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STUDY ON THE GRINDING EFFICIENCY OF NON-DESIGN KARAZHYRA COAL IN BALL DRUM AND HAMMER MILLS

Annotation: *This paper presents a comparative study on the grinding efficiency of non-design Karazhyra coal using two main types of milling equipment: ball mills and hammer mills. The research was conducted to assess the suitability of local fuel for combustion in boiler units not originally designed for this type of coal. Laboratory sieve analysis was performed to determine the particle size distribution of the pulverized fuel. For the first time, polydispersity coefficients for Karazhyra coal dust, processed in both types of mills, were obtained and analyzed. Sieve residue measurements showed that in the product of the hammer mill only 0.2% of particles remained on the 400 μm sieve, whereas in the product of the ball drum mill this value was 2.5%. This indicates an almost complete elimination of coarse fractions during grinding in the hammer mill. It was found that with both grinding methods about 88% of coal dust particles are smaller than*

200 μm. At the same time, the residue on the 90 μm sieve was 32% for the ball drum mill and 53% for the hammer mill. Thus, the hammer mill product is characterized by an increased proportion of medium-sized particles (90-200 μm) in the absence of an excessive amount of ultrafine fractions. The absence of coarse and ultrafine fractions during grinding in the hammer mill contributes to the formation of a higher polydispersity index of coal dust, which was 1.51, whereas for the ball drum mill it was only 0.78. The findings suggest that both mills are suitable for fuel preparation, but the hammer mill ensures better combustion quality and thermal efficiency. Therefore, it is recommended as the more effective solution for the preparation of non-design coal in thermal. The conducted studies serve as a basis for further study of the characteristics and behavior of non-design coal in various operating modes.

Key words: *non-design coal, coal grinding, ball drum mill, hammer mill, particle size distribution, polydispersity coefficient.*

Introduction

Modern power generation facilities operating boiler equipment face the necessity of adapting to changing fuel supply conditions [1-2]. To conserve resources and improve economic efficiency, the use of non-design coal – those not originally intended for use in the equipment's design – is becoming increasingly common [3-4].

Switching to non-design coal entails a range of technical and operational challenges, including variability in calorific value, higher ash and moisture content, as well as potential corrosion and slagging issues. Nevertheless, the introduction of modern fuel preparation, dosing, and combustion technologies, along with improved automatic control systems, allows for the successful adaptation of existing boiler systems to alternative fuels [5-6].

One of the key stages in preparing non-design coal for combustion is grinding. The degree of fineness and the uniformity of particle size distribution affect not only combustion completeness, but also flame stability, ash content, equipment wear, and the overall efficiency of boiler units [7]. According to study [8], the influence of the grinding method and coal-biomass mixing on the atomization processes of fuel blends under varying atomizing air pressure was investigated. To evaluate the milling performance of coal and torrefied wood pellets (TPs), various blend ratios were tested using a bench-scale roller mill in study [9].

In [10] different coal preparation methods for small-capacity boiler applications were evaluated, demonstrating how fuel preprocessing can significantly improve combustion efficiency and environmental performance, reducing fuel consumption and emissions.

Study [11] experimentally assessed how mixing coal with biomass affects boiler performance and emissions, highlighting the operational implications of fuel preparation and dosing strategies.

Karazhyra coal is classified as a non-design fuel [12]. The relevance of this study lies in the need to ensure reliable and environmentally safe operation of boiler units using locally sourced coal. The aim of this work is to evaluate the effectiveness of preparing non-design coal for combustion by analyzing the fineness of coal dust produced by different types of milling equipment.

Methods

Karazhyra coal is predominantly burned in pulverized form, requiring that the coal dust meet specific dispersion standards [13]. Particle size significantly influences combustion efficiency and, consequently, the energy performance of boiler units.

Therefore, determining the particle size distribution of coal dust is a critical step in fuel preparation. Coal dust is a dispersed mixture of particles ranging from 0.1 to 500 μm [14]. To assess the combustion suitability of the coal dust, laboratory analyses were conducted at the Semey TPP-1 to determine grinding fineness. The sieve analysis method was used for this study.

Coal was ground in industrial mills: the hammer mill MMT-1300/1310/750K and the ball drum mill ShBM-10/250/390. The process was conducted at nominal fuel feed and standard air supply, with a calculated throughput of 16 t/h for MMT and 3.5 t/h for ShBM. Grinding parameters followed the manufacturer’s technical specifications. Samples of coal dust after mills were taken from dust pipelines in accordance with the requirements of GOST ISO 13909-4-2018 [15].

Sieve analysis involves screening a dust sample weighing 25-50 g through a set of standardized sieves [16]. Sieves with mesh sizes of 1000, 800, 400, 200, 120, 90, 75, and 60 μm are commonly used. In industrial conditions, sieving with two or three sieves (typically 90, 200, and 1000 μm) is often sufficient, starting with the coarsest.

The portion of material retained on a sieve is expressed as a percentage of the original sample mass and denoted as *R* with the sieve size as a subscript (e.g., R_{1000}). The portion that passes through the sieve is denoted as *D* with the mesh size (e.g., D_{200}). The sum of residue and passing material equals 100%.

Before entering the mills, the non-design coal was pre-cleaned of gravel and metal inclusions and pre-crushed in crushers. A two-stage crushing system is used at the TPP, ensuring a maximum coal chunk size of 200 mm at the crusher outlet.

The sieve analysis of non-design coal involved the following four stages:

1. Sampling 50 g fuel portions after grinding in the ball drum and hammer mills;
2. Sieving each sample for 20 minutes using a vibratory sieve shaker;
3. Measuring the mass of residue on each sieve;
4. Calculating the particle size distribution.

In addition to residue determination, an important parameter in evaluating the grinding quality is the polydispersity coefficient (n), which reflects the uniformity of the particle size distribution [14]. A higher ***n*** value indicates a uniform particle size. It is calculated using Equation (1):

$$n = \frac{lgln\frac{100}{R_{200}} - lgln\frac{100}{R_{90}}}{\lg\frac{200}{90}} \quad (1)$$

Hammer mills typically produce dust with **n** values between 1.1 and 1.6, while ball drum mills yield **n** values between 0.7 and 1. A more uniform grind results in better ignition and combustion of coal dust [16].

Results and Discussion

The sieve analysis yielded integral grain size characteristics of the Karazhyra coal. Figure 1 shows the dependence of residue percentage on particle size **x**.

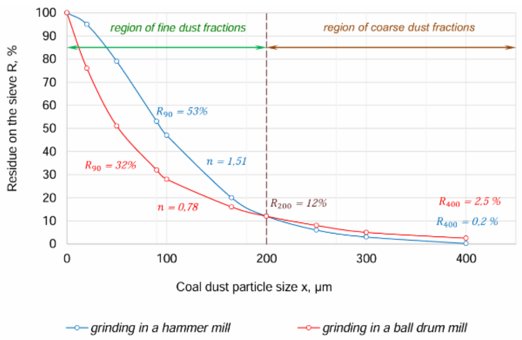

Figure 1 – Integral grain size characteristics of Karazhyra coal dust

The curve representing the integral grain size distribution of Karazhyra non-design coal dust produced in a hammer mill is steeper than the corresponding curve for dust produced in a ball drum mill.

Analysis of the results indicates that coal dust from non-design Karazhyra coal produced in a hammer mill is closer to monodisperse.

The particle residue on the 400-micron sieve was 2.5% for the ball drum mill and only 0.2% for the hammer mill. This indicates that grinding in the hammer mill virtually eliminates the presence of excessively coarse particles, which are characterized by poor combustion performance.

The residue on the 200-micron sieve was 12%, meaning that 88% of the coal dust particles from the non-design fuel were smaller than 200 microns and passed easily through the sieve. Consequently, the high proportion of particles passing through the sieve indicates a low content of coarse fractions in the dust obtained by both methods of non-design coal grinding.

Most of the coal dust from non-design fuel is concentrated in the fine fraction range. On the 90-micron sieve, the residue was 32% for the ball drum mill and 53% for the hammer mill. This means that the hammer mill retains a larger proportion of medium-sized particles (90-200 μm) without producing an excessive amount of ultrafine fractions. Such a balance is beneficial for stable combustion, as an overabundance of very fine particles leads to fuel losses due to entrainment.

The absence of coarse and ultrafine fractions during grinding in the hammer mill contributes to the formation of a higher polydispersity index of coal dust. The polydispersity coefficient (n) of coal dust obtained by grinding in a ball drum mill was 0.78, while grinding in a hammer mill yielded a value of 1.51.

Table 1 presents the results of a comparative analysis of hammer and ball drum mill performance in preparing coal dust from non-design Karazhyra coal.

Table 1 – Comparative Analysis of Hammer Mill and Ball Drum Mill Performance in Preparing Coal Dust from Non-Design Karazhyra Coal

Parameter	Hammer Mill	Ball Drum Mill
Operating principle	Grinding by hammer impact	Grinding by impact and friction of metal balls inside the drum
Uniformity of non-design fuel grind	n = 1.51 (toward upper range for hammer mills; particles are relatively uniform)	n = 0.78 (toward lower range for ball drum mills; particles are less uniform)
Dust particle size range	88% of particles < 200 μm; fine fractions dominate, ensuring better combustion, higher heat output, and stable burning	

A comparative analysis of the two primary types of mills confirms that both are suitable for producing coal dust from non-design Karazhyra coal. However, the hammer mill showed higher grinding efficiency under the test conditions, providing more stable and economical equipment operation compared to the ball drum mill.

Conclusion

The use of non-design coal, particularly Karazhyra coal, is a promising approach to ensuring energy security and stable operation of boiler units under limited fuel supply conditions. This study led to the following conclusions:

- For the first time, polydispersity coefficients were determined for coal dust from Karazhyra coal ground in two types of milling equipment: hammer mill (**n** = 1.51) and ball drum mill (**n** = 0.78). These coefficients reflect particle size uniformity and enable comparative grinding performance assessments.
- Integral grain size characteristics of coal dust from both mills were established. Sieve analysis revealed greater fineness from the hammer mill.
- Residue on the 400 μm sieve was 0.2% for the hammer mill and 2.5% for the ball drum mill, indicating fewer coarse particles in the former. At 90 μm, the residue was 53% and 32%, respectively, showing a higher proportion of fine particles in the hammer-milled dust.
- Both mills produced coal dust suitable for pulverized coal combustion. However, the hammer mill achieved better grinding homogeneity and fineness.
- Based on the experimental data, the hammer mill can be recommended as the preferred equipment for preparing non-design Karazhyra coal for combustion in existing boiler systems.
- This research highlights the importance of controlling particle size distribution and grinding fineness as key factors in combustion efficiency and environmental safety. The findings can be used to optimize boiler operations when switching to local fuels, reducing operational costs, improving efficiency, and minimizing emissions.

Furthermore, the study provides a foundation for further exploration of non-design coal behavior under various operating conditions, enabling more precise recommendations for equipment settings, combustion modes, and the development of new solutions tailored to local fuel characteristics.

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ШАРЛЫ БАРАБАНДЫ ЖӘНЕ БАЛҒАЛЫ ДИІРМЕНДЕРДЕ ЖОБАЛАНБАҒАН ҚАРАЖЫРА КӨМІРІН ҰНТАҚТАУ ТИІМДІЛІГІН ЗЕРТТЕУ

Жұмыста жобаланбаған Қаражыра көмірді ұнтақтау жабдықтарының екі негізгі түрін: шар барабанды диірмен мен балғалы диірменді пайдалана отырып, ұнтақтау тиімділігінің салыстырмалы түрде зерттеу жасалған. Зерттеулер бастапқыда көмірдің осы түріне арналмаған қазандық қондырғыларында жергілікті отынның жағуға жарамдылығын бағалау үшін жүргізілді. Ұнтақталған отынның гранулометриялық құрамын анықтау үшін зертханалық електен талдау жүргізілді. Алғаш рет диірмендердің екі түрінде де өңделген Қаражыра көмір шаңы үшін полидисперстілік коэффициенттері алынып, талданған. Елеуіште қалдықтарды өлшеу нәтижелері бойынша балғалы диірмен өнімінде 400 мкм өлшемді елеуіште небәрі 0,2 % бөлшек қалса, шарлы *барабанды диірмен өнімінде бұл көрсеткіш 2,5 % болды. Бұл балғалы диірменде ірі фракциялардың іс жүзінде толық жойылатынын көрсетеді. Екі тәсілмен ұнтақтау кезінде де шамамен 88 % көмір шаңы бөлшектерінің өлшемі 200 мкм-ден аз екені анықталды. Сонымен қатар, 90 мкм өлшемді елеуіштегі қалдық шарлы барабанды диірмен үшін 32 %, ал балғалы диірмен үшін 53 % құрады. Осылайша, балғалы диірмен өнімі шамадан тыс ультраұсақ фракциялар болмаған жағдайда орташа өлшемді бөлшектердің (90-200 мкм) жоғары үлесімен сипатталады. Балғалы диірменде ұнтақтау барысында ірі және ультраұсақ фракциялардың болмауы көмір шаңының полидисперстілік коэффициентінің жоғары болуына ықпал етеді, ол 1,51 құраса, шарлы барабанды диірмен үшін бұл көрсеткіш небәрі 0,78 болды. Алынған нәтижелер екі диірменнің де жобаланбаған отын дайындауға жарамды екенін көрсетеді, бірақ балғалы диірмен жақсырақ жану сапасын және жылу тиімділігін қамтамасыз ететіні анық болды. Сондықтан жылу электр станцияларында жобаланбаған көмірді дайындаудың ең тиімді шешімі ретінде ұсынылады. Жүргізілген зерттеулер әртүрлі жұмыс режимдеріндегі жобаланбаған көмірдің сипаттамалары мен мінез-құлқын одан әрі зерттеуге негіз болады.*

Түйін сөздер: *жобаланбаған көмір, көмірді ұнтақтау, шарлы барабанды диірмен, балғалы диірмен, гранулометриялық құрамы, полидисперстік коэффициент.*

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ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ ИЗМЕЛЬЧЕНИЯ НЕПРОЕКТНОГО УГЛЯ КАРАЖЫРА В ШАРОВЫХ БАРАБАННЫХ И МОЛОТКОВЫХ МЕЛЬНИЦАХ

В данной работе представлено сравнительное исследование эффективности измельчения непроектного угля Каражыра с использованием двух основных типов измельчительного оборудования: шаровых барабанных мельниц и молотковых мельниц. Исследования проводились с целью оценки пригодности местного топлива для сжигания в котельных агрегатах, изначально не предназначенных для данного типа угля. Для определения гранулометрического состава пылевидного топлива был проведен лабораторный ситовой анализ. Впервые получены и проанализированы коэффициенты полидисперсности для пыли угля Каражыра, измельченной в обоих типах мельниц. Измерения остатков на ситах показали, что в продукте молотковой мельницы на сите с размером ячейки 400 мкм осталось лишь 0,2% частиц, тогда как в продукте шаровой барабанной мельницы – 2,5%. Это свидетельствует о практически полном удалении грубых фракций при размоле в молотковой мельнице. Установлено, что при обоих способах измельчения около 88% частиц угольной пыли имеют размер менее 200 мкм. При этом остаток на сите 90 мкм составил 32% для шаровой барабанной мельницы и 53% для молотковой. Таким образом, продукт молотковой мельницы отличается повышенной долей частиц среднего размера (90-200 мкм) при отсутствии избыточного количества ультрамелких фракций. Отсутствие грубых и ультрамелких фракций при размоле в молотковой мельнице способствует формированию более высокого показателя полидисперсности угольной пыли, который составил 1,51, тогда как для шаровой барабанной мельницы он равен лишь 0,78. Полученные результаты свидетельствуют о том, что обе мельницы подходят для подготовки топлива, но молотковая мельница обеспечивает лучшее качество сгорания и тепловую эффективность. Поэтому рекомендуется как наиболее эффективное решение для подготовки непроектного угля в тепловых электростанциях. Проведённые исследования служат основой для дальнейшего изучения характеристик и поведения непроектного угля в различных режимах эксплуатации.

Ключевые слова: *непроектный уголь, измельчение угля, шаровая барабанная мельница, молотковая мельница, гранулометрический состав, коэффициент полидисперсности.*

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INVESTIGATION OF THE DYNAMICS OF THE RESPONSE OF THE REFRIGERATION SYSTEM UNDER CONDITIONS OF SEVERE HEAT EXPOSURE

Annotation: *This article presents an assessment of the performance of a vapor-compression refrigeration system under shock thermal load. The study was carried out on a modernized experimental stand «Kholodilnik-2» equipped with a digital monitoring system, including 24 DS18B20 sensors and an STM32 microcontroller. The main objective was to compare the system behavior when introducing an object with temperatures of 40, 60, and 80°C after reaching a quasi-steady-state mode. Temperature curves, transient process duration, and stabilization times were analyzed. Additionally, features of temperature distribution*