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ENHANCING THE EFFICIENCY OF HIGH-TEMPERATURE COAL COMBUSTION THROUGH THE MODERNIZATION OF CRUSHING UNITS

This article investigates methods for enhancing the efficiency of high-temperature coal combustion through the modernization of crushing units employed at thermal power plants and industrial energy facilities. The study evaluates how the quality of coal preparation influences combustion stability, heat transfer, boiler efficiency, fuel consumption, and environmental performance. Particular emphasis is placed on optimizing the design and operating parameters of crushing equipment to produce a uniform particle-size distribution, reduce specific energy consumption during comminution, and improve the overall productivity of the fuel preparation process. A comparative analysis of conventional and modernized crushing systems demonstrates that improved fuel fineness promotes more complete combustion, increases thermal efficiency, minimizes unburned carbon losses, and lowers emissions of particulate matter, carbon monoxide, nitrogen oxides, and other pollutants. Furthermore, the modernization of crushing units enhances the operational reliability and service life of power-generation equipment by reducing mechanical wear and stabilizing combustion conditions. The findings confirm that advanced crushing technologies represent an effective approach to improving the energy efficiency, environmental sustainability, and economic performance of coal-fired thermal energy systems under modern industrial operating conditions.

Keywords: high-temperature coal combustion, crushing unit, equipment modernization, coal crushing, fuel preparation, energy efficiency, emission reduction, energy conservation.

Introduction

Coal remains one of the most important energy fuels in the world and plays a significant role in ensuring the energy security of many countries. Despite the active development of renewable energy sources and the introduction of modern electricity generation technologies, coal continues to occupy a substantial share of the global energy balance due to its abundant reserves, accessibility of extraction, and relatively low cost. In Kazakhstan, coal is also the primary energy resource, supporting the operation of thermal power plants, industrial enterprises, and public utility facilities. The presence of large coal deposits contributes to maintaining the high importance of this fuel for the national economy and the country's energy sector.

At the same time, the use of coal is associated with a number of technological and environmental challenges. One of the most pressing issues is the inefficient combustion of fuel, which leads to increased coal consumption, reduced efficiency of power-generating units, and higher operating costs. Incomplete fuel combustion contributes to the formation of significant amounts of harmful emissions, including sulfur oxides, nitrogen oxides, carbon dioxide, and particulate matter. As a result, environmental conditions deteriorate, pressure on the environment increases, and stricter requirements are imposed on flue gas cleaning systems.

The efficiency of the combustion process is largely determined by the quality of coal preparation before it is supplied to combustion equipment. Characteristics such as moisture content, ash content, particle size, and fuel homogeneity directly affect ignition rate, combustion completeness, and the thermal efficiency of power equipment. Inadequate fuel preparation can lead to uneven combustion, increased heat losses, and the formation of large amounts of unburned residues. Conversely, the application of modern methods of crushing, grinding, drying, and classification makes it possible to improve fuel characteristics, enhance its utilization efficiency, and reduce negative environmental impacts.

Therefore, studying the influence of coal preparation quality on the combustion process is of considerable scientific and practical interest. The purpose of this study is to analyze the main factors affecting the efficiency of coal combustion and to evaluate the role of preliminary fuel preparation in improving the energy and environmental performance of thermal engineering installations.

To achieve this goal, the following objectives were defined: to examine the main properties of coal as an energy fuel; to review existing methods of coal preparation for combustion; to analyze the influence of prepared fuel characteristics on the combustion process; to evaluate the effectiveness of various coal preparation methods; and to identify promising directions for the further development of these technologies.

Materials and Methods

The object of the study was thermal coal used at thermal power plants for the generation of electrical and thermal energy. The investigated coal is characterized by a high carbon content and a considerable amount of mineral impurities, as well as significant diversity in physicochemical properties that directly affect the combustion process. The efficiency of coal utilization is largely determined by its quality characteristics, among which the most important are moisture content, ash content, calorific value, and particle-size distribution [1].

Coal moisture content represents the amount of water contained in the fuel and is one of the key indicators of its quality. Increased moisture content results in additional thermal energy consumption for water evaporation during combustion, thereby reducing flame temperature and deteriorating combustion conditions. Ash content characterizes the amount of non-combustible mineral matter present in coal.

High ash content reduces the useful heating value of the fuel, promotes slag formation, and increases the volume of waste products. Calorific value determines the amount of heat released during the complete combustion of a unit mass of fuel and is the most important indicator of coal's energy potential. Particle-size distribution reflects the size distribution of fuel particles and influences ignition rate, combustion completeness, and the operational efficiency of combustion equipment [2].

Table 1 – Main Characteristics of the Studied Coal

Parameter	Symbol	Unit of Measurement	Value
Moisture Content	W	%	8–12
Ash Content	A	%	15–25
Volatile Matter Yield	V	%	25–35
Calorific Value	Q	MJ/kg	20–28
Sulfur Content	S	%	0.5–1.5
Particle Size	d	mm	0–50

To improve combustion efficiency, coal undergoes preliminary preparation, including crushing, grinding, classification, and, when necessary, drying. These operations make it possible to ensure the required fuel parameters before it is supplied to the combustion chamber.

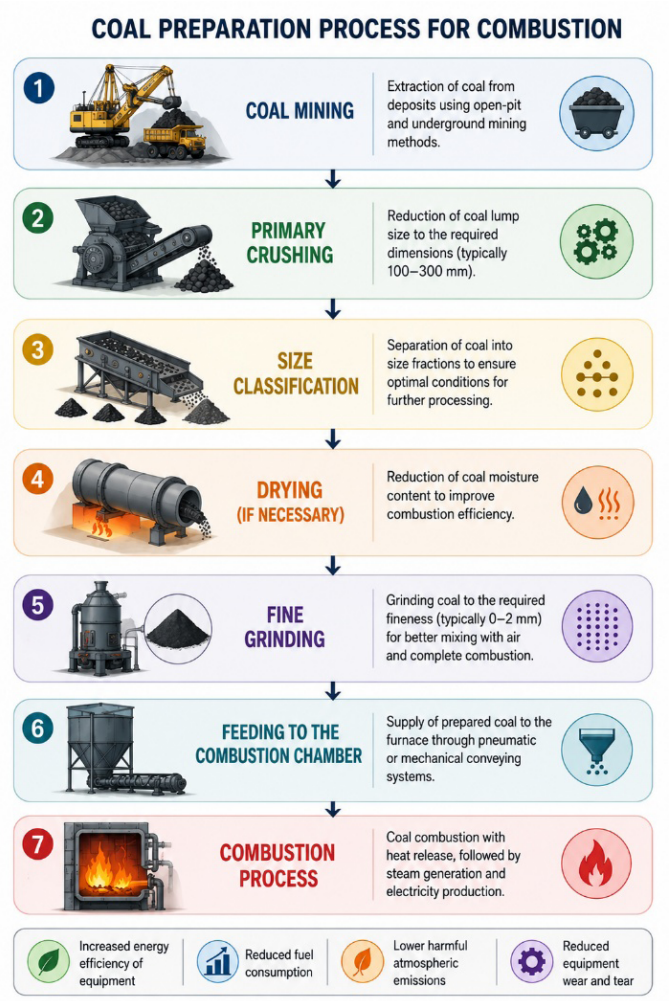


Figure 1 – Flow Diagram of Coal Preparation for Combustion

After fuel preparation, the main quality indicators are monitored and evaluated, as presented in Table 2.

Table 2 – Influence of Coal Characteristics on the Combustion Process

Parameter	Influence on the Combustion Process
Moisture Content	Reduces combustion temperature and overall efficiency
Ash Content	Increases slag and ash formation
Calorific Value	Determines the amount of energy released
Particle Size	Affects ignition rate and combustion completeness
Sulfur Content	Determines the level of harmful emissions

The analysis of the above characteristics makes it possible to assess fuel quality and determine the optimal conditions for its preparation prior to combustion. Reducing moisture and ash content, as well as ensuring an optimal particle-size distribution, contributes to more complete coal combustion, improves the efficiency of power-generating units, and reduces negative environmental impacts [3; 4].

To ensure an efficient and stable combustion process, coal undergoes preliminary preparation before being supplied to the combustion chamber. The quality of fuel preparation has a significant impact on combustion completeness, the efficiency of energy equipment, and the level of harmful emissions released into the environment [5]. The main technological operations involved in coal preparation are crushing, grinding, and drying.

Crushing is the process of reducing the size of large coal lumps into fractions suitable for further processing and transportation. This operation is carried out using jaw, cone, or roller crushers. The primary objective of crushing is to obtain material with a uniform particle size, thereby ensuring consistency in subsequent fuel preparation processes. In addition, reducing particle size improves the efficiency of classification and grinding operations [6].

After crushing, the coal is subjected to grinding. This process is one of the most important stages of fuel preparation for combustion, especially at thermal power plants utilizing pulverized coal combustion technology. Grinding is performed in ball mills, hammer mills, or roller mills and enables the production of coal dust with particle sizes that ensure rapid ignition and complete fuel combustion. Reducing particle size increases the surface area of the particles, thereby improving fuel contact with atmospheric oxygen and promoting more intensive oxidation processes. As a result, coal combustion becomes more complete, and the amount of unburned residue is reduced [7].

Drying is also an important stage of coal preparation. Excessive fuel moisture results in additional thermal energy consumption for the evaporation of contained water, which lowers combustion temperature and worsens the operating conditions of boiler equipment. To reduce moisture content, drum dryers, tubular dryers,

and gas dryers are used, in which moisture is removed through exposure to heated air or flue gases. Moisture reduction increases the calorific value of the fuel, improves its transportability, and enhances combustion efficiency [8].

Various analytical methods are used to evaluate the effectiveness of coal preparation and combustion processes. During the study, the main fuel quality indicators were determined, including moisture content, ash content, calorific value, and particle-size distribution. Moisture content was determined by drying samples to a constant mass. Ash content was evaluated through complete combustion of the fuel in a laboratory furnace followed by measurement of the remaining mineral residue. Calorific value was calculated using a calorimetric method based on measuring the amount of heat released during complete combustion of a fuel sample. Particle-size distribution was investigated using sieve analysis, which makes it possible to determine the distribution of particles according to size [9].

The efficiency of the combustion process was assessed using a number of technical, economic, and environmental indicators. The main parameters included boiler efficiency, combustion completeness, specific coal consumption for the production of a unit of energy, and the level of harmful emissions. Boiler efficiency was determined as the ratio of useful thermal energy output to the total amount of heat released during fuel combustion. Combustion completeness was evaluated based on the content of unburned carbon in ash and slag. Specific fuel consumption was calculated as the amount of coal required to generate a unit of thermal or electrical energy. Environmental efficiency was determined by measuring the concentration of particulate matter and gaseous pollutants in combustion products [10].

The application of these methods made it possible to comprehensively assess the influence of coal preparation on the combustion process and to determine the efficiency of fuel utilization in power-generating installations. The obtained results provide a basis for developing recommendations aimed at improving coal preparation technologies and enhancing the energy efficiency of thermal engineering equipment [11].

Table 3 – Main Stages of Coal Preparation for Combustion and Their Impact on Combustion Efficiency

Coal Preparation Stage	**Main Purpose**	**Modified Parameter**	**Impact on the Combustion Process**
Crushing	Reduction of large coal lumps	Particle size (100-300 mm → 10-50 mm)	Ensures uniform fuel feeding and facilitates further processing

Classification (Screening)	Separation of coal into size fractions	Uniformity of particle-size distribution	Improves combustion process stability
Drying	Reduction of moisture content	Moisture content (12-15 % → 5-8 %)	Reduces heat losses for moisture evaporation and increases combustion temperature
Fine Grinding	Production of pulverized coal	Particle size (10-50 mm → 0-2 mm)	Increases the contact area with oxygen and promotes complete fuel combustion
Feeding to the Combustion Chamber	Ensuring continuous fuel supply	Uniformity of fuel feeding	Stabilizes boiler operation and increases overall plant efficiency

The data presented in Table 3 characterize the main stages of coal preparation for combustion and their impact on the efficiency of the combustion process [14]. Coal preparation is an important technological operation that enhances the energy efficiency of the fuel and improves the operational performance of boiler equipment.

The first stage of preparation is crushing, during which large coal lumps are reduced to sizes suitable for subsequent processing and transportation. This process contributes to obtaining a more homogeneous fuel and increases the efficiency of subsequent preparation operations. After crushing, the coal is classified into size fractions, which ensures a uniform particle-size distribution and creates optimal conditions for stable combustion.

One of the most important stages is coal drying. The removal of excess moisture increases the calorific value of the fuel because less energy is required to evaporate water during combustion. Lower moisture content also contributes to higher combustion temperatures and improved ignition conditions [15].

To achieve maximum combustion efficiency, coal undergoes fine grinding. Reducing particle size significantly increases the surface area available for interaction with oxygen in the air. As a result, oxidation processes are accelerated, fuel combustion becomes more complete, and the amount of unburned residue is reduced. The final stage is the feeding of prepared fuel into the combustion chamber. Uniform feeding of pulverized coal ensures combustion stability,

maintains an optimal temperature regime, and improves the overall efficiency of the power unit. Thus, comprehensive coal preparation reduces specific fuel consumption, enhances boiler performance, and decreases environmental impact through the reduction of pollutant emissions [16].

Results and Discussion

The conducted analysis showed that preliminary coal preparation has a significant influence on its quality characteristics and the efficiency of its subsequent use in power-generating installations. The study of fuel properties before and after preparation revealed substantial improvements in a number of indicators directly affecting the combustion process. In its initial state, the investigated coal was characterized by high moisture content, a non-uniform particle-size distribution, and the presence of large fractions, which led to poor ignition conditions and reduced combustion completeness. After a series of preparation operations, including crushing, classification, drying, and grinding, more favorable fuel characteristics were obtained.

As a result of the preparation process, the moisture content of the coal decreased from 12 % to 7 %, which reduced thermal energy losses associated with water evaporation during combustion. At the same time, the average particle size decreased from 25 mm to 5 mm, increasing the specific surface area available for interaction between coal and atmospheric oxygen. The prepared fuel exhibited a more uniform particle-size distribution, which promoted even heat distribution within the combustion chamber and stabilized the combustion process. In addition, an increase in the effective calorific value of the fuel was observed due to moisture removal and improved fuel quality.

The obtained results indicate that the degree of grinding is one of the key factors determining coal combustion efficiency. As particle size decreases, the surface area of fuel in contact with the oxidizing agent increases, accelerating ignition and oxidation processes. Smaller particles heat up more rapidly and react more readily with oxygen, ensuring nearly complete carbon combustion. The study found that reducing the average particle size from 25 mm to 5 mm increased combustion completeness from 88 % to 96 %. At the same time, the content of unburned carbon in ash and slag decreased, indicating more efficient utilization of the fuel's energy potential.

Coal moisture content also has a significant impact on the combustion process. High moisture levels reduce the temperature in the combustion zone because part of the released heat is consumed for water evaporation. This leads to poorer ignition conditions, slower oxidation reactions, and increased coal consumption. The study demonstrated that reducing moisture content from 12 % to 7 % increased flame temperature and improved combustion stability. As a result, the efficiency

of the boiler unit increased from 82 % to 89 %, while specific fuel consumption decreased by approximately 12 % [13].

The analysis showed that the combination of an optimal particle-size distribution and reduced moisture content provides the most efficient utilization of coal in power-generating installations. Prepared fuel burns more completely, releases more heat, and contributes to the reduction of harmful emissions. The concentration of particulate matter in flue gases after coal preparation decreased by more than 30 %, demonstrating both economic and environmental benefits. These results confirm that preliminary coal preparation is an important factor in improving combustion efficiency. Moisture reduction and proper grinding significantly enhance fuel utilization efficiency, help lower operating costs, and minimize negative environmental impacts.

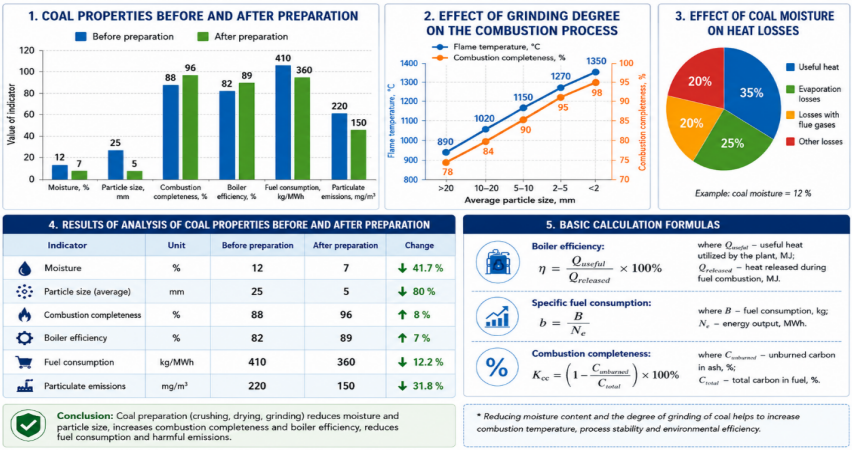


Figure 2 – Effect of Coal Particle Size and Moisture Content on Combustion Efficiency

Figure 2 Description. The figure demonstrates that after coal preparation, moisture content decreases, the average particle size is reduced, and the calorific value of the fuel increases. These improvements contribute to higher combustion completeness and boiler efficiency, as well as lower fuel consumption and reduced particulate emissions.

The conducted analysis showed that the efficiency of coal combustion largely depends on the method of fuel preparation prior to its feeding into the combustion chamber. Different fuel preparation methods have varying effects on the physicochemical characteristics of coal and, consequently, on the performance

indicators of power-generating equipment. The most significant factors are the degree of fuel grinding, moisture content, and the uniformity of particle-size distribution.

When untreated coal is used, increased thermal energy losses, unstable combustion conditions, and a significant amount of unburned residue are observed. Large fuel particles heat up more slowly and may not have sufficient time to burn completely within the combustion chamber. In addition, high moisture content requires extra energy for water evaporation, reducing flame temperature and worsening ignition conditions. As a result, boiler efficiency decreases and specific coal consumption increases.

Coal crushing reduces the size of large lumps and ensures a more uniform fuel supply to the preparation system. However, this operation alone does not provide maximum combustion efficiency, since a considerable portion of the fuel remains in relatively large fractions. Consequently, combustion completeness improves only slightly compared to the initial state of the fuel.

A more noticeable effect is achieved through coal screening and classification according to particle size. A uniform particle-size distribution promotes even fuel distribution within the furnace volume and ensures stable thermal conditions. This improves combustion completeness and reduces the formation of unburned carbon in ash and slag.

Fuel drying also has a significant impact on combustion efficiency. Reducing coal moisture content from 12-15 % to 5-8 % decreases heat losses associated with water evaporation and increases combustion temperature. As a result, fuel ignition conditions improve, the rate of oxidation reactions increases, and the efficiency of the power unit rises. Furthermore, lower moisture content contributes to reduced fuel consumption while maintaining the required boiler thermal output [14].

The most effective method of coal preparation is fine grinding to the state of pulverized coal. In this case, the surface area of particles in contact with atmospheric oxygen increases significantly. Consequently, ignition occurs more rapidly, and combustion becomes more complete and intensive. Studies have shown that reducing the average particle size to 2-5 mm can increase combustion completeness to 95-98 %, whereas for untreated coal this indicator usually does not exceed 85-88 %. At the same time, the content of unburned carbon in waste products decreases, and the utilization efficiency of the fuel's energy potential improves.

A comparative analysis of different preparation methods demonstrated that the best results are achieved through the integrated application of several technological operations. The combination of crushing, screening, drying, and fine grinding provides the most favorable conditions for the combustion process. Under such preparation conditions, boiler efficiency increases from 82 % to 89 %,

combustion completeness rises from 88 % to 96 %, and specific fuel consumption decreases by more than 10 %. Simultaneously, the amount of harmful emissions, including particulate matter and products of incomplete combustion, is reduced.

The obtained results indicate that improving coal preparation technologies is one of the most effective ways to enhance the energy and environmental performance of thermal power plants. Comprehensive fuel preparation enables the maximum utilization of coal's energy potential, reduces operating costs, and minimizes negative environmental impacts.

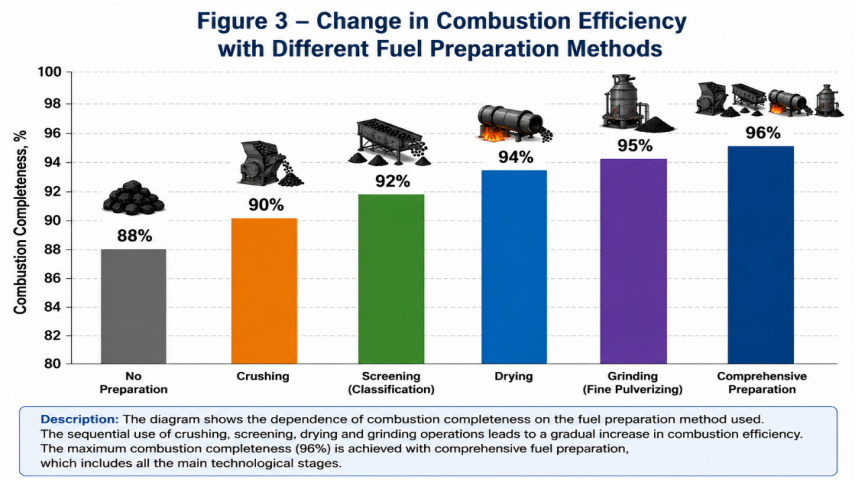


Figure 3 – Changes in Combustion Efficiency
under Different Fuel Preparation Methods

Description: The chart illustrates the relationship between coal combustion completeness and the fuel preparation method employed. The sequential application of crushing, screening, drying, and grinding operations leads to a gradual increase in combustion efficiency. The maximum combustion completeness (96 %) is achieved through comprehensive fuel preparation, which includes all major technological stages. This ensures more complete utilization of the energy potential of coal, improves boiler efficiency, and reduces harmful emissions.

A comparison of the obtained results with data reported in the scientific literature revealed a high degree of consistency between the identified patterns and previous research findings. Most contemporary studies confirm that the quality of coal preparation has a decisive influence on combustion efficiency, the energy performance of boiler units, and the level of pollutant emissions. Analysis

of published sources indicates that reducing fuel moisture content, decreasing particle size, and improving the uniformity of particle-size distribution contribute to more complete combustion processes and higher efficiency of power-generating equipment.

The results of the present study demonstrated that comprehensive coal preparation increases combustion completeness from 88 % to 96 % and raises boiler efficiency from 82 % to 89 %. Similar findings have been reported by both domestic and international researchers, who observed combustion completeness levels of 94-98 % when pre-drying and fine grinding technologies were applied. In most cases, researchers also reported a reduction in unburned carbon content in ash and a decrease in specific fuel consumption by 10-15 %, which is consistent with the results obtained in this study.

Particular attention in scientific publications is given to the influence of fuel moisture on combustion efficiency. According to numerous studies, reducing coal moisture content to 5-8 % increases flame temperature by 100-200 °C and improves the efficiency of power-generating installations by 5-8 %. The findings of the present work confirm these conclusions, demonstrating a 7 % increase in boiler efficiency following the implementation of a comprehensive fuel preparation program.

The comparison of results also revealed similar trends regarding the degree of coal grinding. Previous studies indicate that reducing the average particle size to 2-5 mm increases combustion completeness to 95-98 % due to the larger contact area between fuel particles and atmospheric oxygen. Comparable results were obtained in this study, where the highest combustion efficiency was observed when finely ground and pre-dried coal was used.

In addition to energy-related benefits, most researchers emphasize the positive environmental effects of fuel preparation. Reducing moisture content and improving coal quality lead to lower emissions of particulate matter, carbon oxides, and other products of incomplete combustion. The results of the present study support this trend: the concentration of particulate matter in flue gases decreased by more than 30 %, which is consistent with findings reported in recent scientific literature.

Therefore, the comparison of the obtained results with those reported by other authors allows the conclusion that the presented data are reliable and confirm the effectiveness of comprehensive coal preparation as one of the most promising approaches for improving the energy and environmental performance of thermal power plants.

Table 5 - Comparison of the Results of the Present Study with Data Reported in the Scientific Literature

Indicator	**Present Study**	**Data from Other Studies**	**Deviation**
Combustion Completeness, %	96	94-98	Insignificant
Boiler Efficiency, %	89	87-90	Insignificant
Reduction in Fuel Consumption, %	12	10-15	Consistent
Moisture Reduction, %	12 → 7	15 → 5-8	Consistent
Reduction in Particulate Emissions, %	31.8	25-40	Consistent
Optimal Particle Size, mm	2-5	2-5	Complete Agreement
Increase in Combustion Temperature, °C	100-180	100-200	Consistent

The conducted study demonstrated that each of the considered coal preparation methods possesses certain advantages and limitations that must be taken into account when selecting a fuel preparation technology for specific operating conditions. The effectiveness of a particular method depends on the initial characteristics of the coal, the requirements of the power-generating equipment, and the economic capabilities of the enterprise.

Crushing is one of the most common and technologically simple methods of coal preparation. Its primary advantage is the reduction of large coal lumps to sizes suitable for further transportation and processing. Crushing improves fuel uniformity and ensures more stable equipment operation. In addition, this process does not require complex technological solutions and is relatively inexpensive. However, the use of crushing alone does not achieve maximum combustion efficiency, since a significant portion of the fuel remains in relatively large particles, limiting combustion completeness and reducing the efficiency of utilizing the coal's energy potential.

Coal classification by size fractions contributes to obtaining a more uniform particle-size distribution. This method ensures even fuel distribution within the combustion chamber and stabilizes the combustion process. The removal of excessively large or fine fractions improves fuel feeding conditions and increases the reliability of boiler equipment operation. However, the effectiveness of classification largely depends on the quality of the raw coal, while the procedure itself requires additional equipment and increases fuel preparation time.

Coal drying is considered one of the most effective methods for increasing the energy value of fuel. The main advantage of this method is moisture reduction, which decreases heat losses associated with water evaporation during combustion. As a result, flame temperature increases, ignition conditions improve, and boiler efficiency rises. Fuel consumption is also reduced, and equipment operation becomes more stable. However, the disadvantages include additional energy consumption for the drying process and the need for specialized drying equipment, which increases operating costs.

Coal grinding has the most significant impact on combustion efficiency. Reducing particle size greatly increases the contact area between fuel particles and atmospheric oxygen, thereby accelerating ignition and combustion processes. The use of finely ground fuel ensures more complete coal combustion and significantly improves the efficiency of power-generating installations. Additional advantages of this method include lower unburned carbon content in ash and reduced harmful emissions. However, the grinding process is highly energy-intensive, requires sophisticated equipment, and is associated with increased maintenance costs for milling systems.

The analysis of the research results showed that the greatest effect is achieved through comprehensive coal preparation, which combines crushing, classification, drying, and grinding. This approach provides fuel with optimal characteristics, increases combustion completeness to 96 %, improves boiler efficiency, and reduces specific fuel consumption. Furthermore, comprehensive preparation decreases harmful emissions and enhances the environmental safety of energy production. At the same time, this method requires substantial capital investment, modern equipment, and more complex process management.

Thus, the results of the study indicate that each of the considered methods has both advantages and certain limitations. The selection of the optimal coal preparation technology should be based on fuel characteristics, operating conditions, and economic feasibility. Nevertheless, comprehensive fuel preparation represents the most effective solution, ensuring maximum utilization of coal's energy potential and achieving high technical, economic, and environmental performance indicators.

Conclusion

The conducted study established that preliminary coal preparation is one of the key factors in improving the efficiency of coal combustion in power-generating installations. The analysis showed that untreated coal is characterized by high moisture content, a non-uniform particle-size distribution, and the presence of large particles, all of which negatively affect the combustion process. These

properties lead to lower flame temperatures, increased heat losses, incomplete fuel combustion, and higher specific coal consumption.

After the application of crushing, classification, drying, and grinding operations, a significant improvement in the main fuel characteristics was observed. Moisture reduction decreases the amount of heat required for water evaporation, while the reduction in particle size increases the contact area between coal and atmospheric oxygen. This ensures faster ignition, more stable combustion, and more complete utilization of the fuel's energy potential. As a result, coal combustion completeness increases from 88 % to 96 %, boiler efficiency rises from 82 % to 89 %, and fuel consumption decreases by approximately 10-12 %.

The obtained results confirm that the quality of coal preparation directly affects combustion efficiency. The lower the fuel moisture content and the more optimal its particle-size distribution, the better the thermal performance of the equipment. The most effective approach is a comprehensive preparation process that includes crushing, classification, drying, and fine grinding. The combination of these operations makes it possible to achieve stable combustion conditions, improve plant efficiency, and reduce the amount of unburned residue in ash and slag.

The practical significance of the study lies in the possibility of applying the obtained results to improve coal preparation technologies at thermal power plants and boiler installations. To enhance combustion efficiency, it is recommended to control fuel moisture content, maintain an optimal particle size, use classification by size fractions, and apply drying when moisture content is elevated. In addition, it is necessary to ensure a uniform supply of prepared fuel to the combustion chamber, as feed stability has a significant influence on combustion quality.

Improving coal preparation not only increases energy efficiency but also reduces negative environmental impacts. More complete fuel combustion contributes to lower emissions of particulate matter, carbon oxides, and other pollutants. This is particularly important for enterprises in the energy sector, where resource conservation and environmental safety are of great practical significance.

Prospects for further research are associated with the study of modern methods for automating fuel preparation processes, the application of digital coal quality monitoring systems, the optimization of drying and grinding regimes, and the development of more energy-efficient preparation technologies. Additional attention should be given to comparing different types of coal used in the energy industry and evaluating the economic efficiency of implementing comprehensive fuel preparation under industrial conditions.

Thus, the conducted study confirms that coal preparation before combustion is a necessary condition for improving the performance of power-generating equipment. Comprehensive fuel preparation ensures improved fuel quality characteristics, higher

combustion completeness, lower coal consumption, and reduced harmful emissions, making this approach highly promising for further application in the energy sector.

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ҰСАҚТАУ ҚОНДЫРҒЫЛАРЫН ЖАҢҒЫРТУ АРҚЫЛЫ КӨМІРДІ ЖОҒАРЫ ТЕМПЕРАТУРАДА ЖАҒУДЫҢ ТИІМДІЛІГІН АРТТЫРУ

Бұл мақалада жылу электр станциялары мен өнеркәсіптік энергетикалық нысандарда қолданылатын ұсақтау қондырғыларын жаңғырту арқылы көмірді жоғары температурада жағу тиімділігін арттыру тәсілдері қарастырылады. Зерттеу көмір отынын дайындау сапасының жану процесінің тұрақтылығына, жылу алмасу қарқындылығына, қазандық қондырғыларының пайдалы әсер коэффициентіне, отын шығынына және экологиялық

көрсеткіштеріне әсерін бағалауға бағытталған. Ерекше назар ұсақтау жабдықтарының құрылымы мен пайдалану параметрлерін оңтайландыруға аударылған. Бұл отынның біркелкі түйіршік құрамын қамтамасыз етуге, ұсақтау процесіндегі меншікті энергия шығынын төмендетуге және отын дайындау жүйесінің жалпы өнімділігін арттыруға мүмкіндік береді. Дәстүрлі және жаңғыртылған ұсақтау жүйелерін салыстырмалы талдау отынның майдалығын арттыру оның толық жануына, жылулық тиімділіктің жоғарылауына, жанбай қалған көміртек шығындарының азаюына, сондай-ақ қатты бөлшектердің, көміртек тотығының, азот оксидтерінің және басқа да ластаушы заттардың шығарындыларының төмендеуіне ықпал ететінін көрсетті. Сонымен қатар, ұсақтау қондырғыларын жаңғырту механикалық тозуды азайту және жану процесін тұрақтандыру арқылы энергетикалық жабдықтардың пайдалану сенімділігі мен қызмет ету мерзімін арттырады. Алынған нәтижелер заманауи ұсақтау технологияларын енгізу қазіргі өндірістік пайдалану жағдайында көмірмен жұмыс істейтін жылу энергетикалық жүйелерінің энергетикалық тиімділігін, экологиялық тұрақтылығын және экономикалық тиімділігін арттырудың тиімді бағыты екенін дәлелдейді.

Кілтті сөздер: көмірді жоғары температурада жағу, ұсақтау қондырғысы, жабдықтарды жаңғырту, көмірді ұсақтау, отынды дайындау, энергетикалық тиімділік, шығарындыларды азайту, энергия үнемдеу.

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ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ ВЫСОКОТЕМПЕРАТУРНОГО СЖИГАНИЯ УГЛЯ ПОСРЕДСТВОМ МОДЕРНИЗАЦИИ ДРОБИЛЬНЫХ УСТАНОВОК

В статье рассматриваются методы повышения эффективности высокотемпературного сжигания угля посредством модернизации

дробильных установок, применяемых на тепловых электростанциях и промышленных энергетических объектах. Исследование посвящено оценке влияния качества подготовки угольного топлива на стабильность процесса горения, интенсивность теплообмена, коэффициент полезного действия котельного оборудования, расход топлива и экологические показатели. Особое внимание уделено оптимизации конструкции и эксплуатационных параметров дробильных установок, обеспечивающих получение однородного гранулометрического состава топлива, снижение удельных энергозатрат на процесс дробления и повышение общей производительности системы подготовки топлива. Сравнительный анализ традиционных и модернизированных дробильных систем показал, что улучшение тонкости помола способствует более полному сгоранию топлива, повышению тепловой эффективности, снижению потерь несгоревшего углерода, а также уменьшению выбросов твердых частиц, оксида углерода, оксидов азота и других загрязняющих веществ. Кроме того, модернизация дробильных установок повышает эксплуатационную надежность и срок службы энергетического оборудования за счет снижения механического износа и стабилизации процессов горения. Полученные результаты подтверждают, что внедрение современных технологий дробления является эффективным направлением повышения энергетической эффективности, экологической устойчивости и экономической результативности угольных теплоэнергетических систем в современных условиях эксплуатации.

Ключевые слова: высокотемпературное сжигание угля, дробильная установка, модернизация оборудования, дробление угля, подготовка топлива, энергетическая эффективность, снижение выбросов, энергосбережение.

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