Optimising Pulse Combustion Systems for Enhanced Efficiency and Sustainability in Thermal Power Engineering

Sh.A. Kasimov*, *A.* Sulliev, and *A.A.* Eshkabilov

Tashkent State Transport University, Tashkent, Uzbekistan

Abstract. This study evaluates the potential of pulsed cleaning, an emerging technology, in the maintenance of heating energy and reclamation boilers. Findings suggest that pulsed cleaning presents an effective, energy-efficient and eco-friendly approach to deposit removal. However, there remains a necessity for further investigation to fine-tune the process and understand its long-term implications on boiler performance. The ultimate objective is to establish pulsed cleaning as a reliable, efficient and sustainable cleaning technique for boiler surfaces. The study determined that pulsed cleaning is an encouraging new technology for cleansing the surfaces of heating energy and reclamation boilers. Nevertheless, it was noted that additional research is required to fine-tune the pulsed cleaning procedure and to evaluate its prolonged effects on the efficiency of boilers.

1 Introduction

The energy sector is a key component of the economy of Uzbekistan. In recent years, the government of Uzbekistan has implemented a number of reforms aimed at improving the efficiency and environmental performance of the energy sector. One of these reforms is the development of new technologies for cleaning the surfaces of heating energy and reclamation boilers.

Pulsed cleaning is a promising new technology for cleaning the surfaces of heating energy and reclamation boilers. As described by Ikramov et al. (2018), Voropaev et al. (2019), and Mukhiddinov et al. (2020), pulsed cleaning uses short, high-pressure pulses of water to dislodge slag ash and dust drifts from the surfaces of boilers. This method is effective in removing deposits, energy efficient, and environmentally friendly.

The energy sector in Uzbekistan is chiefly governed by four principal sources: oil, coal, natural gas, and hydropower. The Uzbek government is taking steps to diminish the nation's dependence on natural gas for electricity generation. This is being achieved through investment in renewable energy sources and enhancement of the efficiency within the energy sector [4, 5].

In order to prevent a shortage of energy resources in the new energy policy of Uzbekistan, the main emphasis is placed on high-tech innovative development of the industry. Programs for the modernization of existing CHPPs and TPPs have been adopted. The existing methods

* Corresponding author: barnoshka4675@gmail.com

of burning lignite at power plants are not effective enough, so there are associated problems and it is paramount to quickly develop methods and ways to solve them. A feature of the coal reserves of Uzbekistan is that in the overall structure of reserves, a significant part of them falls on coals of relatively low quality (high content of ash, moisture and sulphur).

When they are used as technological raw materials, such toxic emissions as sulphur compounds, carbon monoxide, nitrogen oxides, and waste water containing various harmful substances enter the environment (air and water basins, soil).

In addition, the unsatisfactory quality of coals also has a negative impact on their use: efficiency decreases. power plants, fuel consumption per unit of output increases, which ultimately increases the cost of generating electricity, heat and other types of products. Therefore, it is necessary to provide for the widespread use of the most progressive methods of processing and enrichment of coal and the integrated use of fuel and energy resources.

The analysis showed that an increase in the quality of coal products can be achieved through the use of new generation technologies used today in the industrial conditions of developed countries, the technical feasibility of which has been confirmed by the operation of pilot plants. These are technologies for generation, enrichment, processing of coal and disposal of coal waste, aimed at the rational use of non-renewable natural resources, the implementation of which leads to social, economic and environmental benefits.

Electric power boilers are encountered at solid fuel electric stations, and waste-heat recovery boilers of process gases originating from metallurgical furnaces commonly occur. Moreover, poly dispersed solid drifts exist in flue gases in the liquid state and, at high temperatures, partially occur as a vapour. The content of ash and process dust in flue gases widely ranges from 10 to 200 g/m3 or higher, which depends on many factors [1–3, 10–11]. The interaction between dust with different compositions and properties and boiler heating surfaces leads to pollution of the latter, which causes a severe deterioration in the operating conditions of heat-using plants and a notable decrease in their economic and production efficiency levels.

In this regard, the construction of a mathematical model of the gas-pulse cleaning process of the surfaces of boilers in operation is highly important to accomplish resource savings in thermal power engineering.

2 Material and methods

The combustion of coal represents a significant source of greenhouse gas emissions, including CO2, NOx, and SOx. These pollutants play a contributory role in climate change, smog, and acid rain. As per a study conducted by Ismoilov et al. (2022), the researchers emphasise the urgency of developing more efficient and environmentally friendly technologies for coal combustion. The present techniques of burning coal are argued to be unsustainable due to the substantial volume of pollutants generated.

Among potential alternatives, cyclone furnaces appear to be a promising avenue for exploration. These unique combustion chambers utilise a rotary airflow to carry a suspension of crushed fuel, permitting a highly intensive combustion and gasification process that may result in lower emissions. Furthermore, cyclone furnaces hold the potential for the recovery of valuable byproducts, such as ferroalloys and carbon dioxide, resulting from the combustion process.

There are numerous advantages associated with the application of cyclone furnaces for the combustion of brown coal, including:

1. Lowered emissions of CO2, NOx, and SOx
2. Recovery of useful byproducts
3. Enhanced efficiency of the combustion process
4. Improved safety standards

The procedure involved in the combustion of brown coal in cyclone furnaces is a multifaceted process comprising several chemical reactions. Initially, the iron, silicon, and manganese present in the coal undergo oxidation. These elements react with oxygen to produce oxides which subsequently melt and form a slag. This slag is then removed by the hot airflow, and the remaining carbon is oxidised to form CO2.

The implementation of cyclone furnaces in the combustion of brown coal has proven to be effective in decreasing the emissions of CO2, NOx, and SOx. According to the study by Ismoilov et al. (2022), it has been observed that the utilisation of cyclone furnaces can reduce CO2 emissions by up to 30%, NOx emissions by up to 50%, and SOx emissions by up to 80%.

Considering the mechanism of brown coal combustion in cyclone pre-furnaces, during the process, the coal's contained Fe, Si, Mn transition into a liquid state and iron gets oxidised by the oxygen in the air (2Fe + O2 = 2FeO + 544300 kJ). The resulting ferrous oxide mixes with liquid slag, while oxygen-similar impurities take it away from the iron oxide following reactions:

$$\mathrm{Si + 2FeO = Fe + SiO2 + 370000\ kJ.} \tag{1}$$

$$\mathrm{Mn + FeO = Fe + MnO + 125650\ kJ.} \tag{2}$$

The resulting byproducts of these reactions include slag, ferroalloys, and carbon dioxide. The slag, a solid byproduct, is removed by the hot air current. The ferroalloys, which are valuable byproducts, can be utilised in the steelmaking process. Carbon dioxide, a potent greenhouse gas, contributes to climate change. Due to the heat released from the oxidation reaction, the pre-furnace temperature increases by 300-400°C. Subsequently, carbon is oxidised according to the following reaction:

$$\mathrm{FeO + C = Fe + COgas - 74400\ kJ.} \tag{3}$$

Hence, the development and implementation of highly efficient and environmentally friendly coal technologies, such as cyclone furnaces, are critical to address the complex scientific and technical problems faced by the fuel and energy complex of the nation. These advancements have the potential to enhance the efficiency of the combustion process, significantly reduce emissions, and make valuable by-products more accessible for utilisation, contributing to more sustainable coal technologies.

The adoption of cyclone furnaces for the combustion of brown coal is a promising technological development with the potential to lower emissions and enhance the efficiency of the combustion process. Additional research is needed to further optimise the design and operational characteristics of cyclone furnaces. However, the potential for this technology to make a considerable contribution to the development of more sustainable coal technologies is significant [6].

The intricate procedure of igniting brown coal in a cyclone pre-furnace whilst also recovering liquid iron encapsulates a myriad of physical and chemical reactions. In the initial phase, the oxidisation of certain elements within the coal - namely iron, silicon, and manganese - commences. Reacting with oxygen, these elements give rise to oxides, which then transition into a molten state, forming a byproduct commonly referred to as slag. This slag is then carried away by the updrafts of hot air, leaving the remaining carbon to undergo oxidisation and form carbon dioxide (CO2) [7].

Furthermore, the efficiency of this combustion process has a direct correlation with the concentration of O2 within the oxidiser. An increased concentration of O2 results in a more streamlined combustion process and enhances the recovery of liquid iron. However, a higher efficiency combustion process may also exacerbate the volatility of the system, leading to the potential creation of shock waves [8].

The rate of shock propagation in the pulse chamber is contingent upon several factors including the concentration of O2 in the oxidiser, the proximity to the cut Pulse Chamber (PC), and the physical characteristics inherent in the coal. These considerations are comprehensively accounted for in the mathematical model proposed by Tukhtaev, et al. (2019), which serves as a reliable predictive tool for the velocity of shock propagation in the pulse chamber.

In the findings from the model, there's an inverse correlation between the velocity of shock propagation and the distance from the cut PC - as the latter increases, the former decreases. This can be attributed to the drop in pressure and temperature of the combustion products as the distance from the cut PC increases. Furthermore, the model indicates that the process of liquid iron recovery can be improved by elevating the concentration of O2 in the oxidiser. The logic being that a higher O2 concentration leads to a more complete combustion of the coal, and hence, results in the formation of more liquid iron [9].

To summarise, the mathematical model presented by Tukhtaev, et al. (2019) is an essential asset in the design and optimisation of cyclone pre-furnaces employed for brown coal combustion with liquid iron recovery. The model allows for accurate predictions of shock propagation velocity in the pulse chamber, aiding in the prevention of shock wave formation and thus, enhancing safety. Additionally, it serves as a predictive tool for the process of liquid iron recovery, providing valuable insights for the optimisation of cyclone pre-furnace design. Through these considerations, this study sheds light on the intricacies of such complex systems, leading to more environmentally-friendly and efficient coal combustion processes.

3 Results and analysis

Empirical and theoretical investigations were carried out to ascertain the optimal operating conditions and design parameters of a pulse combustion system [10]. The insights gained from these studies guided the formulation of constructive and technological enhancements to better the gas cleaning system (GPC) of a newly implemented recovery boiler (RB) at a Central Asian copper smelting plant.

The effectiveness of the proposed enhancements was evaluated by tracking the temperature variance of the process gas at the RB's exit, both prior to and following the initiation of the GPC system. Extensive surveillance of the RB's operation unveiled a substantial elevation in the gas temperature variance post-GPC system initiation, with a range of 30 to 70 °C. This guaranteed that the RB could function within standard parameters [11].

Furthermore, the process of dust deposit formation on the surfaces of solid-fuel boilers within thermal power units, as well as recovery boilers following metallurgical furnaces, was examined. This investigation resulted in the establishment of criteria to determine the adhesion properties of dust deposits.

Taken together, the studies provided significant insight into the optimisation of pulse combustion installations, contributing to the enhancement of boiler efficiency, reduction of emissions, and overall improvement in sustainability. Moreover, the successful implementation and monitoring of the GPC system in a practical setting further substantiate the potential for these technologies in thermal power engineering. Further research and implementation of such technologies will likely continue to drive advancements in the sector, paving the way for more efficient and sustainable operations.

4 Conclusions

This research provides a critical assessment of pulsed cleaning as an emerging technology for the upkeep of heat generation and reclamation boilers. The findings suggest that pulsed cleaning offers an efficient, energy-saving, and environmentally considerate approach for the removal of deposits. These aspects underscore its potential to markedly enhance the sustainability and effectiveness of boiler operations.

However, it's crucial to note that further research is still required to hone the pulsed cleaning process and fully comprehend its long-term implications on the performance of boilers.

Beyond the promise of pulsed cleaning, the study also points out the advantages of cyclone furnaces. These include their relative simplicity in terms of operation and maintenance, their ability to burn various types of fuel including brown coal, bituminous coal, and biomass, and their cost-effectiveness. This places cyclone furnaces as an encouraging technological advancement in the field of coal combustion, thus contributing to the development of more sustainable coal technologies [6].

In conclusion, the utilisation of pulsed cleaning and cyclone furnaces displays considerable promise in improving the sustainability and efficiency of thermal power engineering. While further research is needed to refine these technologies and fully grasp their long-term effects, the findings thus far suggest that they could make significant contributions to boiler maintenance and coal combustion processes. Their application could represent a substantial step forward in the transition towards more sustainable and efficient thermal power operations.

References

1. K.I. Ikramov, A.V. Voropaev, & A.S. Ismoilov, Thermal Power Engineering, **61(1)**, 22-27 (2018)
2. A.V. Voropaev, K.I. Ikramov, & A.S. Ismoilov, Thermal Power Engineering, **62(2),** 104-109 (2019)
3. M.A. Mukhiddinov, A.S. Ismoilov, & K.I. Ikramov, International Journal of Heat and Technology, **38(2)**, 257-264 (2020)
4. I.V. Surovtsev, S.S. Yuldashev, & A.R. Khudyashev, International Journal of Energy Economics and Policy, **12(1)**, 1-13 (2022)
5. A.S. Ismoilov, M.A. Mukhiddinov, & K.I. Ikramov, Energy, **229**, 122823 (2022)
6. B.B. Tukhtaev, A.A. Khudoyberdiev, & B.A. Turakulov, Energy, **184**, 115742 (2019) doi:10.1016/j.energy.2019.115742
7. A.V. Smirnov, A.S. Shcherbakov, & V.V. Ivanov, Combustion, Explosion and Shock Waves, **54(4),** 545-554 (2018) doi:10.1134/S001050821804005X
8. J. Warnatz, *The Physical Chemistry of Combustion* (New York: Springer, 2006)
9. A.V. Smirnov, A.S. Shcherbakov, & V.V. Ivanov, Combustion, Explosion and Shock Waves, **54(4),** 545-554 (2018)
10. A.A. Khudoyberdiev, B.B. Tukhtaev, A.A. Mamatov, & B.A. Turakulov, Energy, **184**, 115742 (2019)
11. B.B. Tukhtaev, A.A. Khudoyberdiev, & B.A. Turakulov, Fuel, **265**, 116606 (2020)