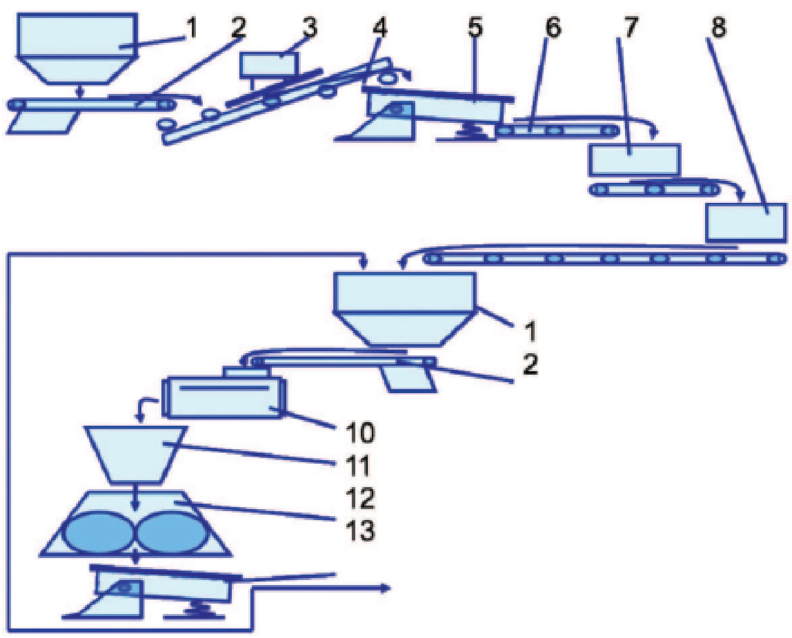
γ – bulk density of briquette, g/cm^3.

Substituting the corresponding values of S and a into formula (1), we obtain

$$S_v = \frac{6M}{d\gamma} \quad (4)$$

Results and Discussion. Of great importance is the uniform distribution of elementary size classes in the briquette charge. It is achieved by choosing a technological scheme for coal classification and the corresponding equipment design. Briquettes have maximum strength with the following ratio of classes of the briquetting mixture: 0–1 mm about 50%, 1–2 mm – 40–45% and 2–4 mm –5–10%. Dust particles (less than 0.2 mm) have a negative effect on briquetting. Their content should not exceed 8–10%.

The size of the coal determines the total surface area of the particles of the briquetted mass. The more developed this surface area is, the greater the number of particle contacts inside the briquettes and the more intense the action of molecular adhesion forces. The increase in the total surface area of the grains can be achieved by crushing. Briquettes made of fine coal have fewer internal defects, a higher packing density, and better plasticity of the briquetted mass. Hence, a more uniform distribution of pressure throughout the entire volume of the briquettes. The optimal size, which ensures sufficiently high strength of the briquettes, is within 0–2 mm. The technological scheme of coal briquettes production is shown in Figure 3.



1 - receiving bin, 2 - electrovibration feeder, 3 - lifting magnet, 4 - belt conveyor, 5 – screen, 6 - belt conveyor, 7 - roller crusher, 8 - hammer crusher, 9 - belt conveyor, 10 – mixer, 11 - hopper with screw feeder, 12 - roller press, 13 - screen

Fig. 3 - Flow chart of coal briquettes production

The quality of briquettes is significantly affected by the distribution of moisture in individual classes. Small particles of coal give up their moisture faster and easier during drying than larger grains. Therefore, to achieve high strength of briquettes, it is necessary to ensure a minimum moisture difference between small and large grains. The moisture difference is affected by the speed and method of drying the coal, the difference in the sizes of the largest and smallest particles of the material, and the nature of the coal. It is important to take into account the uneven distribution of moisture in large grains. After drying, moisture evaporates only from the surface, lingering in the deep areas.

Fig. 4 - Sample of a briquette obtained in a semi-industrial plant

Fig. 5 - Pilot plant for briquette production

The pressing factor is the most important for obtaining strong briquettes. When pressing, under the action of mechanical pressure, brown coal is compressed all around to form a lump product - a briquette. The briquetted material (dry coal) can be considered as a three-phase system: solid, liquid and gas. The gaseous phase is the air in the pores of the coal and the spaces between individual grains.

The bulk of the air is easily removed during the pressing process. Only a small amount of it remains in the pressed coal, weakening the structure of the briquette. Therefore, during the pressing process, maximum air removal is necessary through the appropriate gaps of the pressing devices. A sample of a briquette obtained in a semi-industrial plant is shown in Figure 4.

Before pressure is applied, coal particles contact each other at individual points. With the application of pressure, point contacts become weak surface contacts, and at maximum pressing force, they become strong bonds of molecular adhesion forces. As pressure increases, the entire mass of coal being briquetted is sequentially drawn into the contact zone. The formation of the briquettes' structure is accompanied by deformation of the coal in the press channel and after the briquettes exit it. The deformation of the first period is irreversible or residual, and of the second period it is reversible or elastic.

The technology for producing briquettes can be based on waste from coal enterprises, wood sawdust, lignin, and other industrial waste. Classic pressing technology is used in preparing briquettes. The developed process includes the stages of preliminary preparation of the initial components, mixing and transferring polymers into a plastic state, and molding briquettes using the viscous flow of the mass into molding strains. The pilot plant for producing briquettes is shown in Figure 5.

Experiments were conducted to determine the physical and technical characteristics of the briquettes depending on the conditions of their preparation.

Table 1 shows that the amount of binder plays an important role in the formation of the strength of the briquettes, which increases as the binder increases. If we compare the strength of the briquettes with and without a binder, we see that regardless of the drying temperature, the strength of the briquettes increases by 1.5 times with the introduction of a binder into the briquette.

Table 1 - Physicochemical properties of the briquette depending on the input factors

Samples	Drying temperature, °C	Mass of binder, %	Calorific value, MJ/kg	Ash content, %	Humidity, %	Durability, %
1	25	-	30,6	1,9	14,2	32,2
2	25	5	28,2	3,4	15,3	54,1
3	60	-	28,5	2,3	10,2	34,5
4	60	5	27,8	3,1	11,4	52,8
5	60	10	27,3	4,1	12,8	60,1
6	100	-	29,1	3,1	8,3	23,4
7	100	5	27,5	2,1	9,5	45,7
8	100	10	27,3	2,6	11,2	64,7

It is evident from Table 1 that the binder level has a significant effect on all combustion properties studied. Increasing the binder level decreases the calorific value. This is expected due to the decrease in the proportion of semi-coke, which significantly contributes to the overall calorific value of the mixture. It is also observed that the ash content increases at drying temperatures from 25 to 600 °C, then decreases at drying at 1000 °C, indicating that the lignosulfonate has inorganic volatiles that are not combustible.

In an attempt to characterize the interactions occurring between the lignosulfonate binder and the fine coal particles, we can assume the following interaction mechanism. As preliminary observations show, direct interactions between coal particles and lignosulfonate particles in the granule are not observed with simple mechanical mixing, but interactions occur through the surfactants of the lignosulfonate and the coal surface.

Larger particles in the coal lead to adhesion between adjacent particles. In addition, the presence of moisture enhances the activity of surfactants. Lignosulfonates can act as a surfactant molecules with spherical structures (micelles), where sulfonic acid and carboxylic acid groups are located mainly on the surface of the hydrophobic hydrocarbon core. These functional groups are available for interaction, especially in the presence of surface moisture.

Study of adhesive-cohesive properties of petroleum pitch as a binder

Coal, enrichment and binding fractions enter the mixer from the dispenser in strictly calculated proportions. The purpose of mixing this batch is to maximize their averaging among themselves and to envelop the surfaces of coal and enrichment particles with a thin molten film of petroleum pitch (binder).

Mixing of briquette masses is the first stage of manifestation of adhesive interaction of components and homogenization of the system. The entire complex of adhesive phenomena is the result of manifestation of molecular interaction: from weak van der Waals forces to hydrogen bonds of chemical nature. To calculate the theoretical bond strength for any molecular forces Fm, one can use the transformed Morse equation [15, 16]:

$$Fm = \frac{bD}{2}$$

where b – constant associated with the magnitude of the amplitude of oscillation of interacting particles;

D – bond dissociation energy.

The formation of a particular type of bond is determined by its activation energy. Low activation energy is characteristic of molecular adhesion, which is carried out under the influence of Van der Waals forces, as well as adhesion due to the formation of hydrogen bonds through functional groups located on the surface of particles and in the binding groups.

The most important thermodynamic characteristic of adhesion in the briquette composition is the wettability of the substrate by the adhesive and the surface tension at the phase boundary. The particles of coal and enrichment remain permanently solid during the mixing process, so for the sake of convenience we will call them the base.

In contrast, petroleum pitch, being initially a powder composite, will become a liquid wetting binder during the mixing process under the influence of externally introduced temperature into the working cavity of the mixer. Therefore, petroleum pitch is further called the binder.

The work of wetting the solid surface of the base (substrate) by the binder can be expressed by the Dupre equation

$$W_a = \sigma_{tg} + \sigma_{jg} - \sigma_{tj}$$

where W_a – reversible work, H/m;

σ_{tg}, σ_{jg}, σ_{tj} – surface tension at the liquid-gas interface, H/m.

The equilibrium condition for drops of a binder on a solid surface, expressing Young' s equality

$$\delta_{\mathrm{tg}} = \delta_{\mathrm{tj}} + \delta_{jg} \cos\varphi$$

The present equation with the Dupre equation can be transformed into the Dupre-Young equality.

$$W_a = \sigma_{\mathrm{jg}}(1 - \cos\varphi)$$

where φ – contact angle.

From the Young equation we can derive

$$\cos\varphi = \frac{\sigma_{tg} - \sigma_{tj}}{\sigma_{jg}}$$

In order to achieve comparability in the assessment of adhesive activity, several bases must meet the conditions σ_{jg} = const, then *Wa = f(cosφ)*.

In this case, the adhesion work will be a function of one variable – the contact angle. This is achieved by using the same adhesive for all base samples, i.e. the same binder (petroleum pitch).

For the adhesion to be high enough, the condition must be met:

$$\sigma_{\text{tg}} > \sigma_{\text{jg}} + \sigma_{\text{tj}}$$

When wetting the base surface with a binder $s\varphi >$ 0, and φ < *900*, in the absence of wetting φ > 900.

Adhesive interaction phenomena can be attributed to relatively low-temperature processes. The bonds formed in this case are characterized by low interaction energy: 4.2 kJ/mol for Van der Waals forces, 21 ÷ 42 kJ/mol for hydrogen bonds. At the same time, the formation of chemical bonds in the so-called adhesive-substrate ”cross-linking” reactions have an interaction energy 15 ÷ 20 times higher and are possible in the process of compaction of the hot briquette mass. Only this type of reaction leads to the formation of the composite structure.

However, the structure of the contact layer is generated in the process of adhesive interaction, the compaction process (pressing) only completes the previously formed system. The presence of various adhesion defects (unfilled pores, unwetted areas, cracks, air inclusions, etc.) are potential sources of local stress and destruction of the briquette structure.

Maximum enveloping (wetting) of the base with a binder is the most important task of mixing. Of course, the most favorable course of this process would be the spontaneous entry of the binder into the pores of the base particles. The depth h of spontaneous penetration of the liquid phase into the pores under the action of capillary forces (at a contact angle of wetting φ < 900) is determined by the equation:

$$h = \frac{2\sigma_{jg}\cos\varphi}{\rho r g}$$

where σ_{jg} – surface tension of the binder H/m;

r – pore radius, m;

g – acceleration of gravity, m/s^2.

Using the Poiseuille equation for a laminar flowing liquid of viscosity μ, one can calculate the time τ required for the binder to pass into a capillary of radius r to a depth h. The flow velocity of the liquid w is equal to:

$$w = \frac{\Delta P_k}{h} \cdot \frac{r^2}{8\mu}$$

If $\tau = h/w$ the value of capillary pressure from the Laplace equation:

Calculations using these formulas show that the process of spontaneous impregnation of the base with a binder is very long (up to 4 hours or more). This process can be accelerated by almost an order of magnitude when the contact angle is reduced from 800 to 100.

Pores up to 0.2 mm are completely filled with the binder due to capillary forces (taking into account the maximum grain size of the base of 1.2 mm). It should be taken into account, however, that in the case of a dead-end pore (the mixture borders the walls of the molding tooling), the action of the capillary forces will be inhibited due to the counterpressure created in the pore itself. If in a pore of length l_0 part of its length l is occupied by the binder, then in the free part the air pressure will be

$$\mathit{\Delta}^1 = \frac{l_0}{l_0 - l}$$

The condition of equilibrium of the capillary process will be equality

$$\mathit{\Delta}^1 = \mathit{\Delta}\frac{l_0}{l_0 - l} = \frac{2\sigma_{jg}s\varphi}{r}$$

Where does the depth of penetration of the binder into the dead-end pore under the action of capillary forces amount to

$$l = l_0\left(\frac{1 - r}{2\sigma_{jg}s\varphi}\right)$$

That is, it is determined by the surface tension of the binder, the wetting angle, the radius and length of the pores. It is obvious that for maximum filling of the pores it is necessary

$$\left(\frac{1-r}{2\sigma_{jg}s\varphi}\right)\to 1 \vee \left(\frac{r}{2\sigma_{jg}s\varphi}\right)\to 0$$

For pores, this condition is satisfied when $\varphi \to 0$, $\sigma_{jg} \to \max$. In real mixers, these conditions are achieved by additional pressure ΔP created by the screw turns or mixer blades. In this case, the total pressure in the capillary will be

$$P = \Delta P_k + \Delta P$$

If the value of P is insufficient to squeeze air out of a dead-end pore, it may remain unfilled even in the finished briquette. The nature of filling a narrowing-expanding pore connected by a neck is somewhat different. In the real structure of the base, this geometry of pores is more common than pores of the correct geometric shape.

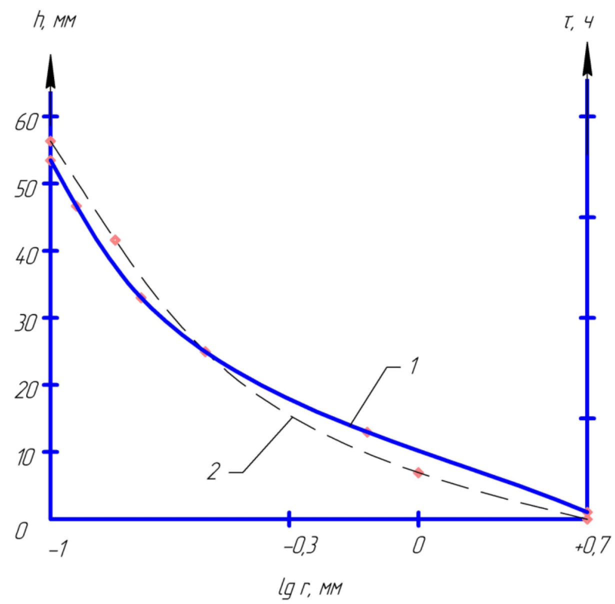


Fig. 6 - Dependence of the height (row 1) and time (row 2) of the capillary rise of the binder on the pore diameter

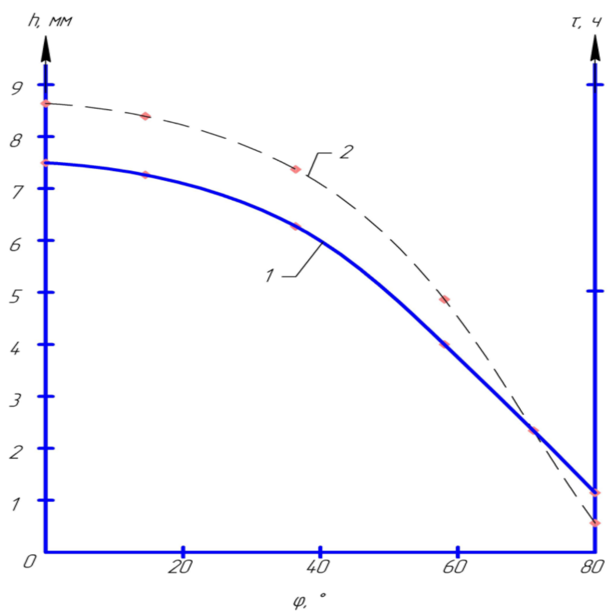


Fig. 7 - Dependence of the height (1) and time (2) of the capillary rise of the binder on the wetting angle of the base by the binder

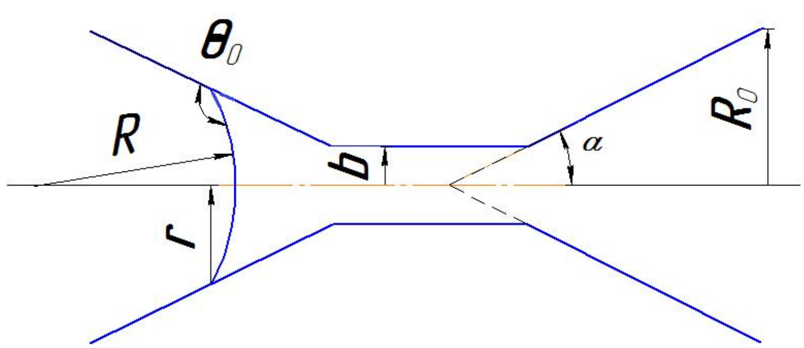


Figure 8 – Schematic of a narrowing - expanding pore

The pressure of the binder in this case is also determined by the Laplace equation. In a narrowing drop, the radius of curvature of the meniscus R, will be equal to

$$R = \frac{r}{\cos(\varphi + \alpha)}$$

In the expanding part, the angle α has a minus sign. Accordingly, the capillary pressure in the converging (+α) and expanding (–α) parts will be

$$\Delta P_k = \frac{2\sigma_{jg}\cos(\varphi \pm \alpha)}{r}$$

In the connecting neck

$$\Delta P_k = \frac{2\sigma_{jg}\cos\varphi}{r}$$

The mixing process takes place in a temperature range 140 ÷ 180 ^{0}C, at the same time $\varphi \approx 90 \pm 10^0$. From the given equations it is easy to establish that the greatest negative pressure preventing the penetration of liquid into the pore is created when the conical part of the narrowing pore passes into the neck. This pressure can be called the ”breakdown pressure”. Exceeding it allows one to overcome the ”narrow” section beyond which the binder fills the pore. This condition is achieved by creating additional pressure in the mixer itself or by achieving the wetting condition, when $\varphi \ll 90^0 + \alpha$.

The interaction of soot dust particles (enrichment agent) with the liquid phase of the binder is also associated with capillary phenomena in briquette compositions. Let there be a thin layer of wetting liquid between two closely located solid soot particles.

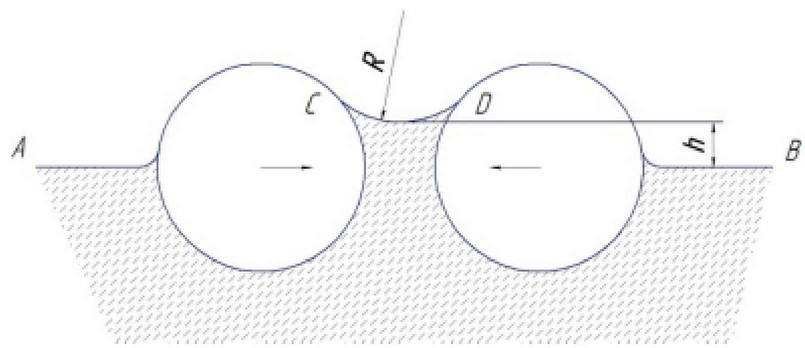


Fig. 9 - Movement of two particles on the surface of a liquid

The surface of the liquid, due to capillary phenomena, acquires a concave shape, raised above the level AB to a height h. Then, according to Laplace’ s law, there will be a negative pressure between the particles in the liquid, equal to

$$P = \frac{-2\sigma_{jg}\cos\varphi}{r}$$

In this case, atmospheric pressure will act on the outer surfaces of the particles, and below atmospheric pressure on the inner surfaces (below CD), which will lead to the particles coming closer together. Thus, a closed film of dust particles is formed on the surface of the liquid. The smaller the diameter of the dust particles, the stronger the forces holding them. The wetting ability of a drop of binder covered with a film is extremely low, which inhibits the processes of capillary penetration of the binder into the pores of the base particles. The filler and binder have a mutual influence in the composition of the briquette composition. By adsorbing on the surface of the filler particles, the molecules of petroleum pitch increase the effective diameter of the particles, which entails an increase in the volume concentration of the filler. According to the Einstein formula for diluted suspensions, with an apparent increase in the volume fraction C of solid spherical particles, the viscosity μ increases according to the formula

$$\mu = \mu_0(1 + 2,5C)$$

where μ_0 – viscosity at C = 0.

For concentrated systems according to the Gutman formula

$$\mu = \mu_0(1 + 2,5C + 14,1C^2)$$

For very high concentrations the formula is recommended

$$\frac{\mu}{\mu_0} = 2,5(1 - \varepsilon C)$$

where ε – coefficient depending on the filler concentration

Viscosity is associated with the phenomenon of filler sedimentation in the liquid phase of the binder. The resistance force experienced by a solid spherical particle of radius r when moving in a viscous liquid is determined by Stokes' law

$$F = 6\pi r \mu w$$

The maximum speed of a small ball falling in a viscous liquid is found using a well-known formula in physics, which follows from Stokes' law:

$$w_{pr} = \frac{\frac{2}{9} r^2 g \left(\rho^1 - \rho\right)}{\mu}$$

where ρ^1, ρ – particle and liquid density.

Using this formula, we calculated the dependence of the settling rate of coal particles, anode dust in petroleum pitch at 170 – 200 ^{0}C.

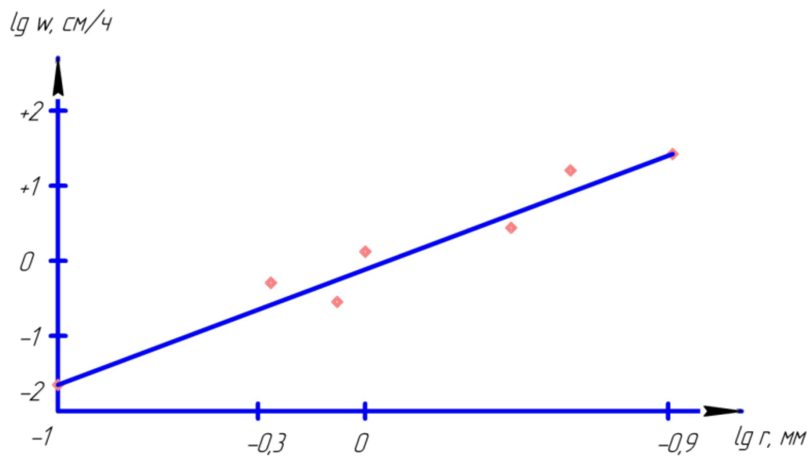


Fig. 10 - Dependence of the settling velocity of particles with a radius of 0.1 ÷ 8 mm in petroleum pitch

In the experiments, for greater clarity, a wider range of particle sizes was taken from 0.2 to 16 mm, although in the briquette mass the granulometry of coal is from 0.8 to 1.2 mm, and that of anode dust is from 0.2 to 0.4 mm.

Thus, with an increase in the particle radius from 0.1 to 8 mm, the settling rate increases from 0.024 to 118 cm/h. Let us further recalculate the viscosity of the binder to the viscosity of the filled system using the Gutman formula. Let us take the volume fraction of the filler as 0.72, while the viscosity of the composition will be an order of magnitude higher than the viscosity of the binder. Accordingly, the settling rate will also decrease by an order of magnitude to 0.0024 ÷ 11.8 cm/h.

The stability of the masses against sedimentation is a determining factor for maintaining the specified recipe in the liquid phase of the briquettes. The temperature dependence of viscosity, according to the Frenkel-Eyring theory, is determined by the expression:

$$\mu = Ae^{\frac{\Delta G}{RT}}$$

where A – constant;

G – free energy of activation of viscous flow;

R – gas constant.

This dependence is generally valid for the briquette mass. It is evident from the equation that with an increase in temperature T, the viscosity of the system decreases and with a large overheating, sedimentation can reach significant values.

Based on the theoretical studies outlined above, we investigated the adhesion processes in briquette compositions, namely, the adsorption of petroleum pitch by the surface of a coal grain, the wetting of the coal substrate with a drop of pitch, as well as the influence of various factors on adhesion in the specified systems.

The dependence of the adsorption capacity of dispersed base powders on their specific surface is shown in Figure 11, and on the grain size in Figure 12.

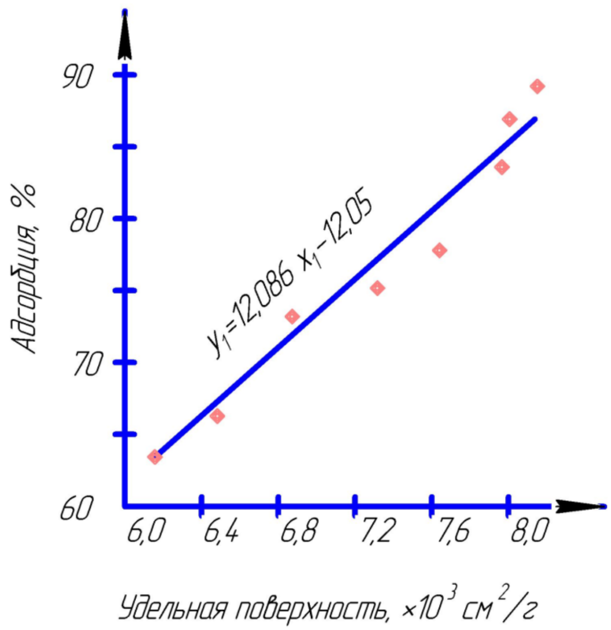


Fig. 11 - Dependence of the adsorption capacity of powders on their specific surface area

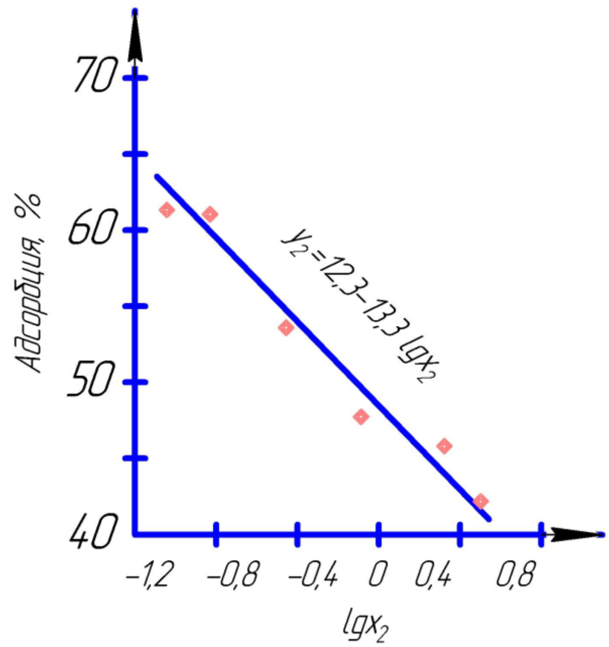


Fig. 12 - Dependence of adsorption capacity of powders on particle size

Evaluation of the quality of mixing of briquette mass

Preparation of briquette mass consists of two closely related processes: mixing (averaging) itself and physical and chemical processes of interaction of all components of the briquette composition. These processes are often superimposed on each other, and partially proceed sequentially.

To evaluate the qualitative side of the mixing process, one of the important indicators is the degree of homogenization of the mixed mass. In the limit, a completely homogenized mass should have the same component and grain composition in any macrovolumes. Therefore, the measure for evaluating the mixer' s operation is the standard deviation of the sample composition taken after a certain mixing time, or the degree of mixing, expressing the ratio of the actual deviation of a particular component of the mixture to the theoretical standard deviation of an ideally mixed mixture. The latter indicator, in the limit equal to 1 (or 100%), is more visual for evaluating the characteristics of the mixer' s operation.

Consequently, the evaluation of the quality of mixing can be partially carried out from the standpoint of statistical distribution parameters. There are dozens of formulas for quantitatively evaluating the distribution of mixed components in the final products. The coefficient of heterogeneity (variation) has become widespread as a criterion for the quality of mixing.

$$V_c = \frac{100S}{\overline{m}} = \frac{100}{\overline{m}}\sqrt{\frac{\sum_{i=1}^{n}(X_i-\overline{m})^2}{n-1}}, \%$$

where S – standard deviation;

$\overline{m}$ – arithmetic mean content of the controlled component in all samples;

n – number of samples;

$_i$—the value of random variable X in the i-th experiment.

It is advisable to evaluate the quality of mixing of masses using some control fraction of base particles (for example, 0.8–1.2 mm or 1–1.5 mm) in single samples *Ci*:

$$V_c = \frac{100S}{\overline{C}} = \frac{100}{\overline{C}}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\overline{C}_i - \overline{C}\right)^2}, \%$$

where – arithmetic mean of the number of particles in the samples studied, %.

However, as was indicated at the beginning of this section, mechanical mixing (homogenization) in itself does not yet mean obtaining a briquette mass as a stable polycomposition. The second stage - adhesion (wetting, sorption), capillary impregnation, etc. ensure the stable formation of the finest layers at the abrasive-substrate boundary, connected by the action of van der Waals, molecular and electrostatic forces. The presence of such forces leads to the formation of a solid volumetric structure. Only after the completion of these processes does the briquette mass turn into a cohesive, loose, extremely concentrated and structurally stabilized substance. It is the spatial structure of molecular forces that gives the substance plasticity, viscosity and stability of the composition.

For a normal (Newtonian) liquid, the movement of layers is caused by an arbitrarily small force. In structured systems, as a result of the presence of a sufficiently strong continuous structural network, it is necessary to apply some force to destroy it. According to a number of studies [17 -18] , the flow of such a system begins only from the moment when the shear stress R exceeds a certain critical value Rk, necessary for the destruction of the structure formed in this system. Such a flow is called plastic, and Rk is the yield point.

In the briquette mass at operating temperatures, a viscous flow is more typical, as in a normal Newtonian fluid. In the mass of the mixture, as a result of a sharp increase in the concentration of the base, one should expect a noticeable manifestation of elastic plastic properties and the yield point, which is especially important when forming briquettes in roller presses. This is what ensures the preservation of a stable shape of the briquettes after they exit the mold cells.

Considering the complexity of the above processes, the technological assessment of the quality of mixing sand-coal masses has a number of features. It is very important to assess the completion of the main processes during mixing: homogenization, adhesive interaction, enveloping, impregnation, etc. The rheological characteristics of the masses (viscous flow and plasticity, sedimentation in the liquid phase of the binder, pressing characteristics, etc.) are also taken into account.

A study of the adhesive-cohesive properties of petroleum pitch as a binder showed that the process of mixing coal and enrichment fractions with pitch plays a key role in the formation of the structure of the briquette mass.

Conclusion. As a result of the theoretical analysis of the briquetting process, the mechanism of coal briquettes structure formation was established taking into account the physicochemical and structural-rheological properties of coal. The main factors influencing the coal briquetting process are: coal moisture and moisture distribution in individual classes, coal size, distribution of elementary size classes in the briquette charge, granulometric composition, pressure, duration and temperature of pressing, that is, in general, the structural-rheological and physicochemical properties of the solid phase, as well as the water content. The application of high pressure during briquetting brings the particles closer together and increases interparticle contact, which results in an attractive force between adjacent particles through weak Van der Waals forces. During this process, particle deformation causes smaller binder particles to fill the voids in the original briquette mixture.

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