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Environmental Assessment Concerning the Use of Char from Biomass in the Iron Ore Sintering Process

Abstract: The article presents results of tests concerning the use of waste biomass-derived char as a partial substitute for solid fuel used in the iron ore sintering process (primarily coke breeze). The tests were performed in a system used for the physical simulation of the sintering process, making it possible for flue gases to be recycled back to the process. During the tests, particular attention was paid to the analysis of properties of flue gases with the simultaneous recirculation of these gases back to the process. The optimal fraction of char from biomass (i.e. not worsening either sintering process or sinter parameters) in the total fuel was determined on the basis of previous experience. It was found that the use of carbonised biomass improved the reducing properties of the sinter and had a positive effect on its strength. At the same time it was observed that the amounts of CO_2 and NO_x as well as of CO and CH_4 emitted when using char were higher than those accompanying the use of coke breeze (only) as fuel. In order to reduce the impact of the char addition on flue gas parameters, sintering process-related tests also included the recycling of flue gas back to the sintering process. Flue gas properties were identified (both before dedusting and in the stack) using stationary flue gas analysers. The tests also included measurements of volatile organic compounds. The measurement results were used to determine the influence of the use of waste biomass-derived char on flue gas properties and primary parameters of the sintering process. The overall test results revealed failure to obtain expected reduction in the emission of undesirable compounds in off-gases (in relation to the use of the constant 15 % fraction of waste biomass-derived char and the gradual 45 % increase in the amount of off-gases recycled back to the process).

Key words: sintering process, char, emissions to the environment, exhaust fumes recycling

1. Introduction

Presently, both in Poland and abroad, the application of alternative fuels in various industrial (not only metallurgical) processes involves primarily the use of biomass as coal substitute. Previously, the alternative fuel applied during the sintering of iron ores was anthracite, the use of which in the process was primarily dictated by its price. The fraction of that fuel in the process usually did not exceed a 30% fraction of solid fuel [1, 2].

The above-presented approach inspired an attempt to use biomass in the process of iron ore sintering. In order to constitute a partial replacement of coke breeze, biomass should be characterised by appropriate properties such as high calorific value and high carbon content with a preferably low amount of volatiles. Research concerning the replacement of coke breeze during the sintering of iron ores was performed by the Indian Institutes of Technology and the National Metallurgy Laboratory in India. The sintering process involving biomass was performed using a variable fraction of biomass in the fuel mixture. The tests revealed that it was possible to replace coke breeze with 10 wt. % of sawdust, 30 wt. % of charcoal and a 30 % mixture of sawdust with charcoal. It was impossible to entirely replace coke breeze and perform the sintering process using 100 wt. % of biomass. The properties of the sinter obtained in the tests were consistent with sinter-related quality parameters [3].

The Nippon Steel Corporation has used raw biomass and char after biomass pyrolysis as a test material. According to test results, the sinter obtained in the tests represented appropriate quality, similar to that obtained when sintering was performed using coke breeze. It was found that, because of emission into the environment, raw biomass could not be utilised directly as fuel in the sintering process as the use of such biomass would necessitate the assembly of additional flue gas purification systems [3, 4].

Unfavourable biomass properties, such as low grindability, low energy density, high humidity, irregular shape and size as well as inhomogeneity impede the use of biomass in its natural form as fuel. Because of the aforesaid reasons precluding the use of raw biomass, the Authors decided to use biomass subjected to pyrolysis.

Carbonisation is a process enabling the production of material characterised by an increased carbon content (higher than that in an organic raw material), leading to the obtainment of nearly pure carbon residue (up to approximately 80 %) and performed at a temperature of up to approximately 1570 K. The above-named feature of char (a carbon content exceeding 80%) was used in the iron ore sintering process.

Waste subjected to the process of carbonisation include carbon fibre composites, glass fibre composites, olive farm waste, farm production plastic waste, plastic waste recovered from waste dumps, citrus fruit processing waste, worn-out tyres, production paper waste, sunflower oil production waste, biogas production waste and logging chips. The foregoing also applies to specific post-production waste of relatively homogenous qualitative composition, e.g. selected fractions of municipal solid waste referred to as refuse derived fuel (RDF), composed, among other things, of plastics, paper, rubber as well as wood and leather waste [3].

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A reverse situation accompanies the use of waste biomass-derived char, increasing process efficiency and simultaneously reducing the emission of NO_x, SO_x and fumes. Because the char combustion rate might be excessively fast, it is necessary to verify its grain composition and humidity [5].

The possible use of biomass in metallurgical furnaces was analysed at Łukasiewicz Research Network – Institute for Ferrous Metallurgy (Instytut Metalurgii Żelaza) in Gliwice (presently the Łukasiewicz Research Network – Upper-Silesian Institute of Technology). Related tests aimed to determine whether the partial replacement of coke breeze with raw biomass (in the iron ore sintering process) could be advantageous from technological, economic and environmentally-friendly point of view.

Tests performed at Łukasiewicz – GIT involved several types of chars as equivalents to coke breeze in the sintering process and were followed by the assessment of char effect on sintering process parameters, sinter properties and emission of pollutants into the environment. The test materials involved chars obtained from wood pellets, conifers, sunflower husks and charcoal.

The tests revealed that the use of carbonised biomass reduced the content of FeO in the sinter, which (from the blast-furnace process point of view) is a very favourable phenomenon as the lower content of FeO in the sinter translates into improved reductivity. The sinter obtained in the aforesaid manner was characterised by higher strength than that obtained only using coke breeze [5, 6]. As can be seen, the use of char could significantly improve both the strength of sinter and its reducing properties.

It was also observed that the amounts of generated CO, CO_2 and NO_x accompanying the use of char only slightly exceeded those generated when using coke breeze. The higher content of CH_4 in relation to that in the basic fuel could result from the increased amount of volatiles contained in the chars [5, 6]. The tests also revealed that, depending on their properties, the contents of various chars used as alternative fuels in the iron ore sintering process should not exceed 10 wt. % to 20 wt. % in the total fuel [5].

In order to eliminate the negative environmental impact of biomass-derived chars, sintering tests concerning the use of char involved the recirculation of flue gases back to the sintering process.

2. Physicochemical properties of test materials

The iron ore sintering tests involved the use of waste biomass-derived char. One of the primary criteria taken into account when selecting fuel for the sintering process was the content of carbon, sulphur, volatiles and ash. Table 1 presents the comparison concerning contents of the aforesaid components in the char and coke breeze. Because the pyrolysis of waste biomass did not include the recycle of char obtained in the process, the material was characterised by a relatively high content of volatiles.

The tests concerning the physicochemical properties of the waste biomass-derived char included the following:

- grain composition,
- bulk density in the dry state,
- chemical and thermal analysis.

Table 1 presents grain-size analysis of the waste biomass-derived char compared with the typical coke breeze used in ore sintering plants.

Figures 1 and 2 present the form of biomass-derived char and coke breeze.

The waste biomass derived char was characterised by more favourable graining than that of the coke breeze. The mean size of the grain amounted to 2.3 mm, whereas the mesh number below 1 mm constituted 23.8 wt. %. The

Table 1. Grain-size analysis concerning coke breeze and waste biomass-derived char

Grain class [mm]	Grain-size analysis , [wt. %]	
	Coke breeze	Waste biomass-derived char
below 0.10	9.18	0.90
0.10–0.16	7.30	0.61
0.16–0.20	6.08	0.65
0.20–0.315	10.92	1.25
0.315–0.40	8.53	1.68
0.40–0.50	4.73	1.59
0.50–0.63	4.22	1.24
0.63–0.80	5.12	3.25
0.80–1.00	3.12	1.14
1.00–2.00	14.57	12.37
2.00–3.15	11.28	7.90
3.15–4.00	5.20	7.26
4.00–5.00	5.02	10.99
5.00–6.30	3.39	7.61
above 6.3	1.3	5.98
Average grain, [mm]	**1.4**	**2.3**
Bulk density, [kg/m^3]	759.9	395.5

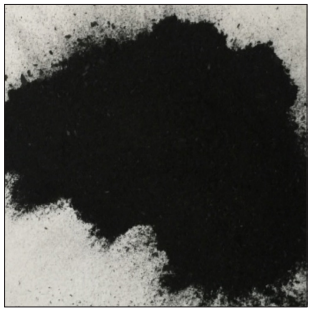

Fig. 1. Waste biomass-derived char

Fig. 2. Coke breeze

mean size of the coke breeze grain amounted to 1.45 mm, with the fraction below 1 mm constituting 64.8 wt. %. Previous industrial experience indicated that during the sintering process it was favourable to use fuel, the graining of which was restricted within the range of 1 mm to 3 mm [1].

Table 2 presents the chemical composition of the char compared with the coke breeze.

Table 2. Chemical composition of the char and coke breeze

Designation [wt. %]	Coke breeze	Waste biomass-derived char
C	81	53.7
Części lotne	5.02	44.9
SiO_2	6.24	1.38
CaO	1.55	0.66
K	0.04	0.21
Na	0.12	0.049
Cl	0.08	0.84
Cu	0.01	<0.005
Fe	1.73	<0.005
Zn	0.01	<0.005
S	0.9	0.02
Al_2O_3	3.36	0.65
MgO	0.48	0.23
Olej	0.01	0.84

The content of carbon in the waste biomass-derived char was significantly lower than that in the coke breeze and amounted to approximately 54 wt. %. The char contained approximately 0.8 wt. % of oil substances. Attention should also be paid to a very high content of volatiles in the char, amounting to 53.7 wt. %. In turn, the content of volatiles in the coke breeze amounted to 5.02 wt. %. During the iron ore sintering process, the above named situation could translate into the intensified emission of hydrocarbons into the environment. The content of chlorine in the char amounted to 0.84 wt. % (compared with 0.08 wt. % in the coke breeze). One of the advantages of the char was a low content of ballast (SiO_2), amounting to 1.38 wt. %. In turn, the coke breeze contained 6.24 wt. % of SiO_2. In addition, CaO contained in the char eliminated the necessity of adding a significant amount of limestone flux to the mix (aimed at the slagging of silicon dioxide). The char nearly did not contain noxious potassium, zinc and copper. Another favourable advantage of the char was its low sulphur content, amounting to 0.02 wt. % (in comparison with 0.9 wt. % in the coke breeze).

Figure 3 presents the results of the thermal analysis of the waste biomass-derived char and that of the coke breeze. The thermal analysis was performed in an oxidising atmosphere. The analysis aimed to identify the moment of material specimen oxidation. The moment of oxidation coincided with the initiation of mass loss on the TG curve.

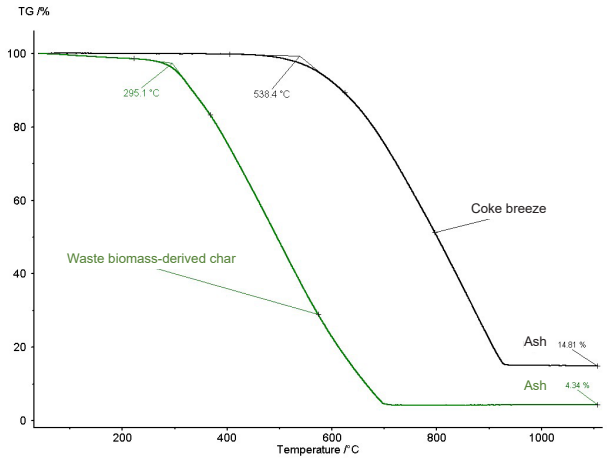

Fig. 3. Curves of the thermogravimetric analysis (TG) concerning the waste biomass-derived and coke breeze (heating performed at a rate of 10°C/min in an oxidising atmosphere)

The above-presented data revealed that, because of the lower values of temperature at the beginning of the oxidising process (identified on the TG curve), the combustion of the char took place at lower temperatures than those accompanying the combustion of coke breeze (where its oxidation initiation on the TG curve was observed at a temperature of approximately 540 °C).

The above-presented observation results led to the conclusion that the use of the aforesaid type of char in the sintering process as a partial equivalent to coke breeze could favourably affect the initiation of the combustion of the primary solid fuel (coke breeze) in the sintering mix. The foregoing was caused by higher contents of volatiles, characteristic of the char subjected to the tests.

The above-presented properties of the waste biomass-derived char (as regards its role of being a partial equivalent to the coke breeze during the sintering of iron ores) necessitated the performance of laboratory sintering tests along with the recycle of off-gases to the sintering process.

3. Laboratory sintering tests involving the use of waste biomass-derived char as an equivalent to coke breeze in the process including the recycle of off-gases to the process

3.1. Sintering testing station

The sintering tests involved the use of a line (possessed by Łukasiewicz – GIT) enabling the semi-industrial simulation of the sintering of iron ores and waste. The schematic diagram of the line is presented in Fig. 4.

The line for the semi-industrial simulation of the iron ore and waste sintering process consisted of a sintering station interacting with sintering pans having working heights of 750 mm, 550 mm and 300 mm as well as an ig-

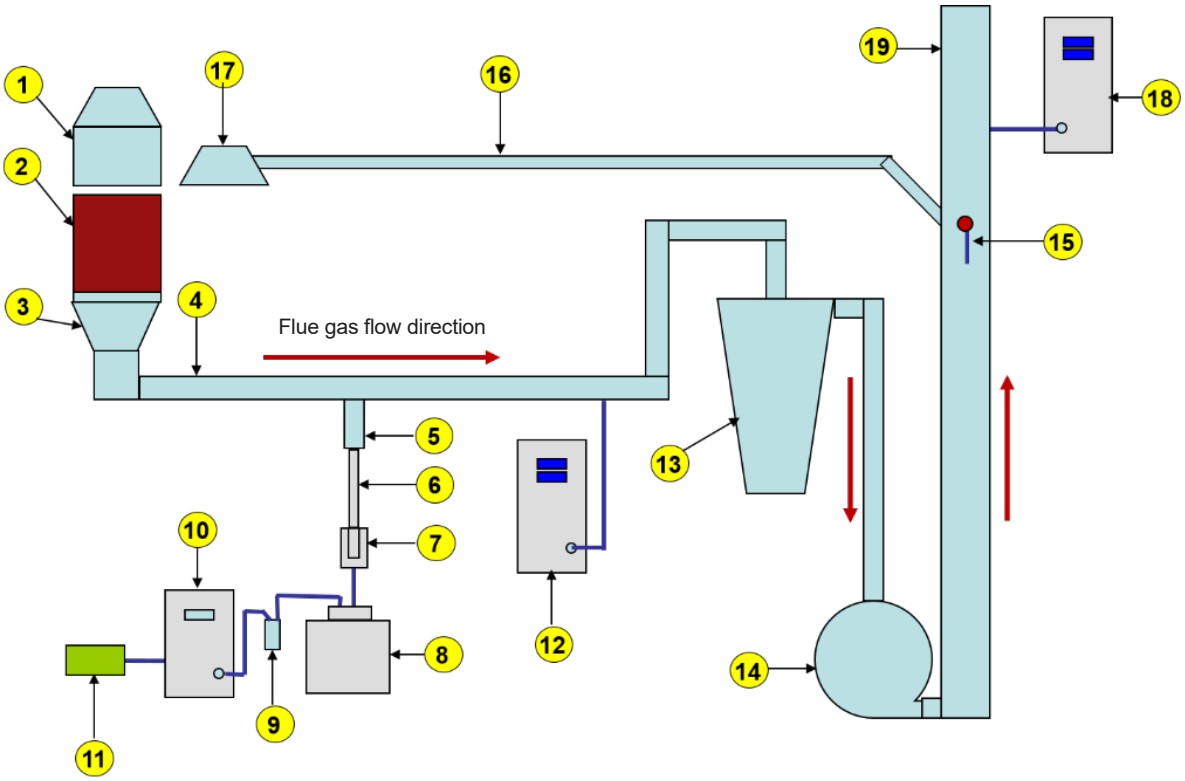

Fig. 4. Schematic diagram of the line for the semi-industrial simulation of iron ore and waste sintering process: 1. Burner, 2. Sintering pan, 3. Temperature measurement, 4. Off-gas pipeline, 5. Extraction point (pipe connector), 6. Probe with a thermostat jacket, 7. Cellulose filter (filter cup), 8. Cooler with a bottle for condensate, 9. Dehydrator, 10. Suction pump with a control system, 11. Continuous VOC measurement analyser, 12. Continuous analysis of flue gases on the dirty side, 13. Ceramic filter, 14. Fan, 15. Off-gas recycle adjustment damper, 16. Off-gas recycle pipeline, 17. Off-gas recycle cap, 18. Continuous analysis of gases on the clean side, 19. Emission source

Fig. 5. Laboratory iron ore and waste sintering station with the process display system

nition furnace having a power of 250 kW. The furnace was located on a rotating column, enabling both vertical and horizontal movements. The system featured the remote control of operation of the burner and mechanical devices with electric drives. The process could be controlled using a control panel located at the station or from a control booth or automatically, by means of a programmable logic controller (Siemens) and a desktop provided with the display of the sintering process (Fig. 5). The sintering process also enabled the recycle of off-gases.

The iron ore sintering station was equipped with a system enabling the discharging of process gases from the sinter pan, ensuring their operation under a pressure of approximately (up to) 18 kPa. The gas exhaust and neutralisation system consisted of two exhaust fans provided with motors having a power of 30 kW and a compression of 10 kPa each as well as of pipelines featuring dampers, pressure sensors and temperature sensors. The fan output amounted to 2400 Nm^3/h, whereas the nominal operating temperature was 350 °C. The purification of flue gases was performed by means a modular vertical ceramic filter (featuring compressed-air recovery in the on-line system), machinery control system equipped with locks and protections and an operator panel for controlling filtering devices. The flue gas purification system was provided with a calcium sorbent feeding system.

The line for the semi-industrial simulation of the sintering process also contained a set of stationary analysers, tasked with the continuous measurement of six process gas components (O_2, CO, CO_2, CH_4, SO_2 and NO_x) before the flue gas

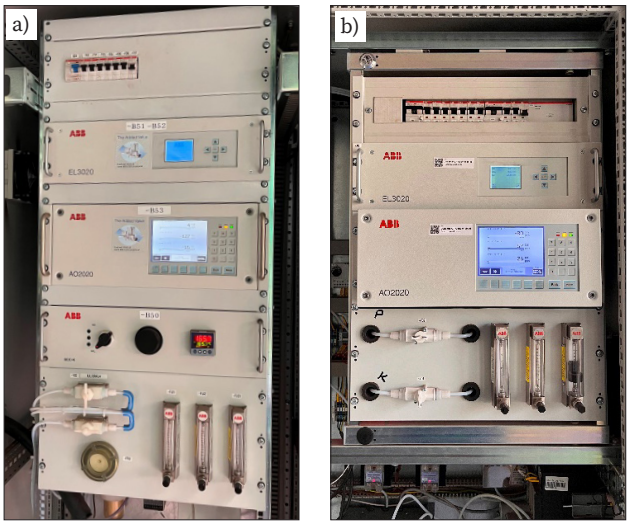

Fig. 6. Stationary system for the continuous analysis of process gas composition: a) on the dirty side and b) on the clean side

purification system (on the dirty side) and behind the flue gas (off-gas) purification system (on the clean side) (Fig. 6).

The concentration of dusts during the sintering tests was measured using a gravimetric sampler (Zambelli).

3.2. Laboratory sintering tests

The sintering tests were performed maintaining all conditions present in industrial sintering lines of Polish integrated steelworks. The sintering tests were performed in accordance with PN-ISO 8263 Iron ore fines – Method of presentation of the results of sintering tests [7]. The sintering tests were carried out so that the return sinter equilibrium index could amount to 100±5 %, which meant that the amount of return sinter added to the mix was balanced with the amount of return sinter obtained in the sintering test; the test results were representative of industrial practice.

The mixture used in the sintering tests was composed of haematites (40 wt. %) and magnetites (60 wt. %). The flux used in the mixture was composed of limestone and dolomite in amounts ensuring the obtainment of sinter characterised by previously assumed alkalinity.

The mixture was provided with 40 wt. % of return sinter having a graining of less than 5 mm. The sinter made without the waste biomass-derived char was treated as reference sinter.

Afterwards, the sintering tests were performed using a constant 15 % fraction of the waste biomass-derived char as an equivalent to coke breeze, reducing its fraction and, at the same time, gradually increasing the fraction of off-gases recycled to the process to up to 45 %. The assumed sinter parameters were the following:

- Fe content – 55 %,
- alkalinity – 1.20,
- MgO content – 1.2 %.

The objective of the sintering tests was to identify the effect of the char on the sintering process parameters, physicochemical properties of sinter and, primarily, the composition of exhaust gases emitted in the process.

The sintering tests were performed using a conventional sintering pan having a diameter of 490 mm. The height of the layer was constant and amounted to 550 mm (as presented in the schematic diagram presented in Fig. 7) [7].

In the sintering tests involving the recycle of flue gases, the ignition of the mixture was followed by the removal of the burner from above the sintering pan, the shift of the off-gas recycle cap over the sintering pan and the opening of the damper (in order to direct the appropriate amount of off-gases onto the sintering pan – see Fig. 5). Table 3 presents the process parameters and sinter properties obtained in the laboratory sintering tests.

The analysis of the test data revealed that the use of 15 wt.% of the waste biomass-derived char in the total fuel and the recycle of 30 % of off-gases translated into sintering process efficiency restricted within the range of 36.7 $Mg/m^2/24$ h to 37.3 $Mg/m^2/24$ h. In turn, the efficiency of the reference sinter-related process amounted to 36.6 $Mg/m^2/24$ h. A decrease in production connected with the 45 % recycle of off-gases to the process amounted to approximately 5 %.

A favourable phenomenon accompanying the use of the char was the reduction of an FeO content in the sinter. The FeO content in the reference sinter (obtained using 100 % of coke breeze) amounted to 8.3 wt. %. As regards the char subjected to the tests, the 15 wt. % of the aforesaid char combined with the 15 % fraction of recycled off-gases led to the obtainment of a lower FeO content of 6.9 wt. %. In terms of the blast-furnace process, the above-presented phenomenon was highly advantageous as the lower content of FeO in the sinter translated into its more favourable reducing properties.

The sinter obtained using the char and the recycle of off-gases was characterised by strength ISO T. The strength of the coke breeze-based sinter was that of ISO T (grain amount > 6.3 mm), i.e. at a level of 69.9 %. The highest strength, i.e. amounting to 70.8 %, was obtained using 15 wt. % of the waste biomass-derived char and the 15% recycle of off-gases.

It should also be noted that the abrasibility of sinter ISO A (mesh number < 0.5 mm) stayed nearly the same.

Another very favourable quality of the char was the fact that its use did not increase the presence of undesired alkalis, chlorine and zinc, the contents of which in the sinter remained nearly unchanged.

In terms of the char subjected to the tests as well as in relation to the production capacity, fuel consumption, the properties of the sinter obtained in the tests, the primary parameters of the sintering process and the properties of the sinter itself, the tests results confirmed those of previous tests concerning the use of various chars applied as an equivalent to the basic fuel used in the sintering process [3, 5 and 6].

The use of chars in appropriate fractions not only did not lead to the deterioration of sintering process primary parameters, but, as a matter of fact, resulted in their improvement.

3.3. Effect of the use of the waste biomass-derived char and the recycle of off-gases on the properties of off-gases

In addition to sintering process parameters and sinter properties, another important factor is the effect of the use of chars on the emission of pollutants into the environment. The sintering tests discussed in the article were accompanied by the continuous analysis of flue gases on the dirty side (i.e. before the ceramic filter) and on the clean side (in the emission source) for the presence of O_2, CO, CO_2, NO_x, SO_2 and CH_4. The sintering process-related tests

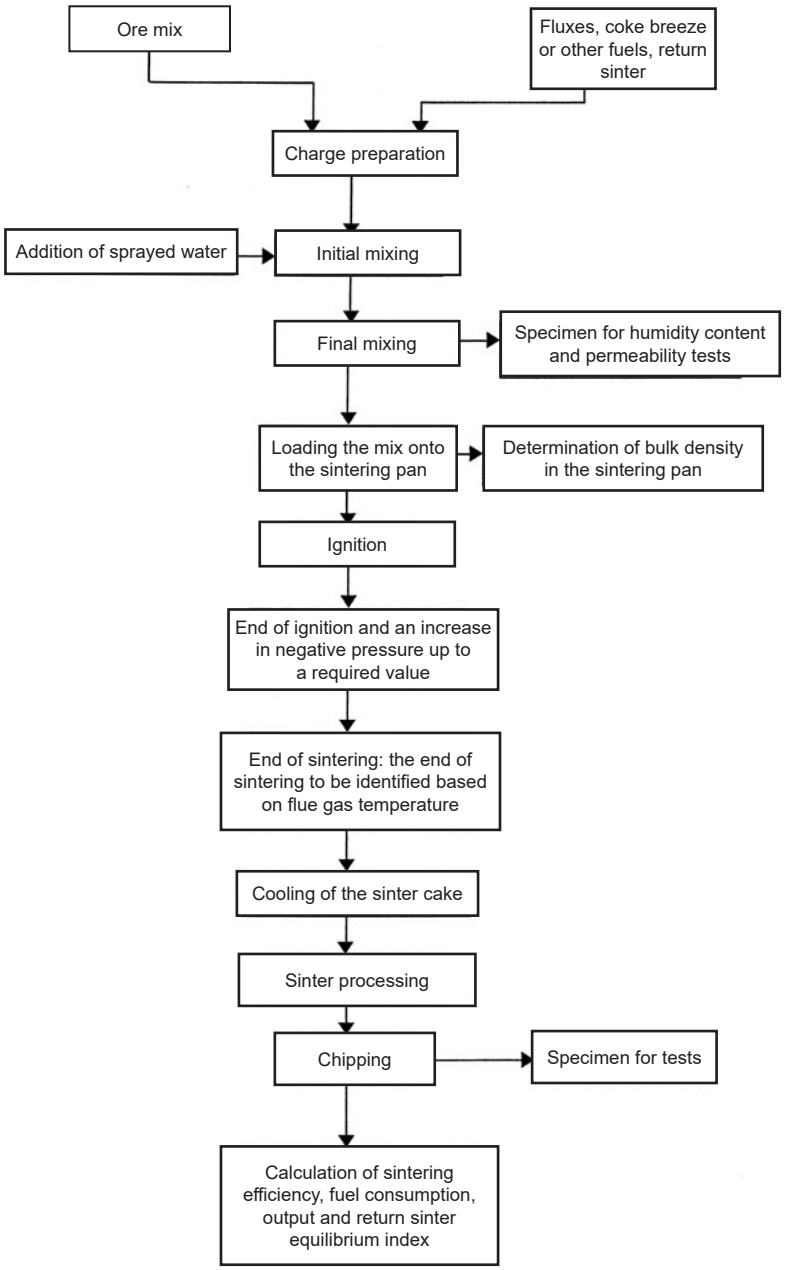

Fig. 7. Schematic diagram of the sintering process technology

also involved gravimetric measurements of dust concentration. The measurements of volatile organic compounds (VOCs) were performed before dust extraction, i.e. on the dirty side.

A SIGNAL MINIFID 3010 analyser of volatile organic compounds was located before the purification system. Flue gases were extracted using a heated probe, providing gas samples to the aforesaid analyser.

The measurement was performed in accordance with the PN-EN 12619:2013-05 standard. Following the guidelines contained in standard [8], the result obtained in ppm C3H8 was converted to that expressed mg/m^3 (concerning mass general gaseous organic carbon).

Table 4 presents results concerning the emission of pollutants into the air, whereas Figures 8–9 present the composition of off-gases on the dirty side and clean side.

It was found that the amount of CO_2 generated during the utilisation the char was higher (restricted within the range of 7.96 % to 10.13 %) than that generated when using the coke breeze (7.33 %) (before dust extraction). Such a result could be ascribed to the concentration of flue gases during their recycle. The amounts of CO_2 measured in the emission source after dust extraction were also higher (in spite of the recycling process). A similar phenomenon was observed in terms of carbon monoxide, the presence of which in the off-gases was expected to decrease.

The amount of CO emitted in the process (restricted within the range of 1.30 % to 1.51 %) was higher than that accompanying the use of the coke breeze (1.14 %), which could indicate the incomplete combustion of the substitute fuel. The increased content of methane (restricted within the range of 207 ppm to 211 ppm) in comparison with that generated when using the basic fuel (39 ppm) indicated that the increased amount of volatiles contained in the char and recycled to the process was not used up in combustion.

The above-named phenomenon was confirmed by the VOC measurement results presented in Table 4. The use of 15% of the waste biomass-derived char was accompanied

Table 3. Mean values of laboratory sintering tests involving a 15% fraction of the char in the total fuel in relation to a gradual increase in the fraction of recycled off-gases

	Parameter	Unit	Reference sinter	15 % of char without the recycle of off-gases	15% of char 15% of recycled off-gases	15% of char 30% of recycled off-gases	15% of char 45% of recycled off-gases
Sintering process primary parameters	Equilibrium indicator	%	100.6	97.3	99.2	102.0	97.7
	Sintering time	min	22.5	22.3	21.9	22.3	23.5
	Production capacity	$Mg/m^2/24$ h	36.6	36.7	37.3	36.7	34.7
	Maximum temperature of flue gases	°C	334.8	329.4	326.2	322.9	338.5
	Unit consumption of the waste biomass-derived char	kg/sinter	0.0	13.5	13.5	13.5	13.6
	Unit consumption of coke breeze	kg/sinter	53.9	49.7	49.8	49.7	49.9
	Total consumption of fuel	kg/sinter	53.9	63.2	63.4	63.2	63.5
Chemical analysis of the sinter	Fe	%	56.77	56.91	56.68	56.79	57.14
	Fe++	%	8.30	6.90	6.90	8.20	9.00
	SiO_2	%	8.01	7.87	7.90	7.93	7.87
	CaO	%	9.38	9.27	9.82	9.41	9.55
	Alkalinity (CaO/SiO_2)	-	1.17	1.18	1.24	1.19	1.21
	Al_20_3	%	0.91	0.87	0.88	0.89	0.88
	TiO_2	%	0.024	0.021	0.020	0.020	0.023
	MgO	%	1.24	1.27	1.23	1.25	1.27
	P	%	0.035	0.035	0.035	0.035	0.034
	Mn	%	0.037	0.036	0.035	0.036	0.035
	S	%	0.015	0.018	0.016	0.015	0.013
	K_2O	%	0.025	0.025	0.025	0.027	0.028
	Na_2O	%	0.033	0.026	0.034	0.026	0.024
	Zn	%	0.004	0.004	0.004	0.004	0.004
	Cl	%	0.008	0.007	0.007	0.006	0.005
Sieve analysis of the sinter	>40 mm	%	13.9	18.1	17.9	15.8	16.0
	>25 mm	%	24.4	29.9	26.9	26.2	25.1
	>15 mm	%	21.7	18.1	19.6	20.7	21.7
	>10 mm	%	16.5	13.1	13.4	14.0	15.1
	>5 mm	%	23.5	20.8	22.2	23.2	22.1
	Median	mm	19.08	23.81	21.84	20.55	20.33
Strength of the sinter	Strength ISO T	%	69.9	69.8	70.8	69.5	69.3
	Abrasibility ISO A	%	6.33	6.39	6.39	6.42	6.55

by more than a 10-fold increase in the emission of volatile organic compounds, in spite of the increased recycle of off-gases to the process.

Similar to previous tests [3, 5 and 6], the dust concentration measurements revealed that the use of the char was accompanied by the increased emission of dust (restricted within the range of 283 mg/Nm^3 to 333 mg/Nm^3), which did not take place when using the standard fuel (195 mg/Nm^3). The foregoing might be attributed to the fine-grained form of the fuel, which could be partly blown off from the sintering mix.

The off-gas purification process involved the use of a catalytic ceramic filter installed in the line for the semi-industrial simulation of the iron ore sintering process. The application of the ceramic filter significantly reduced the emission of pollutants into the air.

It was also observed that the limestone sorbent used in the tests entirely absorbed sulphur present in process

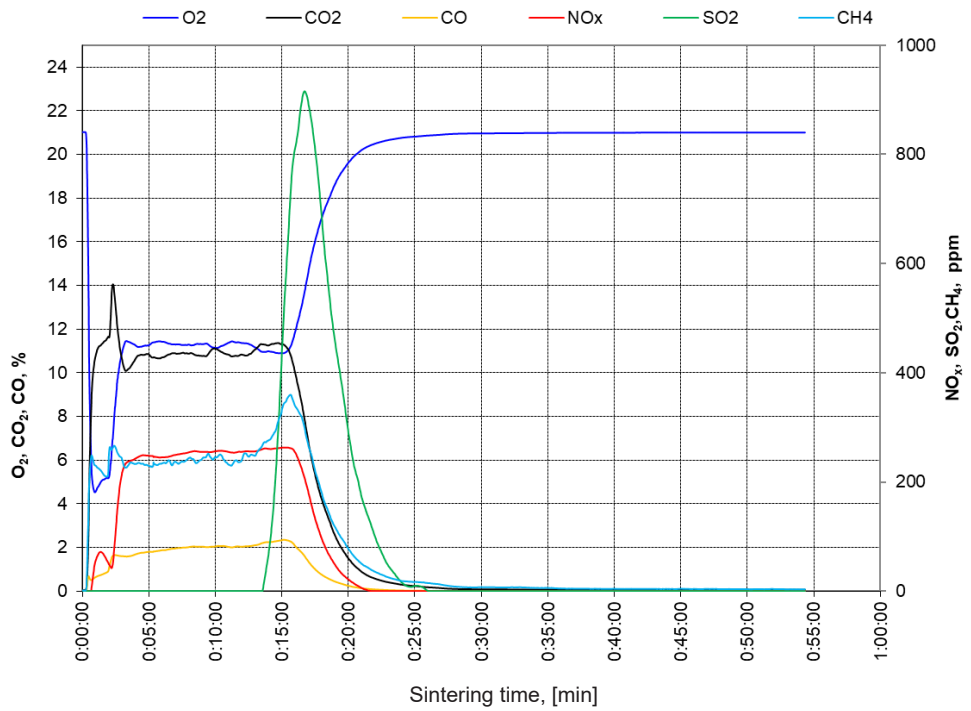

Fig. 8. Exemplary composition of off-gases on the dirty side during the sintering of the mix containing the waste biomass-derived char

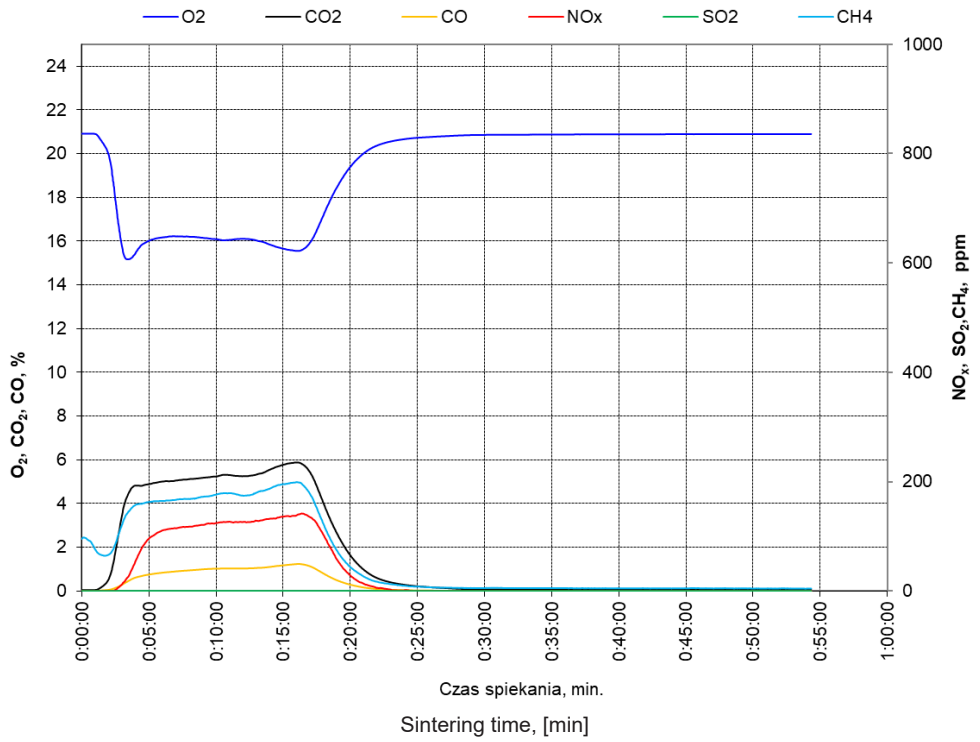

Fig. 9. Exemplary composition of off-gases on the clean side during the sintering of the mix containing the waste biomass-derived char

gases. The gas analyser located on the clean side of the emission source did not reveal the emission of sulphur in any of the tests (determination limit < 1.0 ppm). The green colour in Fig. 8 indicates the appearance of sulphur during the sintering process and the maximum content of SO_2 in off-gases.

4. Concluding remarks

The waste biomass-derived char used in the sintering tests was characterised by more favourable parameters than those of the coke breeze. The mean grain size amounted to 2.3 mm, whereas the mesh number was below 1 mm and amounted to 23.8 wt. %. The mean coke breeze grain

Table 4. Mean composition of flue gases on the dirty side (i.e. before the ceramic filter) and on the clean side (in the emission source) in relation to the sintering process performed using the mixture containing 15 wt. % of the waste biomass-derived char and involving the gradually increasing recycle of off-gases

	Parameter	Unit	Reference sinter	15% of char without the recycle of off-gases	15% of char 15% of recycled off-gases	15% of char 30% of recycled off-gases	15% of char 45% of recycled off-gases
Contents of elements/ compounds in flue gases before dust extraction (dirty side)	O_2	%	13,94	13,14	12,77	12,17	11,60
	CO_2	%	7,33	7,96	8,58	9,50	10,13
	CO	%	1,14	1,51	1,44	1,29	1,30
	CH_4	ppm	39	211	212	187	207
	S_2	ppm	454	484	421	425	439
	NO_x	ppm	181	168	178	187	181
	Pył	mg/Nm^3	195	339	324	303	283
	LZO	mg/Nm^3	23	282	305	257	291
Contents of elements/ compounds in off-gases after dust extraction (clean side)	O_2	%	17,74	17,34	17,22	16,92	16,61
	CO_2	%	3,49	3,68	3,82	4,36	4,69
	CO	%	0,57	0,74	0,68	0,63	0,64
	CH_4	ppm	11	125	133	119	127
	SO_2	ppm	<1,0	<1,0	<1,0	<1,0	<1,0
	NO_x	ppm	87	80	82	89	87
	Pył	mg/Nm^3	<1,0	<1,0	<1,0	<1,0	<1,0

size amounted to 1.45 mm in relation to 64.8 wt. % of the mesh number below 1 mm.

In terms of the char subjected to the sintering tests discussed in the article, the results obtained in the above-presented tests confirmed the results of previous tests involving the use of chars partially replacing coke breeze in the iron ore sintering process [3, 5 and 6] in terms of production process efficiency, fuel consumption, sintering process primary parameters and sinter properties.

The use of the char related to the use of previously defined fractions in the sintering tests not only did not worsen the primary parameters of the sintering process but, on the contrary, resulted in the improvement of the former.

Similar to previous tests [3, 5 and 6], the dust concentration measurements revealed the increased emission of dusts and gases accompanying the use of the char. The recycle of off-gases did not lead to the reduced emission of (primarily) CO_2, CO, CH_4 and volatile organic compounds (VOCs). It was possible to observe a significant increase in the emission of VOCs and the increased generation of CH_4 accompanying the use of constant 15 wt. % of the waste biomass-derived char and the gradually increased recycle of off-gases up to a level of 45 %.

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