DOI https://doi.org/10.30525/978-9934-26-382-8-1

THE ORGANIZATION OF IRON ORE AGGLOMERATE AND PELLETS PRODUCTION WITH REDUCED ENVIRONMENTAL IMPACT

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INTRODUCTION

In 2022, steel production amounted to 1.878 million tons, and according to the recorded demand [1], it is expected to continue growing in the near future. At the same time, the rising cost of traditional energy resources and their negative impact on the environment are leading to an increase in the use of renewable energy sources worldwide. The use of biomass to generate energy using modern technologies is environmentally safer compared to the energy utilization of traditional organic resources like coal. An important aspect is that transitioning from fossil fuel-based energy sources to renewable sources will be more efficient by utilizing local resources and existing infrastructure.

One of the most promising types of renewable energy sources is biomass, which ranks fourth among fuels in significance. Biomass is the only form of energy in nature that contains carbon reserves in a sufficiently large quantity to effectively use it as a substitute for fossil fuels. Annually, biomass provides about 2 billion tons of equivalent fuel, accounting for approximately 14% of the total primary energy consumption in the world (up to 50–80% in some countries). In the EU's energy plans, there is a goal to increase the share of energy produced from renewable energy sources in gross final energy consumption to 20% by 2020, including 14% from biomass. By 2030, this figure is expected to reach 27%[2].

According to the estimation of the Bioenergy Association of Ukraine, as of 2015, the total potential of energy from biomass was 20.2 million tons. The main components of this potential include agricultural by-products (straw from cereals and rapeseed, corn stalks, sunflower stalks, etc.) – 37.6%, and energy crops (willow, poplar, miscanthus) – 39 % [3]. However, according to the State Statistics Service of Ukraine, in 2015, the overall supply of primary energy from biomass was only 2.2%. Therefore, finding ways to increase the share of biomass utilization is a relevant task. A significant reserve for

[1] December 2022 crude steel production and 2022 global crude steel production totals. World Steel Association AISBL

[2] Heletukha H., Zheliezna T. Bioenerhetyka zamist hazu. Ekonomichna pravda

[3] Praktychnyi posibnyk z vykorystannia biomasy v yakosti palyva u munitsypalnomu sektori Ukrainy (dlia predstavnykiv ahropromyslovoho kompleksu). Ahentstvo z vidnovliuvalnoi enerhetyky. Kyiv, 2017. S. 16-17.

increasing the use of energy from biomass is concentrated in industries that are major consumers of energy resources. Metallurgy is one of such industries.

1. Analysis of the potential use of fuel biomass in the production of iron ore agglomerate

Specialized scientific laboratories around the world have been actively studying the use of biomass instead of fossil fuels in various metallurgical processes over the past decade. The ways of utilizing biomass and its derivatives in metallurgy are detailed in the research[4]. It has been demonstrated that the utilization of biomass in metallurgical production is complex in terms of scientific, technological, and economic considerations and requires both theoretical and experimental research.

A significant amount of research has been conducted on the efficiency of using biomass in the agglomeration process of iron ore. The study[5] meticulously investigates the use of sunflower seed husks as additional fuel in the sintering of iron ore. It has been determined that during sintering, with the involvement of sunflower seed husks, replacing 10% of coke breeze does not result in significant changes in combustion characteristics during the sintering of iron ore or in the quality of the produced agglomerate.

The use of wood charcoal instead of some portion of coke or coal during the sintering of iron ore increases the combustion rate. The level of increase depends on the type of initial biomass and its proportion in the fuel composition. The effectiveness of adding wood charcoal decreases in the following order: straw > wood > peat. Additionally, adding biomass reduces the maximum temperature of the sintering material layer, the time required to reach the maximum sintering temperature, and widens the temperature range of sintering. It is also noted that changes in combustion conditions and gasification rates when using biomass do not contribute to the formation of liquid calcium ferrite. This leads to a decrease in the strength of the agglomerate due to a lower proportion of calcium ferrite in the mineralogical structure of the agglomerate[6]. Similar findings are reported by the authors of

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[4] Suopajärvi H., Kemppainen A., Haapakangas J., Fabritius T. Extensive review of the opportunities to use biomass-based fuels in iron and steelmaking processes. *Journal of Cleaner Production*. 2017. V. 148. P. 714-716.

[5] Ooi T. Ch., Aries E., Ewan B.C.R., Thompson D., Anderson D.R., Fisher R., Fray T., Tognarelli D. The study of sunflower seed husks as a fuel in the iron ore sintering process. Minerals Engineering. 2008. V. 21. P. 177.

[6] Gan, M., Fan, Xh., Jiang, T. Fundamental study on iron ore sintering new process of flue gas recirculation together with using biochar as fuel. Journal of Central South University. 2014. 21. P. 4114.

another study[7], who note that regardless of the type and quantity of biomass used in the sintering process, the output of agglomerate and its strength decrease. Possible mechanisms for adjusting the sintering process may involve changes in the particle size and quantity of biomass, the amount of air drawn in, and the properties of the biomass.

It is known that iron ore sintering is a source of a large number of harmful emissions – CO, CO_2, SO_2, NO_x and organic compounds [8]. It has been found that the addition of sunflower seed husk reduces the formation of 2,3,7,8-polychlorinated dibenzoparadioxin and polychlorinated dibenzofuran by about 10 % – from 1 ng/nm^3 to 0.91 ng/nm^3 [9]. When 20 % of coke was replaced with charcoal, dioxin emissions were reduced by about 33 %. Studies have shown that the use of charcoal derived from straw and sawdust in the amount of 40, 20 and 15 wt.%, reduces SO_2 emissions by 38 %, 32 % and 43 %, respectively, and NO_x emissions by 27 %, 18 % and 31 %, respectively. Thus, the use of biomass can reduce the consumption of fossil fuels and reduce emissions. However, the negative effect of replacing coke with biomass is an increase in the CO content of sinter gas. The CO concentration in the gas increases from 2.07 to 2.85-3.11 vol. % for different types of biomass and from 3.0 to 5.0 vol. % when using different types of charcoal in the studies [10]. This problem can be solved by changing the amount of air that enters the fuel combustion zone.

Of particular note is that the use of biomass in metallurgy will reduce CO_2 emissions. This effect is particularly important in terms of the impact of metallurgical processes on climate change[11].

The report of the European Commission's Research Fund for Coal and Steel on the use of alternative carbon materials in iron ore sintering deserves special attention[12]. Blast furnace dust and slag, petroleum coke, anthracite, sunflower husks and olive pits were used as alternative fuels. As for the studies with biomass, its grinding to a size smaller than the optimal size of coke fines

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[7] Wei R., Zhang L., Cang D., Li J., Li X., Xu C.C. Current status and potential of biomass utilization in ferrous metallurgical industry. Renewable and Sustainable Energy Reviews. 2017. V. 68. P. 524.

[8] Mok Y.S., Nam I. Positive pulsed corona discharge process for simultaneous removal of SO_2 and NO_x from iron-ore sintering flue gas. *IEEE Trans Plasma Sci*. 1999. V. 27. P. 1188.

[9] Ooi T. Ch., Aries E., Ewan B.C.R., Thompson D., Anderson D.R., Fisher R., Fray T., Tognarelli D. The study of sunflower seed husks as a fuel in the iron ore sintering process *Minerals Engineering*. 2008. V. 21. P. 177.

[10] Kawaguchi T., Hara M. Utilization of biomass for iron ore sintering. *ISIJ International*. 2013. V. 53. № 9. P. 1606.

[11] Norgate T., Haque N., Somerville M., Jahanshahi S. Biomass as a Source of Renewable Carbon for Iron and Steelmaking. ISIJ International. 2012. Vol. 52. № 8. P. 1481.

[12] European Commission. EUR 25151 – Alternate carbon sources for sintering of iron ore (Acasos). Research Fund for Coal and Steel. Final report. *Luxembourg: Publications Office of the European Union*. 2013, 8 p.

contributed to the improvement of sintering temperature parameters, although the process performance and sinter quality were lower than when using non-coke fines. The main advantage of using biomass is the reduction of SO_2 emissions and improvement of the CO_2 balance.

Based on the literature analysis, it seems relevant to study practical approaches to the use of renewable raw materials as a fuel for iron ore sintering. In accordance with this, the goal was formulated and the main research objectives were defined.

The aim of the study is to experimentally investigate the impact of alternative fuels based on plant biomass on the iron ore sintering process and the quality of the resulting sinter. The main objectives of the study were:

– to investigate the impact of using different types of biofuels on the sintering process and sinter quality by conducting experimental studies using biomass alone as a fuel and in a mixture with coke fines;

– to analyse the differences in the sintering process using biomass compared to traditional fuels such as coke fines and anthracite.

The following materials were used for the study: iron ore, iron ore concentrate, coke fines, common limestone, lime, anthracite, walnut shells, sunflower seed husks and charcoal.

The chemical composition of the charge materials is shown in Table 1. Table 2 shows the technical analysis of the fuels used in the research.

Table 1

Chemical composition of charge materials

Materials	Content, %								
	$Fe_{tot.}$	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	LOI	Other oxides
Iron ore concentrate	65,88	28,27	62,71	6,44	0,30	0,17	0,26	1,85	-
Iron ore	57,75	1,76	80,54	12,71	1,60	1,72	0,62	1,82	0,47
Common limestone	0,28	-	0,40	1,5	0,56	48,5	0,92	43,56	-
Lime	12,66	-	18,09	1,8	26,61	86,8	1,40	-	-

Biomass is characterised by a high content of volatile substances, but low ash content and almost no sulphur. The highest content of non-volatile carbon is noteworthy for charcoal.

The composition of the sintering charge for each sample was calculated individually. The calculation was based on an agglomerate basicity of 1.40. The return flow rate was 25%. The content of iron ore concentrate in the charge was 68%, ore 15%, lime 2%, limestone 15%, and fuel consumption was calculated based on a 6% non-volatile carbon content.

Table 2

Technical analysis of charge materials

Materials	Humidity, W^a, %	Ash content, A^d, %	Volatile matter outcome, V^d,%	Total sulphur, S_t^d, %	Non-volatile carbon C^{fix},%
Coke fines	15,1	15,3	1,5	1,2	82,0
Anthracite	2,0	12,2	8,7	1,8	77,3
Charcoal	3,3	3,7	12,5	-	83,8
Walnut shells	7,2	0,3	75,6	0,2	23,9
Sunflower seed hulls	8,0	2,6	73,0	-	24,4

According to the charge calculation, the materials were weighed, mixed, moistened, mixed again and pelletized in a drum-type pelletiser. The water consumption for each sintering when using coke fines was 7%, while for other sinterings the water consumption varied depending on the moisture content of the raw materials.

The pelletized charge was loaded into a bowl with a grate on which a bed of sinter of 5–10 mm fraction was laid in advance.

A schematic diagram of the sintering unit is shown in Figure 1.

Sintering was carried out in the following sequence. The initial vacuum under the grate was set to 500 mm H_2O. It should be noted that not in all cases sintering could be started exactly at the specified vacuum. This is due to significant fluctuations in the gas permeability of the charge column when using different types of fuel. Next, the charge fuel was ignited for 60 seconds to start the sintering process, with an ignition temperature of 1250°C.

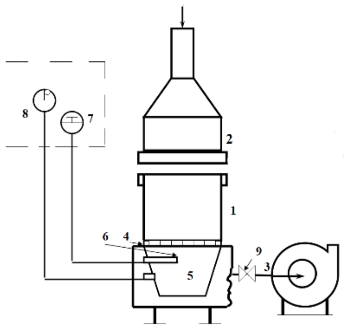

Fig. 1. Schematic diagram of the iron ore sintering plant:

1 – sintering bowl; 2 – ignition horn; 3 – exhauster; 4 – grate; 5 – vacuum chamber; 6 – thermocouple (type R); 7 – temperature indicator; 8 – vacuum gauge; 9 – valve for vacuum control in the vacuum chamber

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During the sintering process, the temperature of the exhaust gases and the discharge under the grate were monitored. These indicators were recorded every minute. Sintering was completed when the temperature of the exhaust gases reached a maximum and began to decrease.

After the sintering process was completed, the finished sinter was tested. The impact strength was determined as a percentage of the sinter fraction after a destructive load of more than 5 mm. The specific productivity of the sintering process was also calculated.

Based on the sintering results, the values of the main indicators of the sintering process, sinter quality and specific productivity of the sinter plant were calculated. The key technical and economic indicators of the sintering process using biomaterials are shown in Table 3.

Table 3

Key indicators of the agglomeration process

Biomaterial content	Type of fuel	Indicators			
		Sintering speed, mm/min	Output of usable agglomerate, %	Specific capacity, t/m2 h	Impact strength, %
-	Coke	30,5	70,4	1,76	92
100% Biofuel	Charcoal	22,9	35,8	0,58	43,5
100% Biofuel	Walnut shells	30,5	24,2	0,406	25
100% Biofuel	Sunflower husks	27,5	14,4	0,12	*
75% Coke + 25% Biofuel	Charcoal	30,5	61,9	1,42	88,5
75% Coke + 25% Biofuel	Walnut shells	34,375	46,7	1,087	55,5
75% Coke + 25% Biofuel	Sunflower husks	91,6	36,1	0,13	*
50% Coke + 50% Biofuel	Charcoal	32,3	63,9	1,552	87
50% Coke + 50% Biofuel	Walnut shells	39,2	62,9	1,791	94,5
50% Coke + 50% Biofuel	Sunflower husks	68,75	27,2	0,825	*
25% Coke + 75% Biofuel	Charcoal	42,3	55,1	1,52	71,5
25% Coke + 75% Biofuel	Walnut shells	30,5	23	0,426	*
25% Coke + 75% Biofuel	Sunflower husks	61,1	9,9	0,173	*

The addition of biomaterials to the sinter charge improves the gas permeability of the sinter layer. Biomaterial particles are located between the charge granules and increase the open porosity of the layer.

Considering the effect of different types of solid fuels on the outcome of a suitable agglomerate, significant fluctuations are observed from 10 to 75 %. The lowest values are achieved when using Sunflower husks and charcoal. This can be explained by a decrease in the bulk density of biomaterials, which results in a sponge-like structure that produces a large amount of fines when crushed. The results of measuring the bulk density of biomaterials in comparison with anthracite and coke are shown in Table 4.

Table 4

Bulk density of biomaterials and fuels

Type of biomass	**Bulk density, kg/m^3**
Sunflower husk	180-210
Walnut shell	350-400
Charcoal	200-250
Coke fines	300-350
Anthracite	600-700

The minimum values of bulk weight correspond to sunflower husk and charcoal 180–210 kg/m^3 and 200-250 kg/m^3. They also correspond to the minimum values of the outcome of usable agglomerate. In general, it should be noted that the addition of biomaterials in an amount exceeding 50 % significantly reduces the output of usable agglomerate.

The vertical sintering rate increases dramatically when using Sunflower husks. At the same time, the maximum temperature of the exhaust gases was 200–280 °C. This indicates a low temperature and thermal regime of the sintering process. This is due to the shorter burning time of biomaterial particles compared to coke and anthracite particles. The study [13] examined the change in the combustion time of anthracite and coke particles depending on their size. The authors point out that for the standard size of fuel particles during agglomeration, the combustion time of coke fines is 48–52 s, and that of anthracite is 72–76 s. However, for sunflower husk particles up to 3 mm in size, the combustion time is up to 40 s. This does not allow to ensure the required temperature level of agglomeration and the proper time for the charge to stay in the temperature zone sufficient for the sintering process.

As a result of the lower temperature level of the process, the amount of primary ore in the heat has increased, which leads to a decrease in the content of hematite formed during the secondary oxidation of magnetite.

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[13] Zhang X., Zhong Q., Liu C., Rao M., Peng Z., Li G., Jiang T. Partial substitution of anthracite for coke breeze in iron ore sintering. Scientifc Reports. 2021. 11:1540.

It should be noted that the low combustibility of anthracite resulted in incomplete fuel consumption during sintering: the amount of residual carbon in the heat was up to 10% of the initial content in the charge.

The specific productivity of the sinter plant depends on the outcome of suitable and vertical sintering rate. Thus, it can be seen that despite the increase in the vertical sintering speed, the addition of biomaterials reduces the vertical specific productivity by reducing the outcome of usable sinter. The maximum content of biomaterials can be called 25 % for charcoal and 50 % for walnut shells. When using sunflower husks, it was not possible to obtain an acceptable specific productivity of the sintering process with 25 % or more. Therefore, this biomaterial requires preliminary preparation to be used in the sintering of iron ore.

It can be seen that the use of more than 25 % charcoal and more than 50 % walnut shells in the fuel leads to a sharp deterioration in impact strength. This is due to an increase in the porosity of the sinter. It should be noted that in the course of the study, due to the very low yield, the amount of agglomerate used when using sunflower husks was insufficient for the strength test.

Thus, based on the results of an experimental study of the impact of alternative fuels based on plant biomass on the iron ore sintering process and the quality of the resulting sinter, it was found that charcoal can be used in an amount of up to 25 % while maintaining the sintering performance at an acceptable level, and walnut shells – up to 50 %. The use of sunflower seed husks is possible with preliminary preparation of the material, such as reducing the bulk weight, for example, by pressing.

To further improve the technological performance of agglomeration when using biomaterials as fuel, it is necessary to conduct research on the use of various pre-treatment methods. Another possible way to improve the agglomeration technology using biomaterials is to use separate pelletising methods.

2. Iron ore pellets production with partial replacement of natural gas with biomaterials

Currently, over 99% of industrial iron ore pellets are produced by high-temperature processing in roasting facilities. The most widely used industrial processes for roasting pellets are the conveyor machine and the grate-tube furnace-cooler unit. The global pellet production accounts for about 60% of the world's pellets produced by conveyor machines and 40% by the grate-tube furnace-cooler. Both schemes are used to produce high-quality pellets for blast furnaces and pellets for direct reduction [14].

[14] Kovalov D.A., Vaniukova N.D., Ivashchenko V.P. Yaholnyk M.V., Boiko M.M. Fizyko-khimichni protsesy vyrobnytstva okuskovanoi syrovyny. Ch. 1. Teoretychni osnovy ohrudkuvannia zalizorudnykh materialiv: Konspekt lektsii. Dnipropetrovsk NMetAU, 2007. 17 s.

Firing in a rotary kiln produces pellets with more uniform properties. The movement in the furnace causes the pellets to be mixed during heating, and their firing temperature becomes more uniform. The use of fuel in this case is more flexible compared to a conveyor machine. In addition to gaseous and liquid fuels, solid fuels such as coal and biomaterials can also be used. This is of particular interest in regions with cheap solid fuels.

Faced with climate change and societal impacts from emissions of harmful pollutants, the steel industry is increasingly shifting its focus towards more sustainable and environmentally conscious production methods [15]. In the search for ways to reduce CO_2 emissions, the use of biomass in metallurgy as a fuel and reducing agent in the pelletising of iron ore raw materials is considered promising[16].

The possibility of partial substitution of fossil fuels during pellet firing with pyrolysed oil, wood pellets, and charcoal pellets was investigated. It was found that for conveyor roasting machines, the replacement of fossil fuels with biofuels is problematic due to changes in the temperature profile of pellets heating during roasting. For the grate-tube furnace-cooler system, it is possible to partially replace fossil fuels with the above biomaterials without significantly changing the process parameters[17].

Various methods of biomass gasification as a substitute for natural gas in the production of pelletised feedstock were evaluated. All the gasification processes evaluated were determined to be economically feasible for full substitution of natural gas, with the exception of the biosynthetic natural gas production process[18].

The paper considers the possibilities of producing partially metallised iron ore pellets containing carbon using agricultural waste. It is established that the use of biomass as a reducing agent for the partial reduction of iron oxides is an attractive method of metallisation and also contributes to the reduction of CO_2 emissions[19].

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[15] Kieush L., Yaholnyk M., Boyko M., Koveria A., Ihnatenko V. Study of Biomass Utilization in the Iron Ore Sintering. *Acta Metallurgica Slovaca*, 2019. Vol. 25. P. 55.

[16] Lina Kieush, Maksym Boyko, Andrii Koveria, Maksym Yaholnyk, Natalia Poliakova Manganese Sinter Production with Wood Biomass Application. *Key Engineering Materials*, 2020. Vol. 844. P. 124.

[17] Henrik Wiinikka, Alexey Sepman, Yngve Ögren, Bo Lindblom, and Lars-Olof Nordin. Combustion Evaluation of Renewable Fuels for Iron-Ore Pellet Induration. Energy Fuels 2019, Vol. 33. P. 7829.

[18] Mariana M.O.C. , Marcelo C., Esa K.V. Biomass gasification for natural gas substitution in iron ore pelletizing plants. *Renewable Energy*, 2015, Vol. 81. P. 577.

[19] Zhulin L., Xuegong B., Zeping G., Wei L. Carbothermal Reduction of Iron Ore in Its Concentrate-Agricultural Waste Pellets. *Advances in Materials Science and Engineering*, Vol. 2018. Article ID 2138268. 5 p.

This paper analyses the efficiency of using sunflower husks as an alternative fuel for pellet firing in a grate-tube furnace-cooler system at the Poltava Mining and Processing Plant (Ferrexpo Poltava Mining), Ukraine.

The schematic diagram of the firing process at the grid-tubular furnace-annular cooler installation is shown in Figure 2. Pellets are dried on the grate, as well as pre-heating zones are located, where the maximum temperatures are 1000–1100 ° C. Pellets acquire mechanical strength during preheating to resist destruction in a rotating kiln where they are fired. Heating is carried out by a burner located in the discharge part of the rotary kiln.

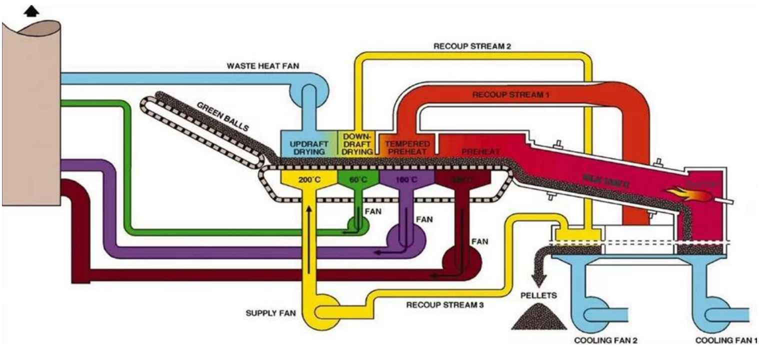

Fig. 2. Grid Installation Diagram – Tubular Kiln – Ring Cooler[20]

The pellets are fired at a temperature of 1240–1265°C. The furnace dimensions are 6705 mm in diameter and 45720 mm in length. After firing, the pellets are sent to a ring cooler, where they are cooled to temperatures of 100–120°C and then transported to the finished goods warehouse via a conveyor system.

The pellets are produced using magnetite concentrate from the concentrator (iron content 65–67%), dolomitised limestone and bentonite. The fuel is usually natural gas.

Sunflower husks are a safe and environmentally friendly fuel. When burned, it releases the same amount of CO_2 as the natural decomposition of the biomass used for its production.

The storage conditions are an undeniable advantage. Sunflower husks have a low flammability, which means that they can be stored in close proximity to heating units. Since it does not absorb moisture, its ability to release heat does not decrease over time, which does not require special storage conditions. In addition, this type of fuel takes up little space, is lightweight, and is easy to transport and store.

[20] Grate Kiln Pelletizing Plant. Metso

Sunflower husk is an agricultural waste, a waste product of processing agricultural products with different moisture content. We use raw materials with a moisture content of up to 12%. During the first stage of cleaning, stones, roots and other foreign objects are separated. Then the raw material is sent by gravity to the drying and grinding section. Crushing involves grinding the raw material into a 2–4 mm fraction using a self-priming hammer crusher at the bottom of the unit. The raw material is then dried by rising in a hot coolant stream to a dynamic classifier located in the upper part of the drying and grinding unit. The dynamic classifier, the frequency of which is set from the control panel, passes only fine and dry raw materials, while large and wet particles of raw materials are returned down to the rotor of the unit. Thus, this process is repeated until the required moisture content and degree of grinding of the raw material is obtained. The output fraction is controlled by a sieve and the size of the hammers.

Table 5 shows the requirements for biofuels and Table 6 shows the main characteristics of sunflower husks used for calcination of iron ore pellets in the grate-tubular kiln-ring cooler unit.

Table 5

The requirements for biofuels

№	Indicator	Features
1	Fraction size, mm	2–4
4	Mass fraction of moist and light substances, %.	No more than 12,0
5	Ash content, %.	No more than 4,0
6	Mass fraction of fat and extractive substances in absolutely dry matter, %.	No more than 4,5
7	Calorific value, MJ/kg	No more than16,89
8	Bulk density, kg/m^3	Up to 150
9	Mass fraction of total sulphur, %	No more than 0,23
10	Mass fraction of crude fibre in terms of absolutely dry matter, %	From 35,0 to 60,0

Table 6

Main features of sunflower husks

Features	Indicators for sunflower husks
C, %	45.82 ± 0.08
H, %	6.32 ± 0.02
N, %	2.61 ± 0.05
S, %	0.14 ± 0.02
O, %	38.31 ± 0.08
Ash, %	6.81 ± 0.51
Combustion heat, MJ/kg	19.31 ± 0.13

To determine the impact of the introduction of the technology of replacing natural gas with biofuels, two periods were compared – when the technological lines worked only on natural gas and the period when biofuels were used together with natural gas. Qualitative and quantitative data of plant operation are given in Tables 7 and 8.

In the experimental period, part of the natural gas was replaced with sunflower husk, the consumption of natural gas was reduced by 38–60%, and the amount of husk was added based on maintaining the required temperature of the pellets burning and the heat flow of combustion products. The productivity of the plant, the strength of the pellets and the iron content in them were determined.

It can be seen that the qualitative and quantitative indicators are approximately the same when using only natural gas and when partially replacing it with sunflower husks, so we can conclude that during the use of biofuels, quantitative and qualitative indicators remain normal. The specific gas consumption decreased by almost 50% and at the same time, this does not have any effect on the pellet production technology. At the same time, the replacement coefficient of natural gas by sunflower husks was about 1.8 kg/m^3.

The maximum degree of replacement of natural gas by sunflower husks reached 60%. The specified value of the degree of replacement was achieved for conditions of low consumption of natural gas and minimum firing temperatures. With an increase in the total consumption of natural gas, it was possible to replace up to 38% of the gas with sunflower husk. This is due to the fact that with a high consumption of natural gas, a large heat flow is formed, and since the combustion rate of sunflower husks is limited, then with a large amount of husk supplied to the burner, it does not have time to burn completely in the flare zone and the heat flow and thermal profile of the pellets burning changes.

Quality indicators of the rounded materials play a decisive role in the blast furnace process and significantly affect the technical and economic performance of blast furnace smelting.

Table 7

Process parameters of pellet production using natural gas

Day	Natural gas specific consumption, m^3/t	Capacity, t/day	Iron content in pellets,%	Strength of pellets, kg/pellet
1	2	3	4	5
1	11,8	7106,2	63,34	231
2	11,89	7555,7	63,44	231
3	12	7662,3	63,98	232
4	12	7926,3	63,98	236
5	12,09	7963,8	64,77	237
6	12,13	8055,5	64,82	237
7	12,14	8246,5	64,88	237
8	12,16	8721,3	65,01	237
9	12,21	8757,6	65,06	237
10	12,24	8803,1	65,07	241

Continuation of table 7

1	2	3	4	5
11	12,24	8805,7	65,13	248
12	12,33	8826,9	65,17	249
13	12,38	8838,7	65,17	250
14	12,52	8933,6	65,17	255
15	12,96	8954,8	65,19	255
16	13,47	9033	65,2	258
17	14,07	9072,4	65,24	258
18	14,08	9115,3	65,25	258
19	14,44	9229,3	65,33	258
20	14,49	9304,2	65,37	261
21	14,61	9381,6	65,39	263
22	14,62	9420,9	65,4	264
23	14,81	9515,8	65,42	264
24	14,82	9532,7	65,46	264
25	14,89	9606,1	65,51	265
26	15,88	9620,3	65,58	265
27	16,85	9631,6	65,6	273
28	17,01	9678,3	65,66	284
29	18,31	9772,5	65,68	284
30	18,48	9790,9	65,68	285

Table 8

Technological indicators of pellet production using sunflower husk and natural gas

Day	**Natural gas specific consumption, m^3/t**	**Capacity, t/day**	**Iron content in pellets,%**	**Strength of pellets, kg/pellet**
1	2	3	4	5
1	4,64	7262	63,19	225
2	4,85	7560,3	63,29	225
3	4,99	7980,8	63,34	226
4	5,01	8348,2	63,84	232
5	5,03	8353,3	63,98	237
6	5,45	8504,1	64,65	237
7	5,59	8640,1	64,66	237
8	5,6	8689,7	64,73	241
9	5,61	8703,1	64,77	252
10	5,67	8803,1	64,77	254
11	5,71	8823,6	64,81	254
12	5,78	8838,7	64,82	255
13	5,83	8889,9	64,88	258
14	5,91	8908,4	64,96	258
15	6,02	8933,3	65	261
16	6,04	8943,7	65,01	263
17	6,25	8960,8	65,1	263
18	6,34	8971,9	65,13	264
19	6,44	8972,8	65,17	264
20	6,55	9005,8	65,19	264

Continuation of table 8

1	2	3	4	5
21	6,58	9017,8	65,33	264
22	6,86	9041,8	65,33	265
23	7,17	9059,9	65,39	265
24	7,23	9115,8	65,4	266
25	7,36	9187,1	65,42	267
26	7,74	9187,1	65,58	269
27	7,89	9210,9	65,6	273
28	8,81	9213,6	65,66	277
29	9,47	9271,6	65,68	282
30	11,01	9284,3	65,68	284

An important indicator is the content of alkali metals in iron ore materials. Exceeding the permissible content of alkali metals in materials that are loaded into the furnace domain per ton of cast iron causes a deterioration in the technological process and reduces the productivity of blast furnaces[21]. Increasing the content of alkaline elements by 0.1% for different operating conditions of the blast furnace increases the specific coke consumption by 15–60 kg/t of cast iron. It is definitely impossible to determine the permissible content of alkali in iron ore materials, since this value depends on the melting conditions and the content of alkali metals in other charge materials and fuels, primarily coke[22].

According to the practical experience of blast furnaces, the acceptable limit of the amount of alkali metals, which is expressed as the sum of Na_2O + K_2O, depending on the blast furnace and its operating conditions, is in a wide range from 2.5 to 8.5 kg/t of cast iron[23]. An important role in this case is played by the quality of the ore raw materials used, which affects the amount of alkaline elements entering the primary metallurgical processes. The K_2O content in the charge for pellets can reach a value from 0.08% to 1.5%, and the Na_2O content ranges from 0.1% to 1.2%[24].

The K_2O content of sunflower seed ash can reach 25% [25], but it is worth noting that there are no changes in the amount of alkaline earth metals in pellets obtained from sunflower husks. This indicates that during the firing

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process, compounds containing alkaline earth metals are transferred to the gas phase. However, when the gas comes into contact with the lining of a rotary kiln, such compounds can be deposited on refractories along with other elements of sunflower husk ash.

Severe fuel ash deposits on the lining of a tube furnace for the production of iron ore pellets can reduce pellet quality and production efficiency. The initial stage of ash deposit formation is crucial for the adhesion and growth of ash deposits on the refractories in the furnace. The study[26] modelled and experimentally investigated the peculiarities of slag deposit formation when pulverised coal is used for pellet firing. The results showed that adhesion on refractory bricks increases with a decrease in the combustion efficiency of pulverised coal and this leads to an increase in the Na_2O content in the deposits, which leads to premature destruction of refractories.

However, crushed sunflower husks have a higher reactivity than coal and their combustion efficiency in pellet firing is much higher. In addition, the ash content in sunflower husks is up to 4%, which is significantly lower than in coal, where its content can reach more than 12%. This minimises ash deposits on the lining of the rotary kiln and extends its service life. No significant ash deposits on the furnace lining were observed in the operation of the grate-tube furnace-ring cooler system using sunflower husk.

The results obtained suggest the effective use of biomaterials in the production of pelletised raw materials. Expanding the types of biomaterials that can be used in pellet agglomeration and firing requires studying the behaviour of other types of biofuels, including after preliminary preparation (pelletising, pressing, pyrolysis), in terms of the possibility of replacing fuels in the pelletising of iron ore raw materials.

CONCLUSIONS

Research has been carried out to study the impact of different types of biomaterials on the iron ore sintering process and the quality of the resulting sinter. The studies revealed that it is possible to replace up to 25% of coke fines with charcoal and up to 50% with walnut shells. At the same time, the process performance and strength of the sinter remain at an acceptable level.

The use of sunflower seed husks due to their low bulk weight in agglomeration technology is possible only if they are prepared beforehand.

The main feature of biomaterials as a fuel for sintering is bulk density, which determines the thermal parameters of the process and the structure of the sinter.

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[26] Shuai W., Yufeng G., Jianjun F., Yu H., Tao J., Feng C., Fuqiang Z., Lingzhi Y. Initial stage of deposit formation process in a coal fired grate-rotary kiln for iron ore pellet production. *Fuel Processing Technology.* 2018. V. 175. P. 63.

The use of biomass will reduce the negative environmental impact of sinter plants.

The article analyses the use of sunflower husks as an alternative fuel by adding crushed husks to the already installed pellet firing system for the grate-tubular kiln-ring cooler installation for the conditions of the Ferrexpo Poltava Mining. It was found that when replacing up to 50 % of natural gas with sunflower husk, the quantitative and qualitative indicators of pellet production remained at the baseline level.

The influence of sunflower husk ash and the content of alkali metals in it on the quality of pellets and the operation of the rotary kiln was analysed. It was found that the content of alkali metals in pellets does not increase. No significant amount of ash deposition on the refractories of the rotary kiln was observed.

It is prospective to investigate the use of other types of bio-raw materials in pellet firing.

SUMMARY

The steady rise in the cost of traditional energy resources and their negative impact on the environment is leading to an increase in the share of renewable energy sources worldwide. The use of biomass for energy generation based on modern technologies is environmentally safer compared to the energy use of traditional organic resources such as coal. A significant reserve for increasing the use of energy from biomass is concentrated in the metallurgical industry, including the production of pelletised iron ore. Research has been carried out to study the impact of different types of biomaterials on the sintering process of iron ore and the quality of the resulting sinter. The study found that, provided that the process performance and sinter quality are maintained at the appropriate level, it is possible to replace up to 25% of coke fines with charcoal and up to 50% with walnut shells. An analysis of the use of sunflower husks as an alternative fuel was carried out by adding them to the already installed pellet firing system for the grate-tubular kiln-ring cooler installation. It was found that when replacing up to 50 % of natural gas with sunflower husks, the quantitative and qualitative indicators of pellet production remained at the baseline level.

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