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A.R. Khazhidinova[1*], A.S. Khazhidinov[2], O.A. Stepanova[1], T.N. Umyrzhan[1], Zh.K. Aldazhumanov[1]
[1]Shakarim University,
071412, Republic of Kazakhstan, Semey, 20 A Glinka Street
[2]Center of Nuclear Medicine and Oncology,
071400, Republic of Kazakhstan, Semey, 3 Kutzhanova Street
*e-mail: khazhidinova1991@mail.ru

STUDY OF A DIRECT INJECTION PULVERIZING SYSTEM FOR INDIVIDUAL BOILER SUPPLY

Annotation: *This paper examines an individual pulverizing system with a hammer mill and direct injection, serving a hot water boiler of the KVT–116.3–150 type. The relevance of the study lies in the crucial role of fuel pulverization in ensuring stable, efficient, and environmentally safe operation of coal-fired boiler plants.*

A functional diagram of the pulverizing system is presented, covering drying, grinding, classification, and conveying of the air-fuel mixture to the boiler burner. The schematic provides a clear representation of the equipment interconnections, identifies key technological nodes, determines the paths of heat carrier, air, and fuel movement, and highlights zones most sensitive to operational parameters. This lays the foundation for further analysis of thermal efficiency and potential optimization reserves.

During the operation of the system, key parameters were recorded: the temperature of the air-fuel mixture at the mill outlet did not exceed 85 °C, the coal dust fineness was R_{90} = 45 ÷ 55%, and the fuel moisture and consumption values corresponded to the operating charts. The data analysis confirmed the stability and efficiency of the system under boiler load variations in the range from 60% to 100% of the nominal capacity.

Special attention is given to the design and technological features of the equipment: the hammer mill with an integrated separator, a recuperative air heater, a downward drying unit, the air supply system, and control elements. Advantages of the individual system include enhanced automation, reduced heat loss, flexible operation control, and adaptability to variable loads or unstable fuel characteristics.

Recommendations are made for optimizing the drying process and implementing a monitoring system for the mill and separator condition. The study concludes that the system is technologically complete, efficient, and promising for retrofitting existing solid fuel-fired boiler units.

Key words: *fuel pulverization, air-fuel mixture, individual system, hammer mill, direct injection, hot water boiler, coal dust.*

Introduction

The modern development of the energy sector requires improving the efficiency and reliability of boiler installations, as well as minimizing their environmental impact. Pulverized fuel preparation systems play a significant role in addressing these challenges, as they directly affect combustion stability, fuel burnout completeness, thermal performance of boilers, and the level of harmful emissions into the atmosphere. The quality of the pulverized fuel preparation process has a decisive impact on the reliability and economic performance of pulverized coal-fired boilers. In particular, the characteristics of the coal dust determine flame stability, boiler efficiency, the level of incomplete fuel combustion, and the concentration of pollutants in the flue gases. Therefore, research aimed at analyzing and optimizing pulverized fuel preparation systems remains a relevant engineering task [1-5]. Improving the efficiency and reliability of pulverized coal-fired boilers remains one of the key objectives in the modernization of thermal power plants. This issue is actively addressed in recent studies focused on enhancing combustion processes, fuel delivery, and coal-dust preparation systems [6-8].

Various pulverized fuel preparation systems are used in energy practice, including centralized systems with dust bunkers, as well as individual systems, some features of which are shown in Figure 1.

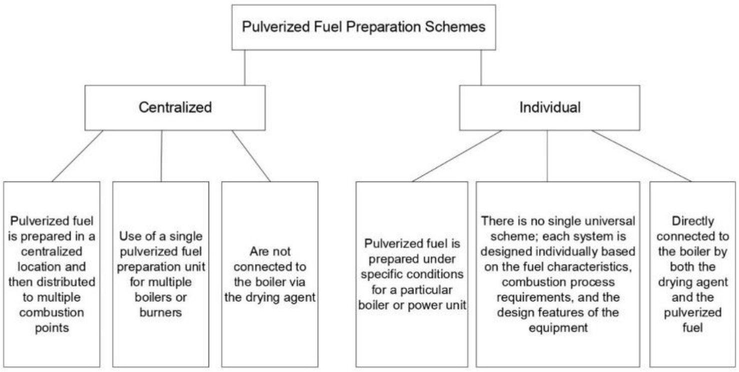

Figure 1 – Features of pulverized fuel preparation systems

Individual pulverized fuel preparation systems are divided into direct and indirect firing schemes. In recent years, individual direct-firing systems have gained particular popularity due to their high level of automation, simplified fuel supply layout, and reduced heat losses. Direct firing involves feeding the prepared pulverized coal directly from the mill to the burners without intermediate storage. This approach is especially effective under variable boiler load conditions or when using fuels with unstable characteristics [9-11].

This study examines the KVT–116.3-150 boiler unit, which is equipped with an individual pulverized fuel preparation system featuring a hammer mill and direct firing. The fuel used is coal from the Karazhyr deposit, which is fed to the furnace in the form of an air-fuel mixture – a dispersed system consisting of fine coal particles and air. Combustion of coal in the form of an air-fuel mixture offers several scientifically and technically justified advantages [12-13]:

1. Increased combustion completeness. The fine-dispersed structure of the coal dust provides a larger specific surface area, promoting more complete and faster oxidation of the fuel.
2. Improved thermal efficiency. Rapid ignition and intense combustion of the air-fuel mixture enable higher temperatures and more efficient heat utilization in the furnace space.
3. Reduced specific fuel consumption. Due to the high combustion efficiency, less coal is required per unit of generated thermal energy.
4. Flexible combustion control. The combustion process of the air-fuel mixture is easier to monitor and automate, including by adjusting the «fuel–air» ratio and mixture feed parameters to the furnace.
5. Lower emissions of unburned substances. More complete combustion results in reduced emissions of solid particles and carbon monoxide (CO), improving environmental performance.
6. Capability to use pulverized coal burners. These systems enable the application of modern burner devices that ensure uniform heat distribution and a more stable flame.

The purpose of this study is to analyze the structure and operating principle of the individual pulverized fuel preparation system serving the KVT–116.3-150 boiler, to identify its design and technological features, and to determine potential modernization directions to enhance the efficiency and reliability of the boiler unit.

Methods

A distinctive feature of the individual pulverized fuel preparation system is its autonomy: it supplies a pulverized coal-air mixture to only one boiler unit – in this case, the KVT–116.3–150 hot-water boiler. This configuration allows for flexible control of combustion parameters, rapid response to changes in thermal load, and adaptation of system operation to specific operating conditions.

[14] Regulate the operation of the pulverizing system. During the operation of the coal preparation units, a continuous supply of coal dust with the required fineness and moisture content is ensured to the boiler burners in an amount corresponding to the current thermal load of the boiler. The operating mode of the direct-firing coal preparation systems is set according to the load schedule, varying within approximately 60 ÷ 100% of the boiler's nominal capacity.

During the operation of the investigated coal preparation system, key parameters – such as the temperature of the air-fuel mixture, fuel moisture content, fuel consumption, and coal fineness – were recorded using control and instrumentation devices installed on the boiler unit. These experimental data allowed a direct assessment of the system's performance under real operating conditions.

In this study, a functional schematic modeling method was used, based on the development of a detailed diagram of the boiler's fuel preparation system. The model was developed through the analysis of technical documentation, equipment specifications, and the results of an on-site survey of the actual system layout. The diagram reflects the sequence of technological processes, the flow of fuel, air, and heat carrier, as well as the structural relationships between the main and auxiliary equipment.

The fuel preparation diagram presented in the Results section was created by the authors using Microsoft Visio software and represents a structured synthesis of information about the design, operating principles, and interaction of system components. Particular attention was paid to key elements such as the hammer mill, feeder, fan, gas ducts, and burner devices. This approach not only enabled the visualization of the system's configuration but also facilitated a structural analysis to identify potential bottlenecks and areas for optimization.

A comparative-analytical method was also applied, involving the comparison of the design characteristics of system components with regulatory values and analogous solutions used in similar pulverized coal installations. This made it possible to assess the efficiency level of the existing technological solution and identify opportunities for its improvement.

A distinctive feature of the MMT-1300/1310/750K hammer mill used in the pulverizing system of the KVT-116.3-150 boiler is its intensive forced ventilation combined with an increased rotor circumferential speed, which ensures high grinding quality and effective fuel drying. The raw material and drying agent are fed into the mill tangentially, which promotes uniform flow distribution and improves the aerodynamic conditions in the grinding zone.

The grinding process occurs due to multiple impacts of the fuel particles against the hammers and the armor plates, as well as abrasion of the material as it moves through the gap between the rotating rotor and the stationary housing. The ground coal, together with the drying and ventilating agent, is carried from the grinding zone into the built-in separator, where coarse fractions are separated and returned for re-grinding. The prepared coal dust is then transported through the dust ducts to the boiler burners.

Results and Discussion

Figure 2 shows the individual system for preparing the air-coal mixture for the KVT–116.3-150 boiler. The conducted analysis demonstrated that in terms of equipment composition, layout, and operating principle, the fuel preparation system of the KVT–116.3–150 boiler corresponds to typical individual configurations widely used in similar boiler installations [15-16].

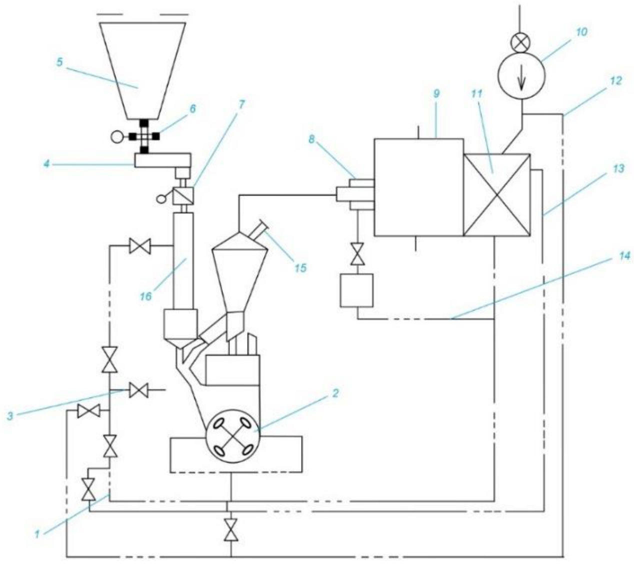

Figure 2 – Individual pulverizing system for the KVT–116.3–150 boiler

1 – hot air box; 2 – hammer mill with separator; 3, 12 – cold air inlets; 4 – raw fuel feeder; 5 – raw coal bunker; 6 – dampers; 7 – flashing valve; 8 – burner; 9 – KVT–116.3–150 boiler; 10 – forced draft fan; 11 – tubular air heater; 13 – mildly superheated air; 14 – secondary air duct; 15 – explosion relief valve; 16 – downward drying unit.

The system operates on a closed circulation principle, which increases drying and grinding efficiency by using hot flue gases. In the air heater (11), heat from the flue gases is transferred to the air. The heated air is sent to the drying unit (16), where moisture is removed from the raw fuel before it enters the hammer mill (2). After grinding and mixing with air, the air-fuel mixture is conveyed to the burner (8) on the boiler (9).

Analysis of the KVT–116.3-150 air-fuel mixture system revealed the following design and process features:

1. **Rational system structure.** The scheme forms a complete closed cycle of coal dust preparation – from raw fuel feeding and drying to combustion. The individual configuration enhances control and adaptability to specific boiler modes.

2. **Core component – hammer mill with separator (2).** This unit ensures effective grinding to the required fineness. The integrated separator stabilizes dust quality and reduces equipment wear by returning coarse particles.

3. **Efficient air supply system** using three air streams:

- hot air from the box (1) for fuel drying,
- cold air (3, 12) for adjusting air-fuel mixture temperature,
- mildly superheated air (13) for improved combustion conditions. Proper balancing of these flows helps reduce temperature overloads and improve heat efficiency.

4. **Control and safety elements:**

- dampers (6) and valves (7) for fuel and air-fuel mixture flow regulation,
- explosion relief valve (15) for overpressure release in emergencies,
- flashing valve (7) for metered fuel feeding into the mill.

5. **Downward drying unit (16).** It plays a critical role in reducing fuel moisture before grinding, enhancing grinding stability and lowering specific energy consumption.

6. **Heat recovery via the tubular air heater (11).** It uses flue gas heat to preheat air, thereby increasing the overall efficiency of the system.

Thus, the diagram (Figure 1) shows that the individual pulverizing system of the KVT–116.3–150 boiler is technologically comprehensive and provides stable and efficient fuel supply. This configuration serves as a basis for further thermal analysis and optimization of the boiler system.

Based on the analysis of the system design and operation, the following recommendations are proposed to improve efficiency and reliability:

1. **Fuel drying optimization.** Further thermodynamic adjustment of the hot gas feed to the drying zone is recommended, based on actual coal moisture. This would reduce heat losses and prevent fuel overheating, especially with varying coal quality.

2. **Mill and separator condition monitoring.** Implementing vibration and temperature monitoring systems for the hammer mill can detect signs of wear or load imbalance early, helping avoid failures and increase equipment reliability.

In contrast to the study [17], which examined a closed pulverized coal preparation system with a ball drum mill and an intermediate bunker for the combustion of Kuznetsk lean coal, the present work analyzes an individual pulverized fuel preparation system with a hammer mill and direct injection designed for the combustion of Karazhyra long-flame coal (grade D).

Analysis of the obtained data indicates that fuel drying is carried out using heated air from a tubular air heater, with a maximum air temperature after the heat exchanger reaching approximately 300 °C at the boiler's corresponding nominal capacity. This ensures intensive moisture evaporation and stabilizes the temperature of the air-fuel mixture at the mill outlet at a level not exceeding 85 °C.

The operating charts developed and used at the plant are designed for boiler operation when burning coal from the Karazhyra seam with the following quality: moisture content not exceeding 18% and ash content not exceeding 20% on a working mass basis. The specific consumption of standard fuel per 1 Gcal ranged from 176.628 kg s.f./Gcal at minimum load to 189.080 kg s.f./Gcal at the boiler's nominal capacity. The coal dust fineness R_{90} was within the range of 45-55%, depending on the boiler load.

Thus, unlike previously studied schemes with bunker storage and vacuum dust feeding, the presented system with a hammer mill and direct injection ensures stable parameters of the air-coal mixture and simpler operation when using long-flame coals of medium moisture content.

Based on the normative methods [18] and the results presented in [17], further work will include detailed calculations of flow rates, heat balances, and an analysis of the influence of process parameters on the overall efficiency of the pulverized fuel preparation system.

Conclusion

The scientific novelty of the study lies in the following:

– experimental data obtained from the operation of a real pulverizing system within the boiler load range of 60-100% of the nominal capacity have been systematized and presented;

– Functional schematic modeling of the system was performed based on the analysis of the actual equipment configuration, which made it possible to identify technological interrelations and specific features of its operation.

The presented diagram serves as a tool for systematic analysis of the process, equipment layout, and flow paths. The data confirm the technological completeness of the pulverizing system, which includes fuel feeding and dosing, drying, grinding, classification, and delivery to the KVT–116.3-150 boiler combustion chamber. Special attention is given to controlling air temperature and flow at various stages, ensuring the required fineness and stable combustion. The individual approach to fuel preparation allows precise adjustment for specific boiler operating conditions.

In conclusion, the individual pulverizing system with a hammer mill and direct injection demonstrates high adaptability for burning non-design fuels. Its compactness, technological completeness, and control elements ensure efficient and safe operation, making the system promising for modernizing existing coal-fired boiler units.

The conducted experimental measurements confirmed the stable operation of the system under various boiler loads: the temperature of the air-fuel mixture at the mill outlet did not exceed 85 °C, the coal fineness (R_{90} = 45 ÷ 55 %), and the fuel consumption and moisture indicators corresponded to the values specified in the operating charts. This confirms the technological efficiency and reliability of the investigated pulverizing system under real operating conditions.

References

1. Zhang Y. Numerical simulation of pulverized coal combustion characteristics under varying particle sizes / Y. Zhang, L. Wang, H. Chen // Fuel. – 2021. – Vol. 287. – Article 119451. https://doi.org/10.1016/j.fuel.2020.119451.

2. Li Q. Investigation of the influence of coal particle fineness on combustion efficiency and NOx emissions / Q. Li, H. Zhou, S. Zhang // Energy. – 2020. – Vol. 213. – Article 118794. https://doi.org/10.1016/j.energy.2020.118794.

3. Singh R. Experimental study on combustion performance of high-ash pulverized coals in utility boilers / R. Singh, A. Dutta // Journal of Energy Resources Technology. – 2022. – Vol. 144, № 8. – P. 082101. https://doi.org/10.1115/1.4052739.

4. Kim D. CFD analysis of combustion and NOx formation in pulverized coal-fired boilers with different burner configurations / D. Kim, S. Lee, J. Park // Applied Thermal Engineering. – 2023. – Vol. 220. – Article 119904. https://doi.org/10.1016/j.applthermaleng.2022.119904.

5. Wang X. Advances in low-NOx pulverized coal combustion technologies for power generation / X. Wang, M. Xu // Progress in Energy and Combustion Science. – 2024. – Vol. 95. – Article 101169. https://doi.org/10.1016/j.pecs.2024.101169.

6. Pulverized Coal-Fired Boilers: Future Directions of Scientific Research / M. Ochowiak et al // Energies. – 2023. – № 16(2). – P. 935. https://doi.org/10.3390/en16020935.

7. Combustion Characteristics of Coal for Pulverized Coal Injection (PCI) Blending with Steel Plant Flying Dust and Waste Oil Sludge / Y. Wang et al // ACS Omega. – 2021. – № 6(25). – P. 16362-16370. https://doi.org/10.1021/acsomega.1c02554.

8. Wang S. Evaluating the Effect of Ammonia Co-Firing on the Performance of a Pulverized Coal-Fired Utility Boiler / S. Wang, C. Sheng // Energies. – 2023. – № 16(6). – P. 2773. https://doi.org/10.3390/en16062773.

9. Zhang J. Design and performance analysis of direct firing pulverized coal systems for flexible boiler operation / J. Zhang, C. Chen, Y. Liu // Energy Reports. – 2021. – Vol. 7. – P. 894-902. https://doi.org/10.1016/j.egyr.2021.01.004.

10. Patel H. Automation and control strategies for direct-firing pulverized coal boilers / H. Patel, R. Shah // International Journal of Coal Science & Technology. – 2023. – Vol. 10, № 2. – P. 211-222. https://doi.org/10.1007/s40789-022-00511-0.

11. Lee H. Improving thermal efficiency and response time in coal-fired units using direct-firing configuration / H. Lee, T. Kim // Applied Energy. – 2020. – Vol. 270. – Article 115165. https://doi.org/10.1016/j.apenergy.2020.115165.

12. Luo M. Combustion behavior and emissions characteristics of pulverized coal–air mixtures in swirl burners / M. Luo, Y. Zhang, Y. Wu // Fuel. – 2021. – Vol. 289. – Article 119899. https://doi.org/10.1016/j.fuel.2020.119899.
13. Thomas G. Technical evaluation of pulverized fuel combustion in modern utility boilers: Fuel–air mixing and combustion stability / G. Thomas, J. Binner, C. Yates // Fuel Processing Technology. – 2020. – Vol. 203. – Article 106392. https://doi.org/10.1016/j.fuproc.2020.106392.
14. Ministry of Energy of the Republic of Kazakhstan. Rules for the Technical Operation of Power Plants and Networks: approved by Order No. 247 of the Minister of Energy of the Republic of Kazakhstan dated March 30, 2015 (as amended on October 14, 2024, Order No. 367). Adilet – Information and Legal System of the Republic of Kazakhstan. Available at: https://adilet.zan.kz/rus/docs/V1500011066.
15. Modeling of Coal Mill System Used for Fault Simulation / Y. Hu et al // Energies. – 2020. – № 13(7). – P. 1784. https://doi.org/10.3390/en130671784.
16. Detecting Coal Pulverizing System Anomaly Using a Gated Recurrent Unit and Clustering / Z. Chen et al // Sensors. – 2020. – № 20(11). – P. 3271. https://doi.org/10.3390/s20113271.
17. Mingaleeva G.R. Analysis of the fuel preparation system of a pulverized coal thermal power plant / G.R. Mingaleeva, Yu.N. Zatsarinnaya, E.K. Vachagina // Izvestiya Vysshikh Uchebnykh Zavedeniy. Problems of Energy. – 2005. – № 1-2. Retrieved from https://cyberleninka.ru/article/n/analiz-raboty-sistemy-podgotovki-topliva-pyleugolnoy-tes (accessed October 16, 2025).
18. Calculation and Design of Pulverized Fuel Preparation Installations for Boiler Units (Normative Materials). – Leningrad: TsKTI, 1971. – 309 p.

А.Р. Хажидинова[1*], А.С. Хажидинов[2], О.А. Степанова[1], Т.Н. Умыржан[1], Ж.К. Алдажуманов[1]
[1]Шәкәрім университеті,
071412, Қазақстан Республикасы, Семей қ., Глинки к-сі, 20 А
[2]Ядролық медицина және онкология орталығы,
071400, Қазақстан Республикасы, Семей қ., Кутжанова к-сі, 3
*e-mail: khazhidinova1991@mail.ru

ҚАЗАНДЫҚТЫ ЖЕКЕ ҚАМТАМАСЫЗ ЕТЕТІН ТІКЕЛЕЙ ҮРЛЕУ ӘДІСІМЕН ЖҮЗЕГЕ АСЫРЫЛАТЫН ҰНТАҚТАУ ЖҮЙЕСІН ЗЕРТТЕУ

Мақалада КВТ–116,3-150 маркалы су жылытатын қазандығын отынмен қамтамасыз ететін, балғалы диірмен мен тікелей үрлеу әдісі қолданылатын жеке ұнтақтау жүйесі қарастырылады. Жұмыстың өзектілігі шаңкөмір қазандық қондырғыларының тұрақты, үнемді және экологиялық қауіпсіз жұмысын қамтамасыз етудегі ұнтақтау процесінің шешуші рөліне байланысты.

Мақалада кептіру, ұнтақтау, классификациялау және аэроқоспаны қазандықтың жанарғысына беру процестерін қамтитын ұнтақ көмір дайындау жүйесінің функционалдық сұлбасы ұсынылған. Мұндай сұлбаның құрылуы жабдықтар арасындағы өзара байланыстарды көрнекі түрде көрсетуге, негізгі технологиялық тораптарды айқындауға, жылу тасымалдағыштың, ауаның және отынның қозғалыс бағыттарын белгілеуге, сондай-ақ жұмыс режиміне ең сезімтал учаскелерді анықтауға мүмкіндік берді. Бұл өз кезегінде жылу-техникалық тиімділікті талдауға және оңтайландыру резервтерін іздеуге негіз болды.

Жүйе жұмысы барысында негізгі көрсеткіштер тіркелді: диірмен шығасындағы аэроқоспа температурасы 85 °С-тан аспады, көмір ұнтағының ұнтақталу дәрежесі R_{90} = 45 ÷ 55 % құрады, ал отынның ылғалдылығы мен шығынының мәндері режимдік карталарға сәйкес келді. Мәліметтерді талдау қазан жүктемесінің номиналды қуаттың 60 %-дан 100 %-ға дейінгі аралығында өзгеруі кезінде жүйенің тұрақтылығы мен тиімділігін растады.

Жабдықтардың конструктивтік және технологиялық ерекшеліктеріне – сепараторы бар балғалы диірменге, рекуперативті ауа қыздырғышқа, төмен қарай кептіру құрылғысына, ауа беру жүйесіне және реттеу элементтеріне ерекше назар аударылды. Жеке сұлбаның артықшылықтары ретінде автоматтандыру деңгейінің жоғарылығы, жылу шығындарының төмендеуі, жұмыс режимдерін икемді басқару және жүктеменің өзгеруіне немесе отын қасиеттерінің тұрақсыздығына бейімделу қабілеті атап етілді.

Кептіру режимін оңтайландыру және диірмен мен сепаратордың жай-күйін бақылау жүйесін енгізу бойынша ұсынымдар тұжырымдалды. Ұсынылған сұлбаның технологиялық тұрғыдан жоғары деңгейде аяқталғаны, тиімділігі және қатты отын пайдаланатын қолданыстағы қазандық агрегаттарын жаңғырту үшін болашағы зор екені туралы қорытынды жасалды.

Түйін сөздер: *ұнтақ көмір дайындау, аэроқоспа, жеке жүйе, балғалы диірмен, тікелей үрлеу, су жылытатын қазандық, көмір ұнтағы.*

А.Р. Хажидинова[1*], А.С. Хажидинов[2], О.А. Степанова[1], Т.Н. Умыржан[1], Ж.К. Алдажуманов[1]
[1]Шәкәрім университет,
071412, Республика Казахстан, г. Семей, ул. Глинки, 20 А
[2]Центр ядерной медицины и онкологии,
071400, Республика Казахстан, г. Семей, ул. Кутжанова, 3
*e-mail: khazhidinova1991@mail.ru

ИССЛЕДОВАНИЕ СИСТЕМЫ ПЫЛЕПРИГОТОВЛЕНИЯ С ПРЯМЫМ ВДУВАНИЕМ ДЛЯ ИНДИВИДУАЛЬНОГО ПИТАНИЯ КОТЕЛЬНОЙ УСТАНОВКИ

В статье рассматривается индивидуальная система пылеприготовления с молотковой мельницей и прямым вдуванием, обслуживающая водогрейный котёл марки КВТ–116,3-150. Актуальность работы обусловлена важнейшей ролью процесса пылеприготовления в обеспечении устойчивой, экономичной и экологически безопасной работы пылеугольных котельных установок.

Представлена функциональная схема пылеприготовительной системы, включающая процессы сушки, измельчения, классификации и подачи аэросмеси в горелку котла. Построение такой схемы позволило наглядно представить взаимосвязь оборудования, выявить ключевые технологические узлы, установить направления движения теплоносителя, воздуха и топлива, а также определить участки с наибольшей чувствительностью к режимным параметрам. Это создало основу для дальнейшего анализа теплотехнической эффективности и поиска резервов оптимизации.

В ходе эксплуатации системы были зарегистрированы ключевые показатели: температура аэросмеси на выходе из мельницы не превышала 85 °С, тонкость помола угольной пыли составляла R_{90} = 45 ÷ 55 %, а показатели влажности и расхода топлива соответствовали режимным картам. Анализ данных подтвердил стабильность и эффективность работы системы при изменении нагрузки котла в диапазоне от 60 % до 100% от номинальной мощности.

Особое внимание уделено конструктивным и технологическим особенностям оборудования: молотковой мельнице с встроенным сепаратором, рекуперативному воздухоподогревателю, устройству нисходящей сушки, системе подачи воздуха и элементам регулирования. Отмечены преимущества индивидуальной схемы, такие как повышенная степень автоматизации, снижение теплопотерь, гибкость управления режимами и адаптация к переменной нагрузке или нестабильным характеристикам топлива.

Сформулированы рекомендации по оптимизации режима сушки и внедрению системы мониторинга состояния мельницы и сепаратора. Сделан вывод о высокой технологической завершённости схемы, её эффективности и перспективности для модернизации существующих котельных агрегатов, использующих твёрдое топливо.

Ключевые слова: *пылеприготовление, аэросмесь, индивидуальная система, молотковая мельница, прямое вдувание, водогрейный котёл, угольная пыль.*

Information about the authors

Akbota Ryspekovna Khazhidinova* – PhD, Acting Associate Professor, Department of Technical Physics and Heat Power Engineering, Shakarim University, Republic of Kazakhstan; e-mail: khazhidinova1991@mail.ru. ORCID: https://orcid.org/0000-0001-8802-1559.

Azamat Saginaevich Khazhidinov – Master of Physics, Cyclotron Engineer, «Center of Nuclear Medicine and Oncology», Department of Healthcare of Abai Region, Republic of Kazakhstan; e-mail: khazhidinov@mail.ru. ORCID: https://orcid.org/0009-0008-9900-4111.

Olga Aleksandrovna Stepanova – Candidate of Technical Sciences, Professor, Head of Department «Technical Physics and Heat Power Engineering»; Shakarim University, Republic of Kazakhstan; e-mail: o.stepanova@shakarim.kz. ORCID: https://orcid.org/0000-0001-5221-1772.

Temirlan Nurlanuly Umyrzhan – doctoral student of the educational programme 8D05302-«Technical Physics» of the Department of «Technical Physics and Heat Power Engineering», Shakarim University, Republic of Kazakhstan; e-mail: timirlan-95@mail.ru. ORCID: https://orcid.org/0009-0008-9111-1975.

Zhan Kassenovich Aldazhumanov – Master of Technical Sciences, senior lecturer of Department «Technical Physics and Heat Power Engineering», Shakarim University, Republic of Kazakhstan; e-mail: Jean1974@mail.ru. ORCID: https://orcid.org/0009-0006-1683-1089.

Авторлар туралы мәліметтер

Акбота Рыспековна Хажидинова* – PhD, «Техникалық физика және жылу энергетикасы» кафедрасының қауымдастырылған профессорының м.а., Шәкәрім университеті, Қазақстан Республикасы; e-mail: khazhidinova1991@mail.ru. ORCID: https://orcid.org/0000-0001-8802-1559.

Азамат Сагинаевич Хажидинов – физика магистрі, циклотрон инженері, Абай облысы денсаулық сақтау басқармасының «Ядролық медицина және онкология орталығы» шаруашылық жүргізу құқығындағы коммуналдық мемлекеттік кәсіпорны, Қазақстан Республикасы; e-mail: khazhidinov@mail.ru. ORCID: https://orcid.org/0009-0008-9900-4111.

Ольга Александровна Степанова – техника ғылымдарының кандидаты, профессор, «Техникалық физика және жылу энергетикасы» кафедрасының меңгерушісі, Шәкәрім университеті, Қазақстан Республикасы; e-mail: o.stepanova@shakarim.kz. ORCID: https://orcid.org/0000-0001-5221-1772.

Темірлан Нұрланұлы Умыржан – «Техникалық физика және жылу энергетикасы» кафедрасының 8D05302-«Техникалық физика» білім беру бағдарламасының докторанты, Шәкәрім университеті, Қазақстан Республикасы; e-mail: timirlan-95@mail.ru. ORCID: https://orcid.org/0009-0008-9111-1975.

Жан Касенович Алдажуманов – техника ғылымдарының магистрі, «Техникалық физика және жылу энергетикасы» кафедрасының аға оқытушысы, Шәкәрім университеті, Қазақстан Республикасы; e-mail: Jean1974@mail.ru. ORCID: https://orcid.org/0009-0006-1683-1089.

Сведения об авторах

Акбота Рыспековна Хажидинова* – PhD, и.о. ассоциированного профессора кафедры «Техническая физика и теплоэнергетика», Шәкәрім университет, Республика Казахстан; e-mail: khazhidinova1991@mail.ru. ORCID: https://orcid.org/0000-0001-8802-1559.

Азамат Сагинаевич Хажидинов – магистр физики, инженер циклотрона, коммунальное государственное предприятие на праве хозяйственного ведения «Центр ядерной медицины и онкологии» управления здравоохранения области Абай, Республика Казахстан; e-mail: khazhidinov@mail.ru. ORCID: https://orcid.org/0009-0008-9900-4111.

Ольга Александровна Степанова – кандидат технических наук, профессор, зав. кафедрой «Техническая физика и теплоэнергетика», Шәкәрім университет, Республика Казахстан; e-mail: o.stepanova@shakarim.kz. ORCID: https://orcid.org/0000-0001-5221-1772.

Темірлан Нұрланұлы Умыржан – докторант образовательной программы 8D05302-«Техническая физика» кафедры «Техническая физика и теплоэнергетика», Шәкәрім университет, Республика Казахстан; e-mail: timirlan-95@mail.ru. ORCID: https://orcid.org/0009-0008-9111-1975.

Жан Касенович Алдажуманов – магистр технических наук, старший преподаватель кафедры «Техническая физика и теплоэнергетика», Шәкәрім университет, Республика Казахстан; e-mail: Jean1974@mail.ru. ORCID:https://orcid.org/0009-0006-1683-1089.

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M. Skakov[1], N. Mukhamedova[1], A. Nassyrova[2]*
National Nuclear Center of the Republic of Kazakhstan,
180010, Republic of Kazakhstan Kurchatov, Beibyt atom st., 2 B
Sarsen Amanzholov East Kazakhstan University,
070000, Republic of Kazakhstan, Ust-Kamenogorsk, st. 30th Guards Division, 34
*e-mail: anar.kenzhebekyzy@mail.ru

THE INFLUENCE OF MECHANICAL ACTIVATION ON THE STRUCTURAL-PHASE STATES AND HYDROGEN ABSORPTION PROPERTIES OF THE INTERMETALLIC COMPOUND $LANI_5$ – REVIEW

Abstract: *The article provides an overview of a number of studies on the use of alloys and intermetallic compounds for hydrogen storage. Among them, a particularly important place is occupied by the inter-metallic compound $LaNi_5$ eye. The latest achievements in the development of intermetallic compounds of the AB_5-type are analyzed. These compounds, in particular $LaNi_5$ and its alloyed counterparts, are widely used due to the ability to regulate their properties by replacing elements. The article also provides an overview of the methods of synthesis and modification of AB5 alloys aimed at improving their efficiency in hydrogen technologies. Both traditional production methods and modern technological approaches , including Spark plasma sintering and mechanical activation, are considered. A review of the scientific literature has shown that mechanical activation is an effective way to modify the $LaNi_5$ intermetallic compound to improve its hydrogen absorption properties.*