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RESEARCH PAPER

PRODUCTION OF IRON ORE PELLETS BY UTILIZATION OF SUNFLOWER HUSKS

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ABSTRACT

Steel production is the most dynamic industry and one of the key sectors for developing the global economy. The growing iron ore production increases its beneficiation and granulating for subsequent iron and steel production use. As a result, CO_2 emissions and harmful substances increase, negatively affecting society and the environment. In this regard, it is important to study the use of biomass for the production of iron ore pellets. Lignocellulosic biomass is a renewable and sustainable source of heat and energy that can mitigate climate change. The influences of alternative fuel use on technological indicators of the process and quality of iron ore pellets have been analyzed. The efficiency of using 40.4-60.7 vol.% of sunflower husks on the combined machine "straight grate - rotary kiln - annular cooler" to partially replace natural gas in iron ore pellets production under industrial conditions has been studied. It was found that the combustion of sunflower husks generates enough heat (19.31 MJ kg^{-1}) to obtain iron ore pellets with good strength. After evaluating the parameters of the combined machine and the quality of the resulting pellets, it was determined that it would be rational to replace up to 48.3 vol.% of natural gas with crushed sunflower husks.

Keywords: iron ore pellets, biomass, sunflower husks, natural gas, biogas, strength

INTRODUCTION

Global crude steel production was 486.9 Mt in the first three months of 2021, up by 10.0% compared to the same period in 2020. In the EU, the same growth trend is observed in crude steel production in the first quarter of 2021 [1]. The need for steel production is extremely urgent, and hence the extraction of iron ore. The primary iron ore materials for blast furnace are sinter and pellets—approximately 98% of all iron ore granulated [2]. At the same time, about 25% of the extracted iron ore is processed into pellets [3]. Iron ore pellet production consists of granulation processes, when iron ore is first crushed into powder, mixed with an additive and a binder, then pelletized into green pellets with the sizes 9-15 mm in diameter. The green pellets are then fed to the induration machine. Pellets are heated to 800-900 °C in the preheating zone, including two drying zones with temperatures up to 400 °C and a preheating zone with 800-900 °C. Then the induration process is finished at roughly 1200-1350 °C [4, 5].
It can be concluded that the pellets are more beneficial to the iron ore sinter in many physical and chemical parameters: uniform size, high metallization rate, increased gas permeability in blast furnaces [6], comparing the complex characteristics of the metallurgical properties of the iron ore sinter and iron ore pellets, regarding the modern requirements. Additionally, iron ore pellets application is preferable to iron ore sinter considering that 19.6% of the CO_2 emissions come from the sintering machine, according to Ariyama and Sato [7].
Generally, industrial iron ore pellets are obtained by high-temperature processing in the induration machine. The most widely used industrial pellets induration processes are straight grate and grate kiln. At the same time, the production of iron ore pellets in the world is about 60% for straight grate and 40% for grate-kiln. Both schemes are used to produce high-quality pellets for blast furnaces and direct reduced iron processes.
When applying the rotary kiln, iron ore pellets with more uniform properties are obtained. The movement in the kiln mixes the pellets during induration, and their induration temperature becomes uniform. The use of fuel, in this case, is more flexible compared to a straight grate. In addition to gaseous and liquid fuels, solid fuels such as coal and biomass can also be used. This is of interest to countries with the availability of cheap solid fuels.
Metallurgy is increasingly shifting its focus to more sustainable and environmentally conscious production practices, faced with a changing climate and the societal impact of harmful pollutants. The prospects of using biomass in metallurgy as a fuel and reducing agents for iron ore sintering and reduction of iron [14, 15] have been considered promising [8-13]. Biogas application instead of natural gas also has environmental and economic benefits [16, 17].
Additionally, considering the climate targets, the use of hydrogen for ironmaking also has gained increased attention. In this regard, the HYBRIT project (Hydrogen Breakthrough Ironmaking Technology) is encouraging and aims to replace the coke traditionally used in iron ore-based steelmaking with hydrogen [18].
In [19], authors considered the possibility of partial replacement of fossil fuels (fuel oil, coal) during the induration of pellets with pyrolysis oil, wood pellets, and charcoal pellets. It has been found that replacing fossil fuels with biofuel for the straight grate is problematic due to a change in the temperature

of heating the pellets during induration. For grate-kiln, it is possible to partially replace fossil fuels with these biofuels without significantly changing the process parameters.
Carvalho et al. [20] analyzed different methods of gasification of biomass as a substitute for natural gas in iron ore pellets production. All evaluated processes were economically feasible for the complete replacement of natural gas, except for biosynthetic natural gas production.
Additionally, the possibility of producing carbon-containing pellets using agricultural waste [21] and palm kernel shells [22] was considered. It has been established that the use of biomass as a reducing agent for iron ore reduction is a suitable method for the upgrading of iron ore, as well as reducing CO_2 emissions.
In our paper, we suggest using sunflower husks as an alternative fuel for the induration of iron ore pellets via combined machine "straight grate - rotary kiln - annular cooler" under Ferrexpo Poltava Mining (Ukraine) conditions.

MATERIAL AND METHODS

Method of producing iron ore pellets

Ferrexpo Poltava Mining has a complete technological cycle from extracting raw ore to producing iron ore pellets. Ore processing produces concentrate and pellets at a processing complex, including a crushing and beneficiating plant, and iron ore pellets production using a grate-kiln machine. For the induration of the pellets, a combined unit was used. It included a lightweight transporter machine for drying and heating the pellets and a tubular rotary kiln for high-temperature induration. Low-temperature drying and heating processes took place on a transporter machine; high-temperature was in a refractory-lined furnace. The gases evacuating the tube furnace were sucked through the pellet bed on the grate, first in the heating and drying zones. Preheating zones were located where the maximum temperature was 1000-1100 °C. Pellets were acquired mechanical strength during preheating to resist destruction in a rotary kiln where induration was performed. Heating was carried out by a burner located in the discharge port of a rotary kiln. The pellet induration temperature was 1240-1265 °C. The diameter of the kiln is 6705 mm, and 45720 mm of the length. After the kiln pellets entered the annular cooler, they were cooled to a suitable temperature of 100-120 ºC for transport to a load-out facility by blown air. The heat of the cooling pellets was transferred to the air, which was then directed to the burners in the kiln, which further reduced fuel consumption.
The main scheme of the grate-kiln induration process [23] is presented in **Fig. 1**.

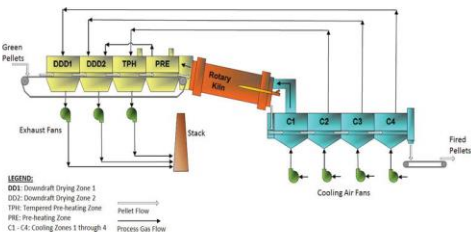

Fig. 1 Main scheme of the grate-kiln induration process [23]

To produce iron ore pellets following materials were used: magnetite concentrate, dolomitized limestone, and bentonite (**Table 1**).
The determination of the crushing strength of pellets was carried out according to ISO 4700:2015 [24].

Table 1 Characteristics of raw materials

Materials	Chemical composition, %				Content, %	
	Fe	SiO_2	CaO	MgO	Moisture	Fraction of –0.05 mm
Magnetite concentrate	65.4	7.2	0.3	0.49	10.5	95.1
Limestone	0.12	0.9	45.92	8.44	0.5	95.0
Bentonite	4.2	60.35	3.0	1.7	4.0	90.0

Biomass preparation

Sunflower husks are a renewable source, which is obtained after processing the sunflower seeds. Additionally, sunflower husks are an environmentally friendly type of fuel. Its combustion emits the same amount of CO_2 as the natural decomposition of biomass used for its production. Sunflower husks' good advantages are storage conditions and low flammability so that this material can be stored near heating units. Additionally, sunflower husks have a weak ability to absorb moisture, so it does not require special storage conditions.
Fig. 2 shows a scheme of implementation of biomass for iron ore pellets production.

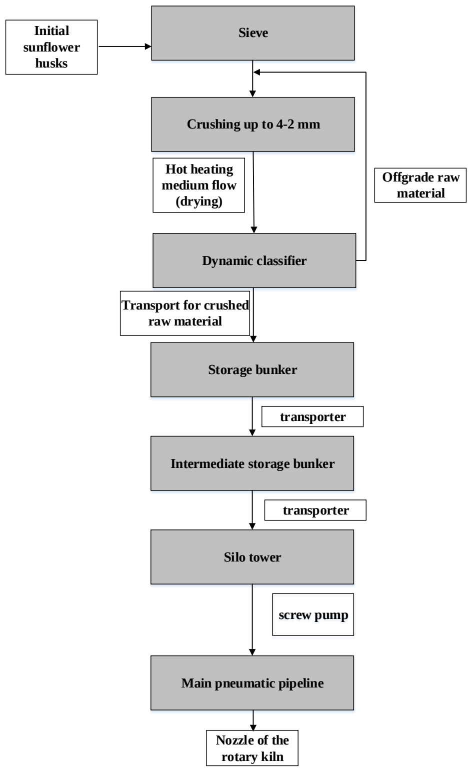

Fig. 2 Scheme of biomass implementation for iron ore pellets production

Sunflower husks with initial moisture, roughly 12% were used. In the process of the first stage of cleaning, roots and other foreign objects were separated. They were crushing consists of grinding sunflower husks in 2-4 mm employing the self-soaking crusher of hammer type. Then the sunflower husks by gravity entered the loading section of the drying-grinding. In its lower part, the sunflower husks were crushed and then dried, rising in the flow of hot heat carrier to a dynamic classifier located in the upper part of the drying-grinding unit. The dynamic classifier, the frequency set from the control panel, passes only small and dry raw materials. Large and wet particles of raw materials were returned down to the unit's rotor. Thus, this process was repeated until the required moisture and the grinding degree of raw materials would be achieved. The fraction was controlled by the sieve and the size of the hammers. The crushed raw material was delivered to the unloading unit by transport. It was gradually unloaded into a storage bunker, from which it entered the intermediate storage bunker through a vibrating screen. Afterward, the raw material was fed to the transporter, from which the metal silo was loaded. In the silo, there was an accumulation of raw materials in the volume of 664.0 m^3. From the bottom of the silo using the feed auger, raw materials got to the screw pump, mixed with air from the compressor. They arrived in the main pneumatic pipeline, brought to a nozzle installed in the rotary kiln.

Table 2 shows the requirements for sunflower husks, and Table 3 shows the main characteristics of sunflower husks used for iron ore pellets production.

Table 2 Requirements for sunflower husks

No	Indicator	Characteristics
1	Fraction size [mm]	2-4
2	Moisture [wt.%]	≤12.0
3	Ash [wt.%]	≤ 4.0
4	Fat and extractives in dry matter [wt.%]	≤4.5
5	High Heat value (HHV), [MJ kg^{-1}]	≥16.89
6	Bulk density [kg/m^3]	<150
7	Total sulfur [wt.%]	≤0.23
8	Crude fiber in terms of dry matter [wt.%]	35.0-60.0

Table 3 Main characteristics of sunflower husks [25]

Main characteristics	Sunflower husks
C [%]	45.82 ± 0.08
H [%]	6.32 ± 0.02
N [%]	2.61 ± 0.05
S [%]	0.14 ± 0.02
$O^{a)}$ [%]	38.31 ± 0.08
A^d [%]	6.81 ± 0.51
$HHV^{b)}$ [MJ kg^{-1}]	19.31 ± 0.13

a) Calculated by difference, O [%] = 100 – C – H – N – S – Ash

b) Calculated by HHV [MJ kg^{-1}] = 0.3491·C+1.1783·H+0.1005·S – 0.0151·N – 0.1034·O − 0.0211·Ash

RESULTS AND DISCUSSION

Two ways were compared to determine the impact of natural gas substitution technology implementation with sunflower husks, namely when the production lines operated only on natural gas and when sunflower husks were used together with natural gas. Qualitative and quantitative data are summarized in Table 4.

In the study, part of the natural gas was replaced by sunflower husks. Natural gas consumption was reduced by 40.4-60.7 vol.%, and several sunflower husks were added to maintain the required temperature of iron ore pellet induration and heat flow of combustion products. That is, 1.3 kg of crushed sunflower husk was used per 1 m^3 of natural gas.

Figures 3-6 show the dependence of the selected indicators of induration iron ore pellets on the type of fuel used.

Table 4 Qualitative and quantitative indicators of the iron ore pellet production depending on the type of fuel

	Natural gas				Natural gas and sunflower husks				
Days	**Specific gas flow (average), m^3/t**	**Total production, t**	**Iron content (average), %**	**Strength (average), kg/pellet**	**Substitution rate of natural gas by sunflower husks, %**	**Specific gas flow (average), m^3/t**	**Total production, t**	**Iron content (average), %**	**Strength (average), kg/pellet**
1	11.8	7106.2	63.34	231	60.7	4.64	7262.0	63.19	225
2	11.89	7555.7	63.44	231	59.2	4.85	7560.3	63.29	225
3	12.0	7662.3	63.98	232	58.4	4.99	7980.8	63.34	226
4	12.0	7926.3	63.98	236	58.2	5.01	8348.2	63.84	232
5	12.09	7963.8	64.77	237	58.4	5.03	8353.3	63.98	237
6	12.13	8055.5	64.82	237	55.1	5.45	8504.1	64.65	237
7	12.14	8246.5	64.88	237	53.9	5.59	8640.1	64.66	237
8	12.16	8721.3	65.01	237	54.0	5.60	8689.7	64.73	241
9	12.21	8757.6	65.06	237	54.1	5.61	8703.1	64.77	252
10	12.24	8803.1	65.07	241	53.7	5.67	8803.1	64.77	254
11	12.24	8805.7	65.13	248	53.4	5.71	8823.6	64.81	254
12	12.33	8826.9	65.17	249	53.1	5.78	8838.7	64.82	255
13	12.38	8838.7	65.17	250	52.9	5.83	8889.9	64.88	258
14	12.52	8933.6	65.17	255	52.8	5.91	8908.4	64.96	258
15	12.96	8954.8	65.19	255	53.6	6.02	8933.3	65.00	261
16	13.47	9033.0	65.20	258	55.2	6.04	8943.7	65.01	263
17	14.07	9072.4	65.24	258	55.6	6.25	8960.8	65.10	263
18	14.08	9115.3	65.25	258	55.0	6.34	8971.9	65.13	264
19	14.44	9229.3	65.33	258	55.4	6.44	8972.8	65.17	264
20	14.49	9304.2	65.37	261	54.8	6.55	9005.8	65.19	264
21	14.61	9381.6	65.39	263	55.0	6.58	9017.8	65.33	264
22	14.62	9420.9	65.40	264	53.1	6.86	9041.8	65.33	265
23	14.81	9515.8	65.42	264	51.6	7.17	9059.9	65.39	265
24	14.82	9532.7	65.46	264	51.2	7.23	9115.8	65.40	266
25	14.89	9606.1	65.51	265	50.6	7.36	9187.1	65.42	267
26	15.88	9620.3	65.58	265	51.3	7.74	9187.1	65.58	269
27	16.85	9631.6	65.60	273	53.1	7.89	9210.9	65.60	273
28	17.01	9678.3	65.66	284	48.2	8.81	9213.6	65.66	277
29	18.31	9772.5	65.68	284	48.3	9.47	9271.6	65.68	282
30	18.48	9790.9	65.68	285	40.4	11.01	9284.3	65.68	284

As can be seen from **Figures 3-6**, the qualitative and quantitative indicators are approximately the same when using only natural gas and partially replacing it with sunflower husks (from 40.4 to 60.7 vol.%). The specific gas flow has decreased by almost 50%, and at the same time, the technology of production of iron ore pellets is not affected. The maximum replacement of natural gas by sunflower husks was reached up to 60.7 vol.% (or the substitution coefficient was reached up to 0.62 if the HHV value of natural gas is 31.0 MJ kg^{-1}). This was achieved for low natural gas consumption and minimum induration temperatures; with an increase in the total natural gas consumption, it was possible to replace a minimum of 40.4 vol.% of natural gas. This is because, with high consumption of natural gas, a large heat flow is formed. Since the rate of sunflower husks' combustion of the burner is limited, with a large amount of it supplied to the burner, it does not have time to burn completely in the torch zone, and the heat flow changes iron ore pellet induration.

Quality indicators of pelletized materials play a significant role in assessing their impact on blast furnace's technical and economic indicators. An important indicator is the content of alkali metals in iron ore materials. Exceeding the permissible alkali content in the loading of a blast furnace per ton of iron causes process failures and reduces the productivity of blast furnaces [26]. An increase in the content of alkaline elements by 0.1% for various conditions increases coke consumption by 15-60 kg/t of iron. It is impossible to determine the permissible alkali content in iron ore materials since it depends on coke's melting conditions and alkali content [27]. The required level of alkali, 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 iron [28]. An important role here is the quality of the charged ore raw materials, which affects the number of alkaline elements entering the primary metallurgical processes. The K_2O content in the mixture to produce iron ore pellets reaches a value of from 0.08% to 1.5%, and the Na_2O content ranges from 0.1% to 1.2% [29].

In the sunflower husk ash, the K_2O content can reach 25% [30], but it should be noted that there are no changes in the number of alkaline earth metals in the obtained pellets. This indicates that in induration, the compounds containing alkaline-earth elements go into the gas phase and can be deposited with other ash elements on the rotary kiln's refractories. Significant deposits of fuel ash on the lining of a rotary kiln to produce iron ore pellets can reduce the quality of the pellets and production efficiency. The initial stage of deposit formation is crucial for adhesion and their growth on refractories in the kiln. In the study [31], authors simulated and experimentally studied the formation of deposits when using pulverized coal fuel for iron ore pellets production.

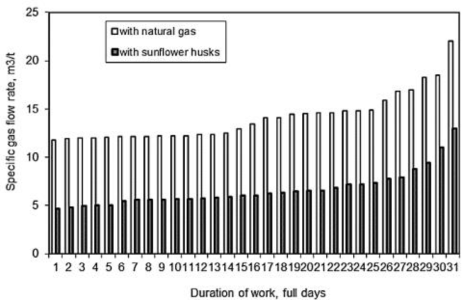

Fig. 3 Change in specific gas flow rate per day

The results showed that the adhesion on refractory bricks increases with a decrease in the efficiency of the combustion of pulverized coal, leading to an increase in the content of Na_2O in the deposits, which leads to its premature destruction. However, the crushed sunflower husks have higher reactivity than coal, and their combustion efficiency under pellets induration is much higher. Additionally, the ash content in the sunflower husks is up to 4%, which is significantly lower than in coals, where its content can reach more than 12%. This minimizes ash deposits on the lining of the rotary kiln and extends its life.

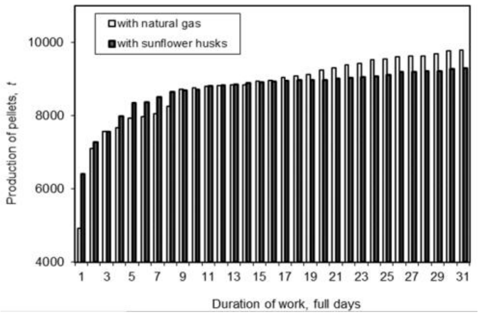

Fig. 4 Change in the daily production of iron ore pellets per day

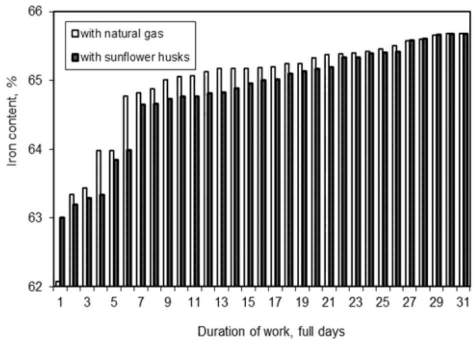

Fig. 5 Change in iron content within iron ore pellets per day

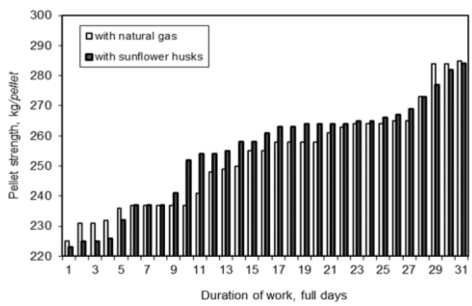

Fig. 6 Change the strength of the iron ore pellets per day

The study results provide a good ground for studying other types of biomass, including biomass subjected pyrolysis as possible substitutes for natural gas to produce iron ore pellets.

CONCLUSION

In this paper, we studied the use of biomass in the induration of iron ore pellets is promising in order to reduce natural gas consumption. The investigation of the sunflower husks application as an alternative fuel by adding crushed husks to the iron ore pellet production via combined machine "straight grate - rotary kiln - annular cooler" under Ferrexpo Poltava Mining (Ukraine) conditions has been carried out. Natural gas was replaced in the amount from 40.4 to 60.7 vol.%. After analyzing the operating parameters of the combined machine and the quality of the resulting pellets, it was determined that it is rational to replace up to 48.3 vol.% of natural gas with crushed sunflower husk. The scheme of implementing sunflower husks as a partial replacement of natural gas in iron ore pellets production has been presented. This scheme has been used industrially and can be applied to other types of lignocellulosic biomass.

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