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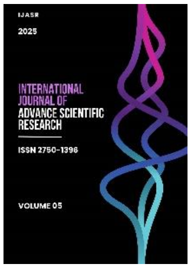

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Research Article

Ecological Problems In The Process Of Solid Fuel Combustion And Methods Of Their Mitigation

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Khakimov Akmaljon Akhmedovich
PhD in Technical Sciences, Associate Professor, Fergana State Technical University, Fergana, Republic of Uzbekistan

Salikhanova Dilnoza Saidakbarovna
Doctor of Technical Sciences, Leading Researcher at the Institute of General and Inorganic Chemistry, Academy of Sciences of the Republic of Uzbekistan

Karimov Ikromali Tozhimatovich
Doctor of Technical Sciences, Professor, Fergana State Technical University, Fergana, Republic of Uzbekistan

Abstract

The article analyses the by-products formed during the combustion of briquettes produced under the following parameters: nozzle diameter Dn = 25 mm, compressive force of the variable-pitch screw Fc = 2.4 kN, working chamber diameter Dw.c = 100 mm, addition of 10–15% water and binder for briquetting, a 9:6% aqueous mixture of alcohol stillage and paraffin waste, briquetting temperatures of 90, 95, and 100 °C, mixing time of 20 minutes with thermal treatment, and addition of hard and soft nutshells in the range of 10, 20, and 30% relative to the total mass. The combustion analysis of the obtained briquettes was carried out in accordance with GOST 12.1.005-38.

The study established that preliminary drying of coal powder and heat-assisted mixing of the blend partially reduce the volatile gases present in the briquette composition. It is explained that this process can be controlled through monitoring or by applying dust–gas cleaning methods. However, recommendations

are provided on the complexity of monitoring various emissions generated during the combustion of finished briquettes in compliance with MPC standards.

Keywords

Alcohol bar, paraffin waste, ash content, compressive strength, working chamber, preliminary drying.

Introduction

The process of solid fuel combustion can have a significant impact on the environment. During this process, various ecological problems arise, the most common of which are the emission of harmful gases into the atmosphere, including carbon dioxide (CO_2), nitrogen oxides (NO_2), sulphur oxides (SO_2), and other pollutants that contaminate the air and contribute to climate change and global warming. In addition, the combustion of solid fuels can release particles and chemical substances into the air, including mineral dust and certain metals, which pose serious risks to human health, especially the respiratory system. Since solid fuels such as coal and petroleum products are composed of organic matter, their combustion triggers new chemical reactions that can release further harmful substances into the atmosphere.

Modern methods to mitigate these problems include reducing the use of solid fuels or substituting them with alternative energy sources such as solar power. However, this approach can only partially meet demand and cannot fully supply the population. Another option is to replace solid fuels with organic or renewable energy sources, but these are intermittent and not consistently available, while the technologies required for their large-scale use are not yet fully developed. Upgrading combustion technologies by using advanced filtration, gas-cleaning, and recycling systems can help reduce environmental impacts, but the diversity and complexity of pollutants make it difficult to achieve a complete solution, and current aspiration devices cannot fully resolve the problem. Expanding the use of alternative energy sources such as wind, photovoltaic, geothermal, biogas, and biomass fuels is also important, but their widespread application in industry and society remains limited.

The methods reviewed above do not significantly reduce the demand for solid fuels in economic and technological terms. Therefore, identifying specific technological parameters to minimize the environmental impact of mined solid fuels and their briquettes may provide a practical solution to the broader problem [3,4]. Based on the results and conclusions of the above analytical study, the environmental impact of the recommended briquette was investigated.

Literature review

The ash generated after the combustion of briquettes determines their ecological efficiency. Therefore, studying the addition of different types and amounts of binders is considered an important

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factor in assessing the ecological performance of the produced briquettes. During the combustion of briquettes, both settled and volatile ash are mainly formed [5]. According to analytical studies conducted by researchers, 75–80% of the total ash produced in the combustion process is in a settled state with particle sizes of 60–90 μm, while about 20% consists of volatile ash with particle sizes of 0.1–20 μm, which are released into the atmosphere together with the air flow. It has also been observed that this condition depends on the type of binder added to the briquette. Based on the above, both theoretical and experimental studies were carried out to determine the ash content of the briquettes obtained in the investigated object.

Theoretical studies

Based on the determined values of the variable parameters, briquette samples were produced and laboratory analyses were carried out in accordance with GOST 11022-95. The studies were conducted within the following limits of variable parameters: nozzle diameter Dn = 25 mm, compressive force of the variable-pitch screw Fc = 2.4 kN, working chamber diameter Dw.c = 100 mm, addition of 10–15% water and binder for briquetting, a 9:6 aqueous mixture of alcohol stillage and paraffin waste, briquetting temperatures of 90, 95, and 100 °C, mixing time of 20 minutes with heat treatment, and addition of hard nutshells in the range of 10, 20, and 30% relative to the total mass [6].

For this purpose, 15 briquette samples prepared in advance at room temperature were weighed individually on an electronic scale to determine their mass. Each sample was then burned sequentially in a special closed furnace. During combustion, the start and end times of burning, as well as the temperature of heat released at maximum glowing, were measured. The ash generated after combustion was collected and weighed on an electronic scale to determine its mass.

In addition, a fan was installed in the closed furnace to draw in the smoke and dust layers formed during combustion at a rate of 2.5 m/s, directing them to an ANKT-410 dust and gas analyzer in accordance with GOST 12.1.005-38. In the analyzer, FPP-type perchlorovinyl fabric was used as the filtering material. The fabric was fixed to a paper protective ring and mounted inside a metal or plastic cartridge. The mass of dust collected in the gas analyzer filter was compared with the pre-weighed mass of the filter.

To theoretically calculate the concentration of dust in the air, the following formula was used, mg/m^3:

$$A_{k.m.} = 0,98c + A \qquad (1)$$

Here, **C** represents the amount of ash carried by the air during the combustion process of the briquette, which is determined according to the following formula, kg:

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$$c = 0,98\left[\frac{2,76\cdot 10^{6} G(273+t_s)}{V\tau P_b}\right] \quad (2)$$

бунда G — чанг массаси, кг; tc — қуруқ термометр бўйича ҳаво ҳарорати, °C; V — air flow rate passing through the equipment, m^3/min; τ — duration of air intake, min; Pb — barometric pressure, Pa; 0.98 — filter collection efficiency, %.

The amount of ash residue A, %, by mass, remaining after the combustion of the analytical sample in a closed furnace, was calculated according to the following formula, kg:

$$A = \frac{m_3 - m_1}{m_2 - m_1}\cdot 100 \quad (3)$$

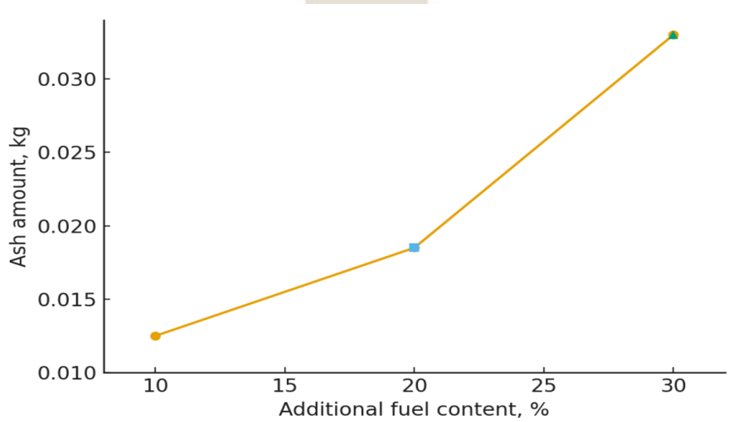
Where m_1 — mass of the steel plate intended for briquette combustion, kg; m_2 — mass of the steel plate together with the ash formed after combustion, kg; m_3 — mass of the steel plate together with the coal briquette before combustion, kg. In this case, equation (3) takes the following form, kg:

$$A_{k.m.} = 0,98\left[\frac{2,76\cdot 10^{6} G(273+t_s)}{V\tau P_b}\right] + \frac{m_3 - m_1}{m_2 - m_1}\cdot 100 \quad (4)$$

According to equation (4), it becomes possible to determine the amount of ash generated during the combustion process of the briquette.

Results of the experiment conducted in laboratory conditions 1; are presented in Figures 2 and 3.

Experimental studies:



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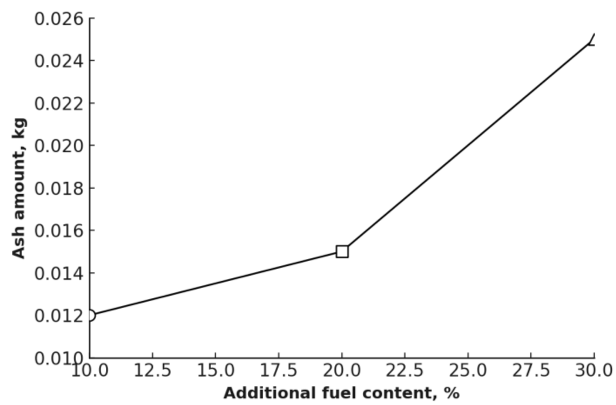
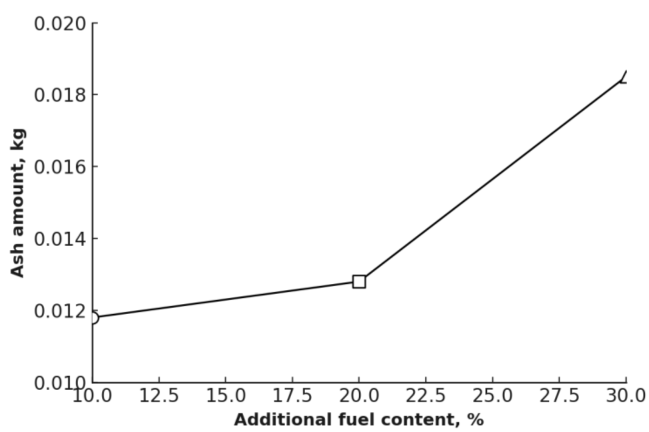
○ - *Briquette with 10% binder;* □ - *briquette with 12.5% binder;* △ - *briquette with 15% binder;*

Figure 1. Graph of ash amount variation depending on additional fuel content. Processing temperature t_{proc} = 90 °C (constant).



○ - *Briquette with 10% binder added;* □ - *Briquette with 12.5% binder added;* △- *Briquette with 15% binder added;*

Figure 2. Graph of ash amount variation depending on additional fuel content. Processing temperature t_{proc} = 95 °C - const.



○ - *Briquette with 10% binder added;* □ - *Briquette with 12.5% binder added;* △- *Briquette with 15%*

binder added;

Figure 3. Graph of the change in ash content depending on the additional fuel. Processing temperature t_{proc} = 100 °C - const..

It can be seen from the experiments that as the proportion of additional binder materials in the briquette composition increases, the amount of ash generated during the combustion process also increases.

For example, at the lower limit of the variable parameters, when 15% binder was added to the briquette, the processing temperature was tproc = 100 °C (constant), and the additional fuel content (nut shell) was 30%, the amount of ash formed in the settled state was 0.0162 kg, while the amount of ash released into the atmosphere with air was 0.0018 kg, resulting in a total ash amount of 0.018 kg. Under these parameters, the total ash content was found to constitute 12% of the briquette mass [7,8].

At the upper limit of the variable parameters, when 10% binder was added to the briquette, the processing temperature was tproc = 90 °C (constant), and the additional fuel content (nut shell) was 10%, the amount of ash formed in the settled state was 0.010 kg, while the amount of ash released into the atmosphere with air was 0.001 kg, resulting in a total ash amount of 0.011199 kg. Under these parameters, the total ash content was determined to be 8% of the briquette mass.

According to standard requirements, the amount of ash generated during the combustion process of briquettes should constitute 7–10%. Analysis of the research results shows that when the variable parameters were within the range of 12–15% binder, a processing temperature of tproc = 95–100 °C, and additional fuel content (nut shell) of 20–30%, the ash amount generated fully met the established standard requirements [9].

In order to further process the research results and to evaluate the error between theoretical and experimental values, the following empirical formulas were obtained for the specified values of the variable parameters [10].

1 – At a processing temperature of tproc = 90 °C (constant):

$$y = 0.003x^2 - 0.0008x + 0.017 \qquad R^2 = 0.9997 \qquad (5)$$

2 – At a processing temperature of tproc = 95 °C (constant):

$$y = 0.0022x^2 - 0.0007x + 0.0155 \qquad R^2 = 0.9993 \qquad (6)$$

3 – At a processing temperature of tproc = 100 °C (constant):

$$y = 0.0016x^2 - 0.0005x + 0.014 \qquad R^2 = 0.9995 \qquad (7)$$

The research results differ from the theoretical calculated results by no more than 2%. The values in equations (5–7) are valid when the variable parameters include 12–15% binder content in the briquette, a processing temperature of tproc = 95–100 °C, and additional fuel content (nut shell) in the range of 20–30%.

In addition, the median particle size of ash produced during combustion is also of significant importance, as this indicator is considered a key parameter in evaluating the ecological efficiency of the briquette. For example, according to current production standards, the ash formed in the settled state should be greater than 80% with a median size above 90 μm, while the ash released into the atmosphere with air should be less than 10% with a median size of 0.1–20 μm [11].

Based on the above, the median particle size of ash formed during the combustion of the obtained briquettes was analyzed under laboratory conditions to verify compliance with standard requirements. The experiments were conducted in two stages.

First, according to GOST 12.1.005-38, ash contained in the air stream directed to the ANKT-410 dust and gas analyzer was collected on a filter fabric, and the collected ash was photographed using a DSM-310 chamber and a LANGDORPSSESTENGER-1603201 SM001-CYANS microscope. Along the microscope's 10 μm scale line, the amounts of ash in the size ranges of 0.01–5 μm, 5–10 μm, and 10–20 μm were compared as percentages. The image processing was performed using MATLAB software. The microscope magnification was set at 40×. The results are presented in Figures 4a and 4b.

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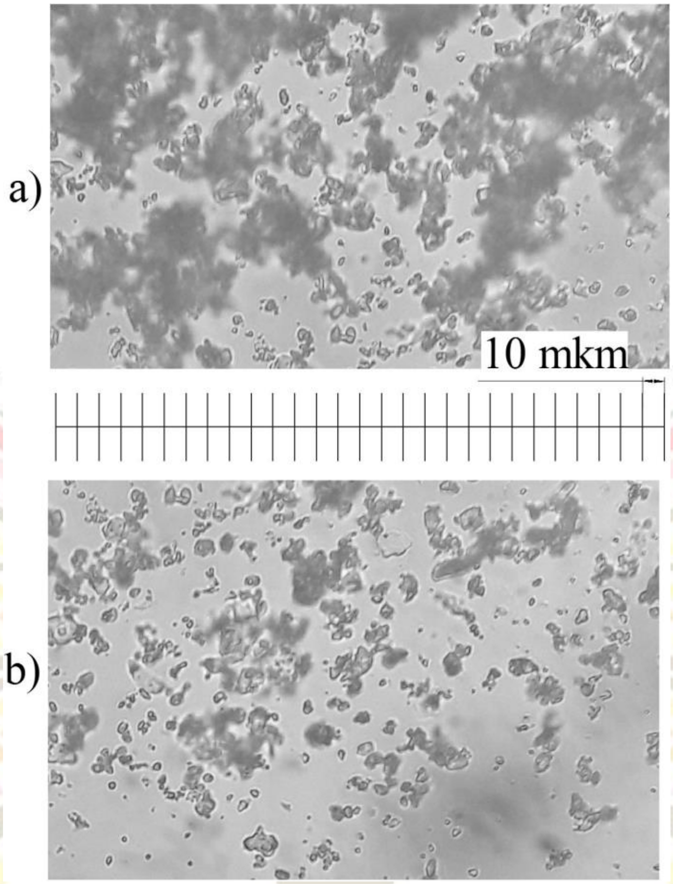

a) Mixture treated at a temperature of 100 °C; b) Mixture treated at a temperature of 90 °C.

Figure 4. Photograph of ash taken using a DSM-310 chamber and a Langdorpssestenger-1603201 SM001-CYANS microscope.

Based on the results of laboratory analyses determined by the microscopy method, a comparative graph of the dispersive composition of dust particles was constructed (Figure 5).

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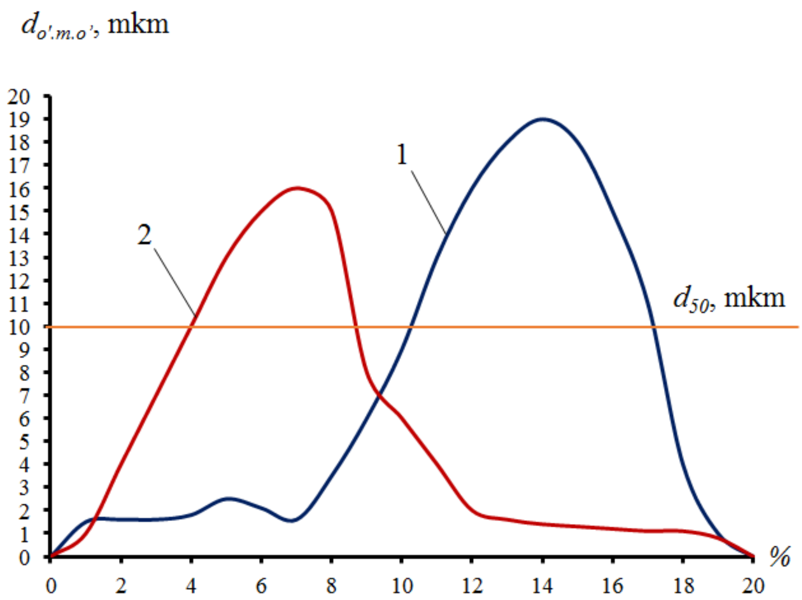

Mixture treated at a temperature of 100 °C; Mixture treated at a temperature of 90 °C.

Figure 5. Comparative graph of the dispersive composition of ash formed during the briquette combustion process.

The error between the microscopy method and theoretical calculations was found to be 4%. From the dependence shown in Figure 5, it can be observed that with an increase in the mixing temperature of the composition, the median particle size of the ash formed during combustion also increases. This phenomenon is explained by the improvement in mass transfer processes under the influence of heat. In addition, as noted earlier, when the processing temperature exceeds 100 °C, the briquetting process of the mixture becomes more complicated. From this, it can be concluded that when the processing temperature lies within the range of 95–100 °C, both technical and ecological requirements meet the established standard norms [12].

CONCLUSION

During the briquetting process of coal powder, in addition to ash, other volatile substances are also generated. For example:

– Carbon dioxide (CO_2): Approximately 99% of the carbon in coal converts to CO_2 during combustion.

– Carbon monoxide (CO): Not a primary emission (denoted FCO_2), but formed as a by-product under oxygen deficiency conditions.

– Sulfur dioxide (SO_2): Globally, coal combustion generates about 75 Tg/year (74 million tons) of SO_2, which accounts for a large share of total SO_2 emissions, on average 80–90%.

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– Nitrogen oxides (NO_x): Produced as a result of nitrogen–oxygen reactions during combustion; coal-fired power plants contribute 60–80% of the total NO_x emissions.

These statistics are mainly based on the experiences of the USA, Europe, and China; however, the trends are common to producers and consumers worldwide.

The use of coal and any type of coal-derived fuels contributes significantly to global atmospheric pollution through CO_2, SO_2, NO_x, particulate matter (PM), and critical toxic metals. Therefore, preliminary drying of raw materials, redesign of gas-cleaning systems for the volatile gases produced during drying, and strengthening the monitoring of gases released into the atmosphere are among the most important tasks. In the present study, preliminary drying of coal powder and mixing with thermal assistance were applied, which led to a partial reduction of volatile gases in the briquette composition. This process can be managed either through direct control or by applying dust–gas purification methods. However, monitoring the diverse emissions generated during the combustion of finished briquettes according to MPC (Maximum Permissible Concentration) standards remains a complex issue.

For this reason, in standard requirements imposed on manufacturers in this field, ecological efficiency takes precedence over technical efficiency. Based on the above, the amount of volatile gases generated during the combustion of briquettes produced under different variable parameters was determined experimentally.

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