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The environmental efficiency of the combined combustion of low-grade Ekibastuz coal and plant biomass

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ABSTRACT
This article presents the results of a study on the layered combustion of low-grade Ekibastuz coal blended with biomass additives aimed at improving the energy efficiency and environmental sustainability of small- and medium-scale energy systems. Corn waste, which is a by-product of agro-industrial production, was used as a bio-additive. Comprehensive physico-chemical analysis of the original components was carried out, including determination of their calorific value. Based on the obtained data, fuel mixtures with different biomass contents were prepared, which allowed an in-depth analysis of co-combustion processes and the relationship between the proportion of biomass, the calorific value of the mixture, the combustion efficiency, and the level of pollutant emissions to be determined. The results showed that the most optimal composition is a fuel mixture with a biomass content in the range of 20-30% and coal in the range of 70-80%, providing the best combination of energy and environmental performance. Calculations and experimental studies of layered combustion parameters in installations with a fixed layer have been performed. It was demonstrated that the addition of 20–30% biomass intensifies the combustion process, increases the overall calorific value of the fuel blend, and reduces the concentration of harmful substances in flue gases compared to the combustion of pure coal. Rational process conditions have been defined, including the optimal height of the fuel layer, temperature regimes, and combustion duration. The results confirm the high prospects of using fuel mixtures based on low-grade coal and biomass as a cleaner and more sustainable solution for heat supply of small and medium-sized energy systems in Kazakhstan.

Keywords: layered combustion, low-grade coal, corn biomass, combustion efficiency, carbon footprint decline.

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Introduction

One of the largest sources of anthropogenic emissions is the energy sector, in particular, the coal-based power industry. Coal continues to play a significant role in the global power industry: in 2024, it accounted for about 35 % of global electricity generation [1]. One of the promising approaches to reducing the environmental impact of coal-based power generation is the combined combustion of coal and biomass. Using biomass as an additional fuel makes it possible to partially replace fossil fuels and thereby reduce fossil CO_2 emissions per unit of energy produced. At the same time, the carbon balance of biomass depends on the origin of the raw material, the methods of its harvesting, transportation, and preparation, so its environmental benefits should be assessed taking into account the full life cycle [[2], [3]]. A significant advantage of co-combustion technology is the possibility of using the existing energy infrastructure with relatively limited equipment upgrades. However, coal combustion is accompanied by the formation of CO_2 and other pollutants, including SO_2 and NO_x, which are associated with negative impacts on air quality, ecosystems, and public health [[4], [5]]. To reduce the environmental consequences of using fossil fuels, various approaches are employed, including improving energy efficiency, enhancing combustion technologies, and partially replacing coal with renewable fuels. Biomass is considered one of the renewable energy sources suitable for partially replacing coal. Depending on the type of raw material, biomass may be characterized by a lower sulfur content and a different composition of organic and mineral components compared to coal, which affects combustion processes and the formation of gaseous pollutants [[6], [7]]. One of the promising ways to use biomass in the energy sector is the co-combustion of coal and biomass. The results of published studies show that partial replacement of coal with biomass can lead to a decline in fossil CO_2 emissions, as well as to changes in the levels of SO_x and NO_x, depending on the fuel composition and process conditions [[8], [9]]. In addition, co-combustion makes it possible to use the existing infrastructure of coal-fired power plants and is considered a relatively low-cost way to integrate renewable fuels into the traditional energy sector. Studies of co-combustion show that an increase in the proportion of biomass can significantly affect the characteristics of ignition, combustion, ash formation, and gaseous combustion products. At the same time, the nature of the changes in NO_x, SO_2, and CO depends on the type of coal and biomass, their ratio, temperature, air excess ratio, and the design of the combustion device Therefore, the choice of the ratio of fuel mixture components requires experimental assessment for a specific type of coal and a specific type of biomass. The use of agricultural waste as a fuel component is of particular interest, since its energy use simultaneously makes it possible to obtain energy from secondary raw materials and reduce waste volumes. The literature considers the co-combustion of coal with various agricultural residues, but the process characteristics significantly depend on the chemical composition, ash content, moisture content, volatile matter content, and calorific value of the specific type of biomass [9]. Corn waste represents a significant resource of agricultural biomass and can be considered a potential component of fuel mixtures with coal. Its use is of interest from the perspective of the energy utilization of agricultural waste; however, the characteristics of combustion and the formation of pollutants when corn residues are co-burned with low-grade, high-ash coal require additional study. In particular, it is necessary to determine the effect of the ratio of mixture components on the calorific characteristics, the stability of the combustion process, the completeness of combustion, and the composition of flue gases. In this regard, an experimental study of the effect of co-burning low-grade Ekibastuz coal with corn residues on the combustion process characteristics and the concentration of major pollutants in flue gases is relevant. This work aims to determine the effect of the proportion of corn waste in the fuel mixture on the technological characteristics of combustion and the concentrations of CO, CO_2, NO_x and SO_2, as well as to determine the recommended ratio of mixture components for further application.

Experimental part

Selection of raw materials and preparation of samples. Coal from the Ekibastuz deposit in the Republic of Kazakhstan was selected as the initial fuel; it is characterized by a lower heating value of about 12.2 MJ/kg and a high ash content of more than 40 %. To improve its fuel properties, corn residues, sunflower meal, and wheat husk were used as additives. The biomass is characterized by low ash content, renewability, and a high content of volatile substances that enhance ignition and combustion. The coal and biomass were dried at 110 ± 15 °C to a constant mass, then crushed in a jaw crusher and a disc grinder. The resulting material was sifted through a 60 mesh (≈250 µm) sieve to ensure a uniform particle-size distribution. The mineral component of Ekibastuz coal is predominantly represented by clay minerals (about 54 %) and quartz (28 %); siderite, calcite, magnetite, and gypsum are also present. The ash is dominated by SiO_2 (56–59 %) and Al_2O_3 (26–33 %), which accounts for the high ash content of the coal. The particle-size distribution significantly affects the processes of grinding and pulverized combustion. During grinding, the organic and mineral components are distributed unevenly across fractions, and after combustion, predominantly fine-dispersed fly ash is formed. It has been established that as the particle size increases from approximately 2 to 116 µm, the SiO_2 content decreases, while Al_2O_3 and Fe_2O_3 increase. As the particle size increases from 2 to 25 µm, the quartz content also decreases, while the proportion of mullite and iron-containing spinel increases.

Table 1 - Characteristics of the main fractions

Grain size class	General characteristics
Large fractions	Pieces of coal formed during mining and transportation; they contain organic matter and mineral layers.
Medium fractions	Crushing products; they are characterized by a higher degree of exposure of mineral inclusions.
Fine fractions	They are formed during crushing and grinding; the surface area of the particles increases.
Thin fractions, <0.1 mm	They are characteristic of pulverized fuel and the products of its combustion.
Fractions of the order of several to tens of micrometers	Typical of a significant portion of fly ash; characterized by a complex mineral and phase composition

Consequently, the granulometric composition has a significant impact on the distribution of mineral phases and the properties of the ash. The generalized granulometric distribution of materials produced during the processing and combustion of Ekibastuz coal is presented in Table 1.

The elemental composition of Ekibastuz coal, including the content of main and trace elements, is presented in Table 2 .

Table 2 - Elemental composition of Ekibastuz coal

Element	Content
Al	6.41–7.78 wt. %
Si	14.33–17.92 wt. %
Fe	1.20–2.30 wt.%
K	0.53–0.68 wt.%
Ca	0.19–1.81 wt.%
Ti	0.323–0.450 wt.%
Cu	37.6–52.0 µcg/g
Zn	23.2–25.0 µcg/g
Pb	<10 µcg/g
Cd	4.4–4.7 µcg/g
V	100–150 µcg/g
Mn	201–365 µcg/g
Ni	35–65 µcg/g
Ga	14.0–19.9 µcg/g
Rb	13.4–18.1 µcg/g
Sr	187.1–276.2 µcg/g
Y	22.6–24.7 µcg/g
Zr	125.0–167.3 µcg/g

The obtained literature data indicate a complex mineral composition of Ekibastuz coal and the presence of both main mineral components and a number of trace elements. This characteristic is important for assessing the processes of ash formation and behavior during coal combustion and its combined combustion with corn waste. It should be noted that the values presented are literature data for the studied samples of Ekibastuz coal, not the results of the own XRF analysis of the sample used in this work.

Analysis of the structure and fraction composition of fuel mixtures. In order to substantiate the possibility of energy use of compositions based on low-grade coal and maize biomass (stalks, foils and leaf mass), studies of the morphology of samples, their elemental composition and granulometric characteristics have been carried out. The results of these studies make it possible to assess the influence of the structural and dispersive properties of fuels on heat and mass transfer processes, and also provide the initial data for calculating combustion parameters and developing effective technologies for the combined combustion of coal and biomass (Fig. 1).

Preparation of fuel mixtures. Coal from the Ekibastuz energy fields and ground maize waste were used as components of the fuel mixtures. The biomass was pre-dried to a constant mass; after which it was crushed to a finely dispersed state. The composition of the tested mixtures varied in the following ranges: coal - 95-70 % by mass; corn waste - 5-30 % by mass.

Determination of moisture in fuel mixtures. The moisture content of fuel mixtures was determined according to GOST 27314-91 (ISO 589) [10]. Fuel blend samples weighing 10 ± 1 g were placed into pre-weighed weighing bottles and dried at 105–110 °C until a constant mass was achieved. The weighing bottles were weighed before and after drying using a ViBRA HT 224RCE analytical balance with a precision of 10^{-4} g. To evaluate the effect of temperature on moisture removal, additional moisture determinations were performed at 40 °C and 140 °C. The moisture content was calculated from the difference between the sample mass before and after drying.

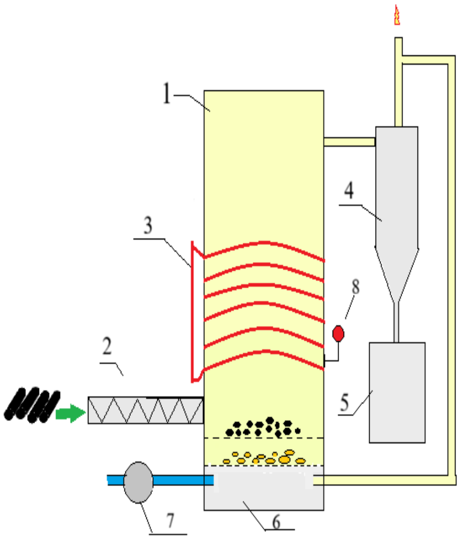
Determination of the release of volatile substances. The release of volatile combustion products is an important fuel characteristic that determines the ignition conditions and stability of combustion in combustion devices. The mass fraction of volatile substances was determined by the sample mass difference before and after heat treatment.

Determination of the ash content of fuel mixtures. The ash content of fuel mixtures was determined according to GOST 11022-95 [10]. The 1 ± 0.1 g fuel sample was distributed evenly in porcelain boats and placed in a cold muffle furnace. Determination of combustion heat. The maximum heat of combustion of blended fuels was determined by calorimetric burning according to GOST 147-2013 (ISO 1928) [11]. Experiments were conducted on the GDY-1C Oxygen Bomb Calorimeter. The 0.8-1.0 g fuel sheath was placed in a bomb filled with oxygen at 30 kgs/cm^2. When the sample burned completely, the increase in water temperature in the calorimetric system was measured.

The burning rate of a mixture of coal and corn residues is determined by kinetic solid-phase oxidation reaction parameters, which depend on the chemical composition and volatile content of the fuel. Adding up to 20-30% biomass of maize waste to a coal mixture changes the combustion kinetics, leading to an increase in the proportion of volatile components and a decrease in reaction activation energy compared to pure coal, which leads to faster transition of fuel into the active phase. This effect is manifested by an increase in the combustion rate of the fuel blends due to the easier release of volatile compounds during pyrolysis and the higher reactivity of biomass compared to coal under heating conditions. In particular, corn residues exhibit greater thermal reactivity than coal. The incorporation of biomass also alters the mass-loss rate profiles observed in thermogravimetric and derivative thermogravimetric analyses, indicating an enhanced rate of thermal decomposition and overall combustion of the blended fuel [12].

Results and Discussion

Coal and biomass co-combustion is seen as one of the promising ways to improve energy efficiency and reduce the carbon footprint of thermal power. In Kazakhstan, where substantial reserves of low-grade coals are available from the Ekibastuz, Karazhyra, and Shubarkol deposits, the incorporation of locally available biomass resources derived from agricultural residues, such as corn residues, sunflower cake and wheat husks, offers an opportunity to partially replace fossil carbon with renewable carbon sources. The study of coal combustion processes was carried out in a laboratory installation of a layered combustion with a stationary layer. The installation diagram is shown in Fig. 1.



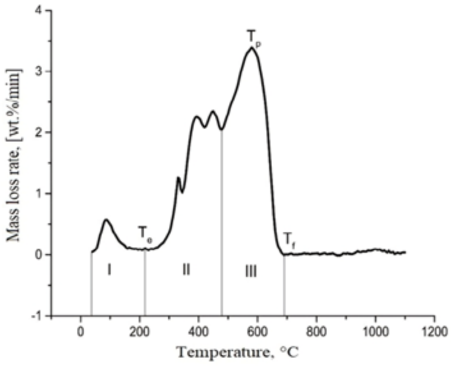
1 - combustion chamber (furnace); 2 - charging system (screw); 3 - heat exchanger (snake); 4 – cyclone; 5 - collection of ashes; 6 - ash; 7 - air; 8 - thermal sensor

Figure 1 - Fuel system for co-combustion of coal and biomass (corn waste)

Table 3 presents the results of thermogravimetric analysis of the studied fuel mixtures based on low-grade coal and corn biomass, including their main thermogravimetric characteristics.

Table 3 – Thermogravimetric characteristics of biomass and coal

Characteristic	Biomass				Coal
	Wheat husk	*Sunflower cake*	*Wood biomass*	*Corn stalks*	
Moisture content, %	9 - 25	8-25	30- 45	7 - 10	10 -15
Volatile matter yield, %	19.8 - 69.0	15-16.0	70 - 75	70 - 75	15 - 30
Fixed carbon (dry basis), %	8 - 43	9-50	20 - 25	20 - 25	50 - 55
Bulk density, kg/m^3	0.20 - 0.25	0.30-0.45	0.55 - 0.75	0.75 - 0.85	0.20 - 0.25
Energy density, GJ/m^3	2.0 - 3.0	2.5-3.5	7.5 - 10.4	15.0 - 18.70	2.0 - 3.0
Lower heating value (as received), MJ/kg	16.0 - 17.4	18.0-19.0	9 - 12	15 - 16	23 - 28



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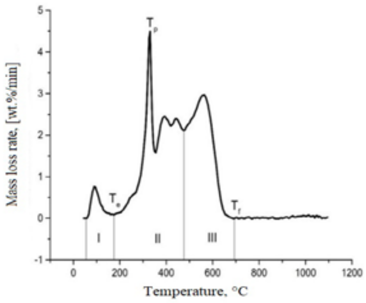

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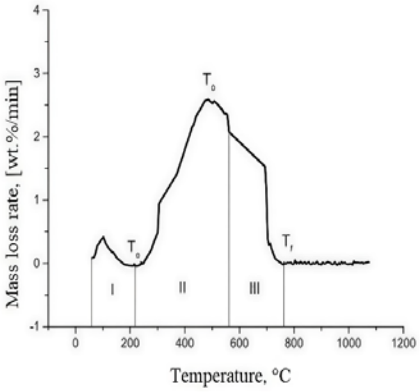

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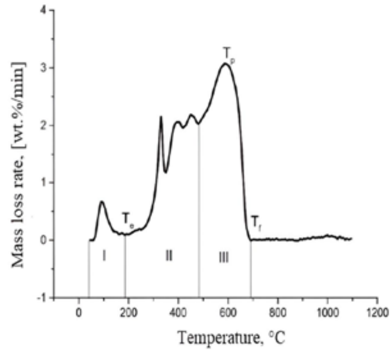

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T_e - the temperature at the onset of thermal decomposition of the fuel blend; T_p - the temperature corresponding to the maximum decomposition rate; and T_f - the temperature at which the thermal degradation process is completed

Figure 2 - Temperature-dependent rate of thermal decomposition of fuel mixtures. Coal to biomass ratio: (a) -100/0; (b) -90/10; (c) -70/30; (d) -50/50

With further temperature rise to 350-580 °C, thermal degradation of cellulose and lignin is observed. In the range of 580-700 °C, the decomposition of the coal content of the fuel mixture becomes a major process. It has been found that an increase in maize biomass to 30 % reduces the temperature corresponding to the maximum rate of thermal decomposition by 20-30 % relative to the original coal. In addition, the decomposition of mixtures is completed at lower temperatures. This effect is due to the high release of volatile substances from biomass and its lower ignition temperature compared to coal, which promotes the intensification of thermochemical processes in fuel composition.

Table 4 - Temperature rate dependency of fuel mixtures

Coal: Corn biomass blend	**T_e* – Onset temperature, °C**	**T_p* – Peak decomposition temperature, °C**	**T_f *– Final decomposition temperature, °C**
100 : 0 (Pure coal)	360	460	550
90 : 10	355	455	545
70 : 30	345	445	535
50 : 50	335	435	525

* T_e – represents the threshold temperature at which thermal decomposition processes are initiated and the intensive release of volatile compounds begins;
* T_p- corresponds to the temperature of maximum thermal degradation intensity, at which the decomposition reactions of the fuel blend proceed at the highest rate;
* T_f - denotes the final temperature of fuel thermal transformation, at which the release of volatile products has virtually ceased, and the organic fraction of the fuel has been largely converted into ash residue and gaseous products.

An increase in the maize biomass content of the investigated fuel blends resulted in a decline in the decomposition onset temperature and a shift of the maximum decomposition rate region toward lower temperatures. These findings indicate improved fuel reactivity and demonstrate a synergistic interaction between coal and biomass during the co-combustion process.

Determination of the dependence of the ash and humidity of Ekibastuz coal on the composition of the burnt mass. High humidity reduces combustion efficiency, as a large part of the energy is consumed by evaporating water. Therefore, it is recommended to pre-dry wet coal under natural conditions. Analysis of the thermogravimetric curves showed that in the temperature range from 150 to

400 °C, intensive decomposition of hemicellulose and the most volatile organic components of the biomass occurs (Figure 2, Table 4).

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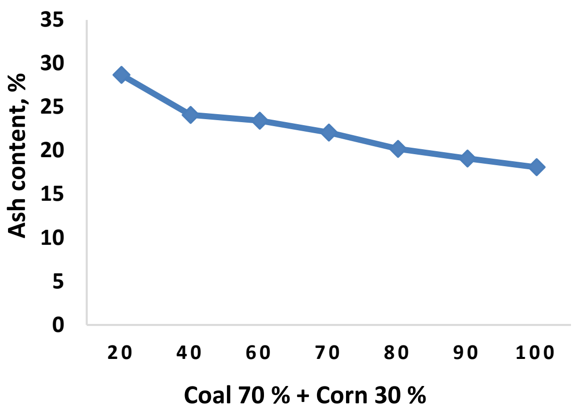

Figure 3 – Coal ash dependency on combustion mass composition

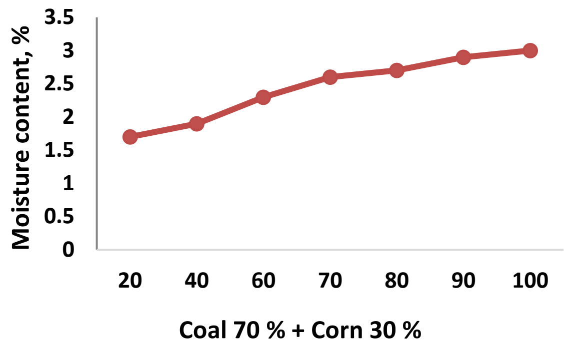

Figure 4 - Coal moisture dependence on the composition of the burned mass

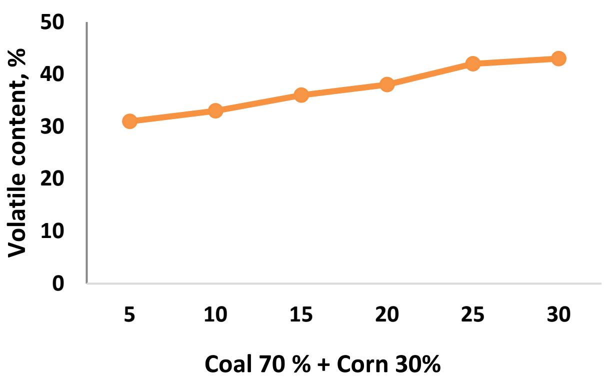

Figure 5 - Volatile matter dependency of the coal mixture

Environmental indicators

To assess the impact of co-firing Ekibastuz coal and corn biomass on flue gas composition, we experimentally determined concentrations of CO, CO2, NOx, and SO2. We measured gaseous component concentrations in the flue gases using a Testo 350 multicomponent gas analyzer (Testo SE & Co. KGaA, Germany). This instrument is designed for analyzing flue gases and industrial emissions and, depending on the installed measuring unit and sensors, can determine the concentrations of O_2, CO, CO_2, NO, NO_2, SO_2, and other components. In accordance with the instrument's technical specifications, concentrations of CO, CO_2, NO, NO_2, SO_2, and O_2 were determined; the NO_x concentration in this study was calculated as the sum of the measured NO and NO_2 concentrations [13]:

$$NO_x = NO + NO_2 \quad (1)$$

Flue gases were sampled after the active combustion zone at a steady-state temperature. Before feeding the sample into the measuring unit, the gases were pre-cleaned to remove particulate matter. Identical experimental conditions were maintained for all fuel compositions studied. Measurements were conducted after combustion stabilized, allowing for comparison of the obtained concentrations between different fuel mixture compositions. The initial experimental data are presented in Table 5.

Table 5 - Concentrations of the main components of flue gases during the combined combustion of Ekibastuz coal and corn biomass

Fuel composition	CO, ppm	CO_2, %	NO_x, ppm	SO_2, ppm
E100	4200	16.8	480	205
E90K10	3900	16.7	465	195
E80K20	3500	16.6	450	180
E70K30	3100	16.5	430	165
E60K40	2700	16.4	415	150
E50K50	2300	16.3	400	135
E40K60	1900	16.2	385	120
E30K70	1600	16.1	370	105
E20K80	1300	16.0	355	90
K100	900	15.5	330	—

To quantitatively assess the change in pollutant concentrations when biomass is added, the relative concentration decline was used compared to the combustion of the original coal (E100): according to the formula (2):

$$\mu i = \frac{CE100-Ci}{CE100} * 100\% \quad (2)$$

where E stands for Ekibastuz coal, and K stands for corn biomass. μ_i — the relative decline in the concentration of the pollutant, %; C100-C_i — the concentration of the pollutant when 100 % of

Ekibastuz coal is burned, ppm or %; C_i — the concentration of the same pollutant when Ekibastuz coal and corn biomass are co-burned, ppm or %.

Thus, the reduction values presented in Table 6 are not the results of independent experimental measurements but represent calculated indicators determined based on experimentally measured concentrations. This allows you to trace the origin of each numerical value and reproduce the calculation.

Table 6 - Relative decline in the concentrations of gaseous components of flue gases during the combined combustion of Ekibastuz coal and corn biomass

Fuel composition	Biomass fraction %	Decline CO, %	Decline CO_2, %	Decline NO_x, %	Decline SO_2, %
E100	0	0.0	0.0	0.0	0.0
E90K10	10	7.1	0.6	3.1	4.9
E80K20	20	16.7	1.2	6.3	12.2
E70K30	30	26.2	1.8	10.4	19.5
E60K40	40	35.7	2.4	13.5	26.8
E50K50	50	45.2	3.0	16.7	34.1
E40K60	60	54.8	3.6	19.8	41.5
E30K70	70	61.9	4.2	22.9	48.8
E20K80	80	69.0	4.8	26.0	56.1
Note: the relative decline is calculated					

The relative decline is calculated relative to the concentrations obtained when burning 100 % of Ekibastuz coal (E100), using the formula (3):

$$\mu CO = \frac{4200-1300}{4200} * 100 = 69{,}0\% \qquad (3)$$

That is, when the share of corn biomass is increased to 80 %, the CO concentration decreases by 69.0 % compared to the combustion of pure Ekibastuz coal. Similarly, for NO_X (4):

$$\eta NO_x = [(480 - 355) / 480] \times 100 = 26{,}0\ \% \qquad (4)$$

for SO_2 (5):

$$\eta SO_2 = [(205 - 90) / 205] \times 100 = 56{,}1\ \% \qquad (5)$$

and for CO_2 (6):

$$\eta CO_2 = [(16{,}8 - 16{,}0) / 16{,}8] \times 100 = 4{,}8\ \% \qquad (6)$$

The obtained experimental data demonstrate a consistent decrease in the concentrations of CO, NO_x, and SO_2 as the proportion of corn biomass increases. For the E20K80 composition, compared to E100, the CO concentration decreased from 4200 to 1300 ppm, NO_x from 480 to 355 ppm, and SO_2 from 205 to 90 ppm. In relative terms, this corresponds to a decrease of 69.0 %, 26.0 %, and 56.1 %, respectively.

The decrease in CO concentration may be associated with changes in the conditions of the combustion process and the degree of oxidation of combustible components. The decrease in SO_2 concentration is consistent with the replacement of part of the coal fuel with biomass, since an increase in the proportion of biomass reduces the amount of the coal component, which is a source of sulfur. The decrease in NO_x may be due to changes in temperature conditions and the composition of the fuel mixture; however, to unambiguously establish the mechanism of NO_x formation, additional analysis of the temperature field and fuel composition is required [[14], [15], [16], [17], [18], [19], [20]].

At the same time, it is necessary to distinguish between a decline in the concentration of pollutants in flue gas and a decline in their mass emission. The presented experimental data directly confirm the change in concentrations. To make a quantitative statement about the decline in mass emissions, it is necessary to additionally take into account the flue gas flow rate and the consumption/mass of the fuel being burned, as well as to ensure the comparability of the results regarding the oxygen content in the flue gases. Therefore, in this work, it is more accurate to speak of a decline in the concentrations of CO, NO_x, and SO_2 if the corresponding calculation of mass emissions has not been carried out separately. Regarding CO_2, its concentration varies from 16.8 % for E100 to 16.0 % for E20K80, which corresponds to a calculated decline of 4.8 %. Consequently, the statement previously cited in the article about a 10–15 % decline in CO_2 is not supported by the experimental data and should be excluded. Taken together, the results show that within the studied range of compositions, an increase in the proportion of corn biomass is accompanied by a decrease in the measured concentrations of the main gaseous components, primarily CO and SO_2. However, the environmental efficiency of co-combustion should be assessed taking into account not only the concentrations but also the specific mass emissions of pollutants per unit of mass or the energy content of the fuel.

Conclusions

An experimental study was conducted on the co-combustion of Ekibastuz coal and corn waste in various ratios. It was found that adding corn residues stalks to the fuel mixture has a positive effect on the combustion process characteristics and the composition of the resulting flue gases.

An increase in the proportion of corn residues in the fuel mixture is accompanied by a decrease in the concentrations of the main pollutants studied. With a composition of 70 % Ekibastuz coal and 30 % corn waste (E70K30), the CO concentration decreases from 4,200 to 3,100 ppm compared to burning 100 % coal, which corresponds to a 26.2 % decline; the NO_x concentration decreases from 480 to 430 ppm (10.4 %), and the SO_2 concentration decreases from 205 to 165 ppm (19.5 %). The CO_2 concentration changes from 16.8 % to 16.5 %, which corresponds to a decrease of 1.8 %.

The results obtained show that co-firing Ekibastuz coal with corn waste makes it possible to reduce the concentrations of CO, NO_x, and SO_2 in flue gases compared to using coal alone. The most pronounced decline among the studied components is observed for CO and SO_2. At the same time, the given values characterize the decline in the concentrations of pollutants; to determine the mass decline in emissions, it is necessary to additionally take into account the flue gas consumption and fuel consumption. Taking into account the obtained experimental data, a fuel mixture in the ratio of 70 % Ekibastuz coal: 30 % corn waste is recommended for further practical research. This composition allows coal to be retained as the main component of the fuel while simultaneously enabling the utilization of agricultural corn waste as a fuel additive. To ensure a stable process of co-combustion, it is recommended to maintain the temperature in the active combustion zone within the range of 800–900 °C, and in the afterburning zone — above 850 °C. Compliance with these conditions promotes more complete combustion of the fuel mixture and reduces the formation of incomplete combustion products.

Thus, the combined use of Ekibastuz coal and corn waste in the ratio of E70%: K30% is a promising direction for improving the environmental characteristics of the incineration process and the rational use of agricultural waste. The recommendations obtained relate to the Ekibastuz coal and cornstalks studied and the experimental conditions established in the work; their application to other types of coal or biomass requires additional experimental verification.

Conflicts of interest. There are no competing interests for all authors.

CRediT Author Statement: **S. Myrzalieva:** Supervision, Conceptualization, Methodology, Validation, Writing – Review & Editing; **Sh. Akilbekova:** Investigation, Data Curation, Formal Analysis, Writing – Original Draft Preparation; **H. Retnawati –** Proofreading, Writing – Review & Editing; **S.Yermishin:** Investigation, Data Curation, Formal Analysis.

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Төмен сұрыпты Екібастұз көмірі мен өсімдік биомассасының аралас жануының экологиялық тиімділігі

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[1]Қазақстан Республикасының минералдық шикізатты кешенді қайта өңдеу жөніндегі ұлттық орталығы РМК, Алматы, Қазақстан

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Мақала энергетикалық тиімділікті және шағын және орта жылуэнергетикалық жүйелердің экологиялық тұрақтылығын арттыру мақсатында биомасса қоспаларымен араластырылған төмен сортты Екібастұз көмірін қабаттап жағуды зерттеуге арналған. Биологиялық қоспа ретінде жүгері қалдықтары — агроөнеркәсіптік өндірістің жанама өнімі — пайдаланылды Отынның бастапқы компоненттеріне кешенді физика-химиялық талдау жүргізілді, соның ішінде олардың жану жылуын анықтау да қамтылды. Алынған деректер негізінде биомасса

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үлесі әртүрлі пайыздық құрамы бар отын қоспалары дайындалды, бұл көмір мен биомассаны бірлесіп жағу процестерін егжей-тегжейлі талдауға және қоспадағы биомасса үлесі, оның жану жылуы, жану тиімділігі мен атмосфераға шығарылатын зиянды заттар деңгейі арасындағы байланысты анықтауға мүмкіндік берді. Ең оңтайлы құрам биомассаның үлесі 20–30% және көмірдің үлесі 70–80% болатын отын қоспасы екені анықталды, бұл энергетикалық және экологиялық көрсеткіштердің ең жақсы үйлесімін қамтамасыз етеді. Тұрақты отын қабаты бар қондырғыларда қабатты жану параметрлерін есептеу және эксперименттік зерттеу жұмыстары жүргізілді. 20–30% биомассаны қосу жану процесін қарқындатып, отын қоспасының жалпы жану жылуын арттыратыны және таза көмірді жағумен салыстырғанда түтін газдарындағы зиянды заттар концентрациясын төмендететіні көрсетілді. Тұтынудың оңтайлы технологиялық мөлшері анықталды, отын қабатының биіктігі, температуралық режим мен жану ұзақтығы. Алынған нәтижелер төмен сұрыпты көмір мен биомасса негізіндегі отын қоспаларын Қазақстанның шағын және орта энергетикалық жүйелерін келешекте жылумен қамтамасыз ету мәселесін шешудің неғұрлым таза әрі тұрақты жолы болып табылады, бұл отынның қолайлы энергетикалық сипаттамаларын сақтай отырып, қоршаған ортаға зиян әсерді азайтуға ықпал етеді.

Түйін сөздер: жану, төмен сортты көмір, жүгері биомассасы, жану тиімділігі, көміртегі ізін азайту.

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Экологическая эффективность совместного сжигания низкосортного Экибастузского угля и растительной биомассы

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АННОТАЦИЯ
Статья посвящена исследованию слоевого сжигания низкосортного Экибастузского угля в смеси с биомассовыми добавками с целью повышения энергетической эффективности и экологической устойчивости малых и средних теплоэнергетических систем. В качестве биодобавки использовались отходы кукурузы — побочный продукт агропромышленного производства. Проведён комплексный физико-химический анализ исходных компонентов топлива, включая определение их теплоты сгорания. На основе полученных данных подготовлены топливные смеси с различным процентным содержанием биомассы, что позволило провести детальный анализ процессов совместного сжигания угля и биомассы и установить зависимость между долей биомассы в смеси, её теплотой сгорания, эффективностью горения и уровнем выбросов загрязняющих веществ в атмосферу. Установлено, что наиболее оптимальным составом является топливная смесь с содержанием биомассы в диапазоне 20–30% и угля — 70–80%, обеспечивающая наилучшее сочетание энергетических и экологических показателей. Выполнены расчётные и экспериментальные исследования параметров слоевого сжигания в установках с неподвижным слоем топлива. Показано, что добавление 20–30% биомассы интенсифицирует процесс горения, повышает суммарную теплоту сгорания топливной смеси и снижает концентрацию вредных веществ в дымовых газах по сравнению со сжиганием чистого угля. Определены рациональные технологические параметры процесса, включая оптимальную высоту топливного слоя, температурные режимы и продолжительность горения. Полученные результаты подтверждают перспективность применения топливных смесей на основе низкосортного угля и биомассы как более чистого и устойчивого решения проблемы теплоснабжения малых и средних энергетических систем Казахстана, способствующего снижению негативного воздействия на окружающую среду при сохранении приемлемых энергетических характеристик топлива.

Ключевые слова: сжигание, низкосортный уголь, кукурузная биомасса, эффективность сжигания, снижение углеродного следа.

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