Stiff Extrusion Agglomeration. Can it Compete with Sintering?

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Roller-pressed Briquettes for BF

Composition of briquettes for BF

Mill scale:	57%
BF and BOF sludge	4%
Flue dust:	4%
Binder 1:	3%
Binder 2:	10%
Binder 3:	5%
fines:	12%
water:	5%

Share of briquettes in BF charge – up to 30 kg/t of HM

Roller-pressed Briquettes for BF

PRIMETALS TECHNOLOGIES

Capacity 240 kty of briquettes
Fe content 50-60%
Binders: lime and molasses

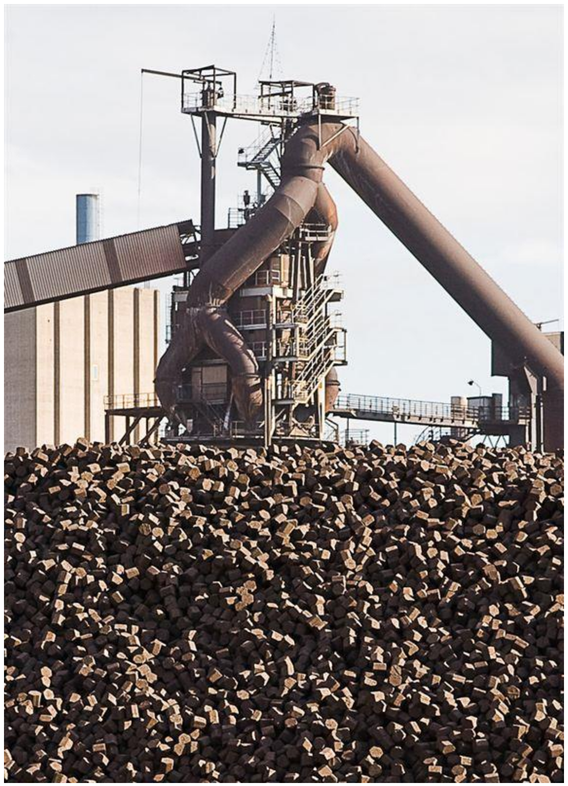
Coke rate – 2 kg/t HM
Sinter rate reduction– 9 kg/t HM

Briquettes share in BF charge 12 kg/ t HM.

ILVA S.p.A., Italy

STEELE Since 1889

Vibro-pressed Briquettes for BF



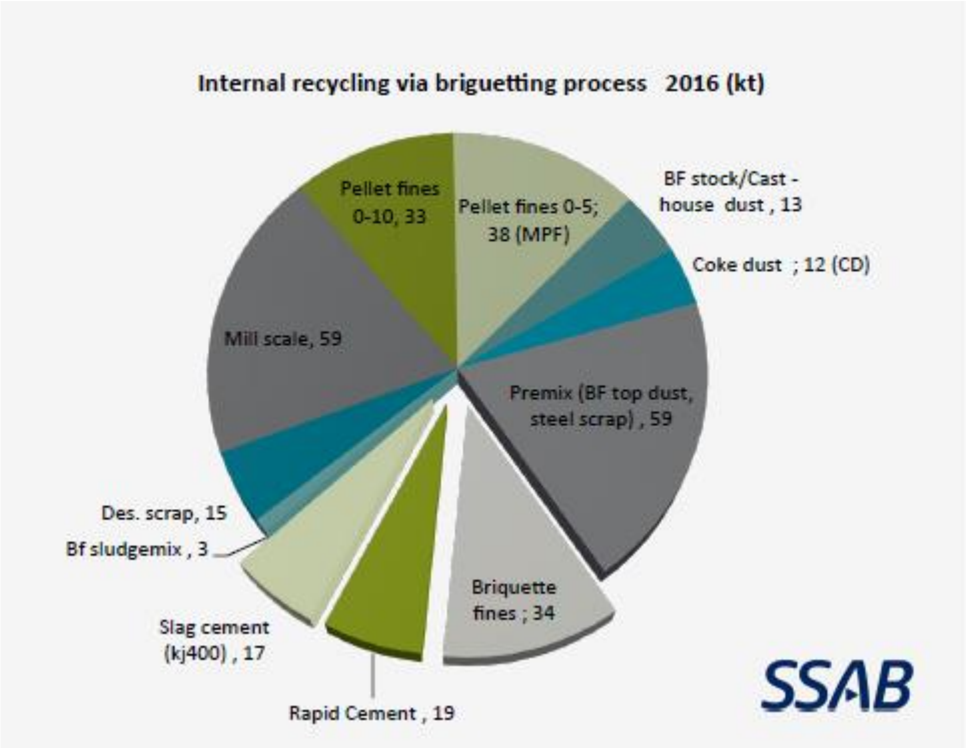
In operation since 1993

Vibropressed briquettes (60x60mm), shape - hexagonal prism

Composition: 10-12 % PC, 25% flue dust, 5-8 % water, 50% scrap and LD sludge mix (0-5mm) 5-8% aspiration dust.

Share in BF charge 40-85 kg/t HM

Vibro-pressed Briquettes for BF



Biggest not used “waste” streams:
Converter sludge “BOF-s” 60 000 Mt;
Blast furnace sludge “BF-s”, 30 000 Mt

Briquetted charge consisted of: mixture of *pellets fines* (71000 tons), *coke dust* (12000 tons), premix of *flue dust and steel scrap* (59000 tons), *mill scale* (59000 tons), *briquettes fines* (34000 tons) and *scrap* (15000 tons), slag cement (17000 tons) and rapid cement (19000 tons). Total amount of briquettes recycled via blast furnace process is 283 000 tons per year.

Vibro-pressed Briquettes for BF

First Russian vibropressing factory was commissioned at the company JSC Tulachermet in 2003 year.

Capacity - 8000 ton of briquettes per month.

Design compressive strength of briquettes - at least **6.0 MPa**. After drying -3.83 **MPa,** after heat-moisture treatment **- 6.9 MPa**.

Total amount produced **52 thousand** tons of briquettes Maximum share of briquettes in blast furnace charge BF#1**- 32 kg/t** of HM, BF#2**- 56 kg/t** of HM.

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Vibro-pressed Briquettes for BF

2003, NLMK. Full-scale testing of vibropressed briquettes in the charge of blast furnace (1000 m^3)

The first stage: recycling of iron-zinc-containing sludge, smelting of **2500** tons of briquettes (65% BOF sludge, 20% of the coke breeze and 15% Portland cement).

Briquette consumption **50-70** kg/t of HM in the first 5 days and up to **190** kg/t in the last 24 hours and averaged 121 kg/t of iron.

Vibro-pressed Briquettes for BF

The second stage: **2475 tons** of briquettes (iron ore concentrate, coke breeze and Portland cement), share in the charge (consequently) **- 122, 198, 303 kg/t of HM**.

The results confirmed that these briquettes are ***high-grade self-reducing components*** of BF charge, which ensures reduction of Coke consumption in ironmaking, proportional to their consumption. The proportion of such a component in the blast furnace charging only slightly limited by the decrease in performance of the furnace due to lower iron content in charge and can reach **50%** or more.

Vibro-pressed Briquettes for BF

The third stage: **2560 tons** of briquettes (BF sludge **- 59 %**, mill scale **- 20 %**, coke breeze **- 10 %** and Portland cement **- 11 %**) were smelted in BF with volume **2000 m^3**.

Average share in charge **- 62 kg/t of HM**.

A slight decrease in performance of blast furnace was due mainly to a decrease in iron content in the charge, as well as the negative impact of high basicity and viscosity of slags, formed from oxides of briquettes gangue.

Vibro-pressed Briquettes for BF

The results of the campaigns are as follows:

•Vibropressing can provide the required values of the strength of briquettes with Portland cement as a binder not less than **8-10%** by weight of the briquette.

•The value of the compressive strength was not less than **30 kg/cm^2** and ensure their integrity during overloads and transportation with the fines generation (-10 mm) less than **5-7%**.

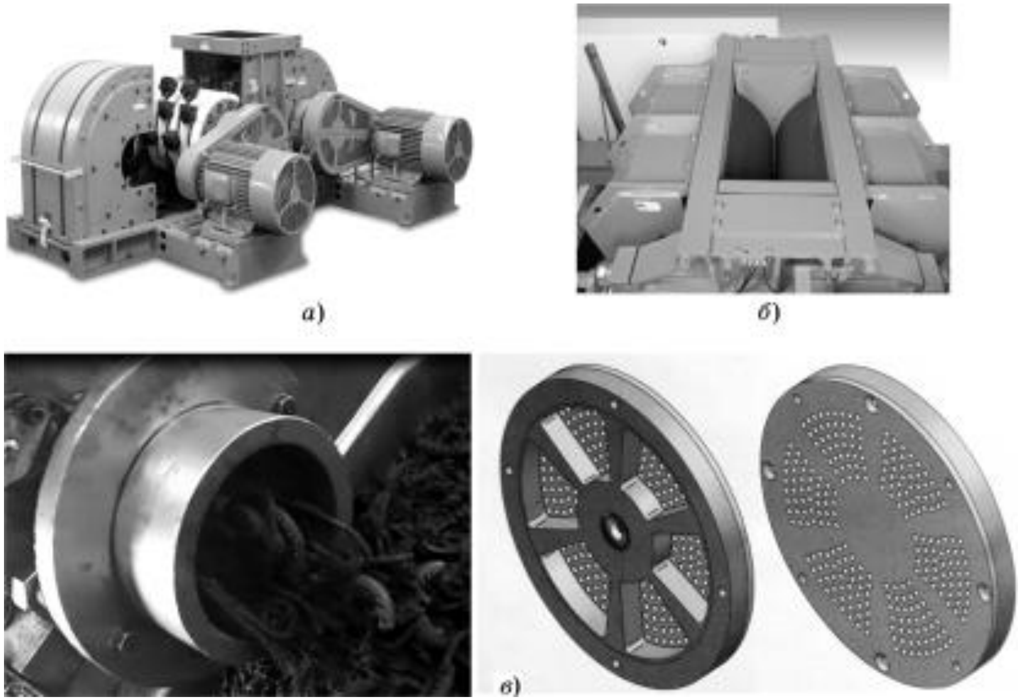
Dr. IVAN KURUNOV
27.01.1939- 31.08.2017

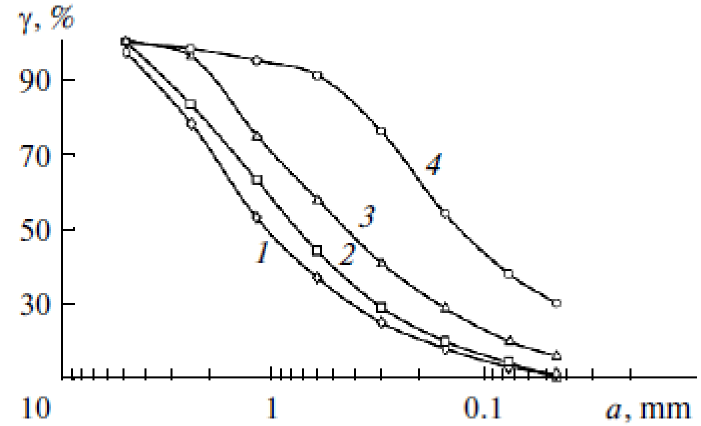
On August 31 NLMK has announced the beginning of the construction of the Stiff Extrusion Plant with the capacity of 700 kty in Lipetsk. It will be commissioned in 2018.

Classification of Extrusion Types

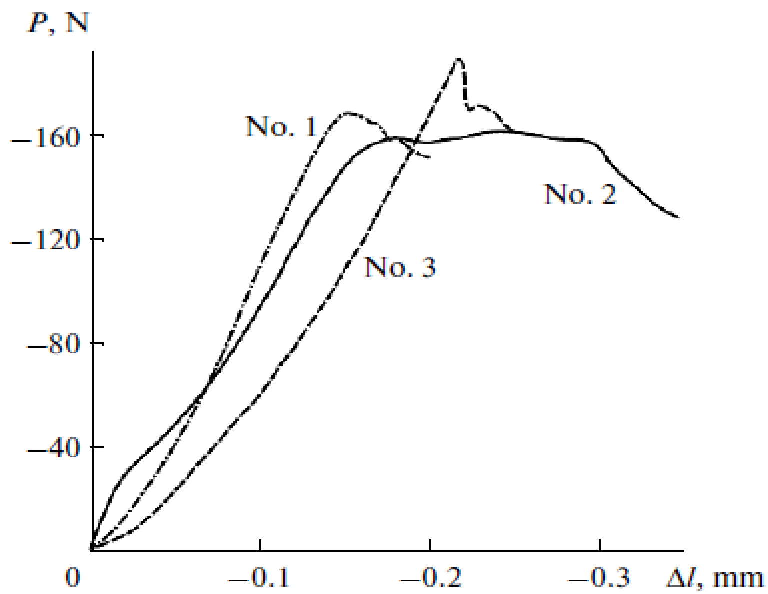
Type of extrusion	Low pressure extrusion	Medium pressure extrusion	High pressure extrusion	
Description used in ceramic industry	Soft extrusion	Semi-stiff extrusion	Stiff extrusion	
Extrusion moisture	10-27	15-22	12-18	10-15
Extrusion pressure, MPa	0.4-1.2	1.5-2.2	2.5-4.5	Up to 30

Influence of Shear Stress





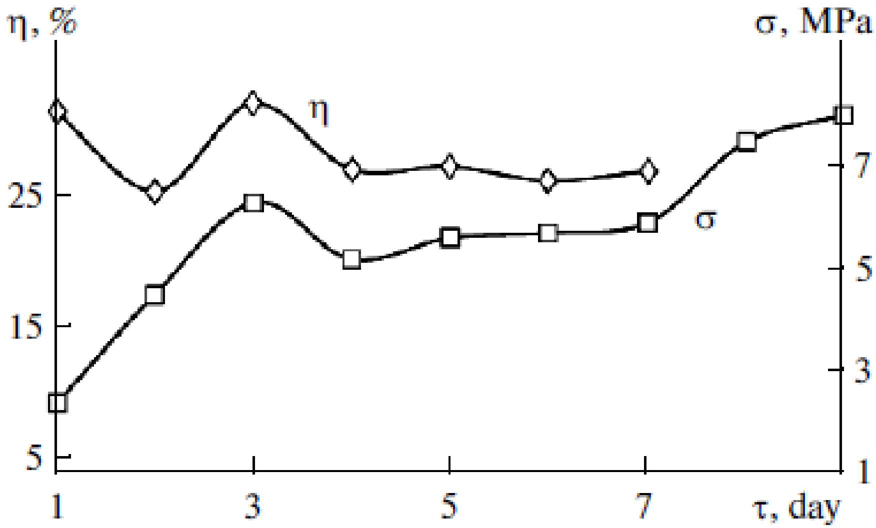
Granulometric composition of coke breeze in the following states: (1) initial and (2–4) after additional grinding in a hammer mill, in a roll crusher, and double extrusion in an extruder. respectively.



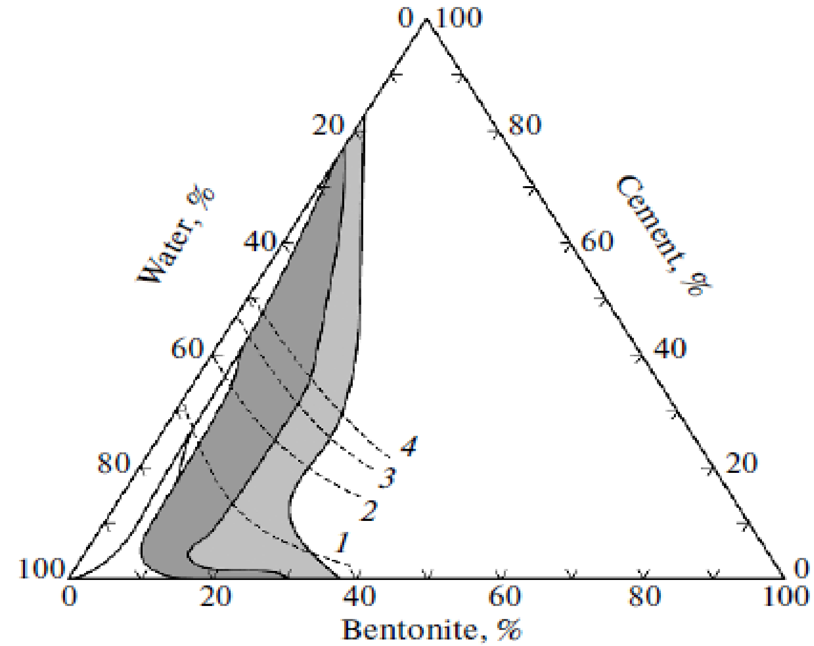
Extruded briquettes made of coke breeze(94%; 5% PC; 1% Bentonite.

No.1 – roll crusher
No. 2 – double extruded
No. 3 – hummer milled

Industrial Brex for Blast Furnace



Changes in compressive strength σ and porosity η of brex during strengthening 9-day storage.



Compressive strength

day 3 day 7

Tensile splitting

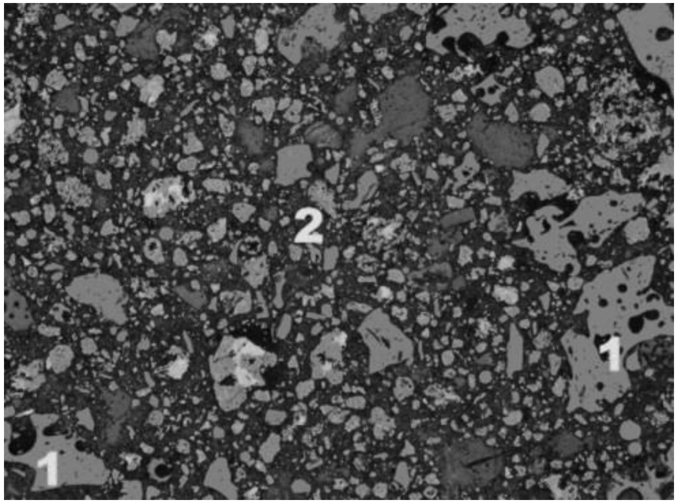
day 3 day 7

Testing of Metallurgical Properties of Brex for Blast Furnace

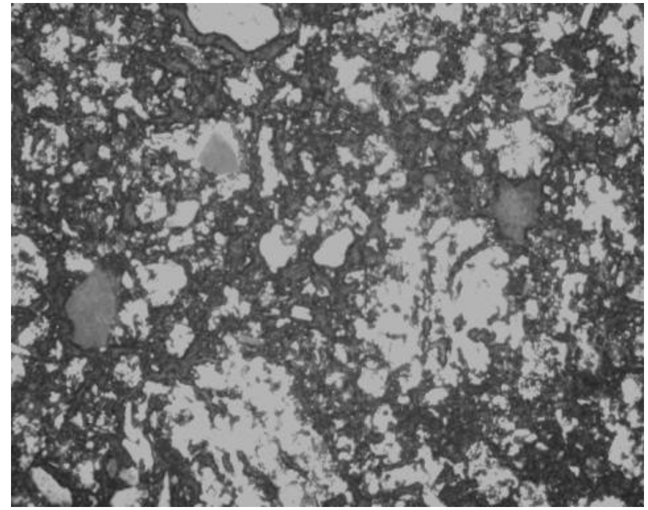
Components	Mass share, %	
	#1	#2
Portland cement	9.1	9.0
Coke breeze	-	13.5
Bentonite	-	0.9
BF sludge	54.5	-
BOF sludge	36.4	-
Iron ore concentrate	-	76.6

Test material	$RDI_{(+6.3)}$, %
Brex #1 (1.93)	**61.9**
Brex #2 (basicity 0.75)	**96.5**
Sinter (basicity 1.2)	64
Sinter (basicity 1.4)	60
Sinter (basicity 1.6)	77

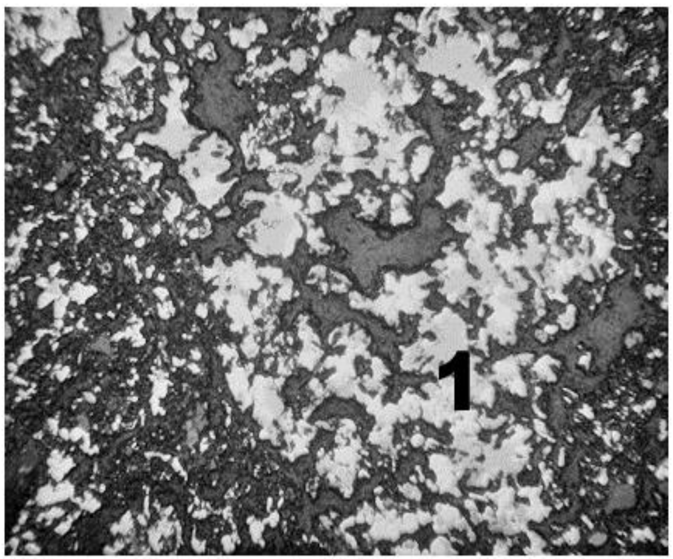
Mineralogical Study of Raw and Reduced Brex



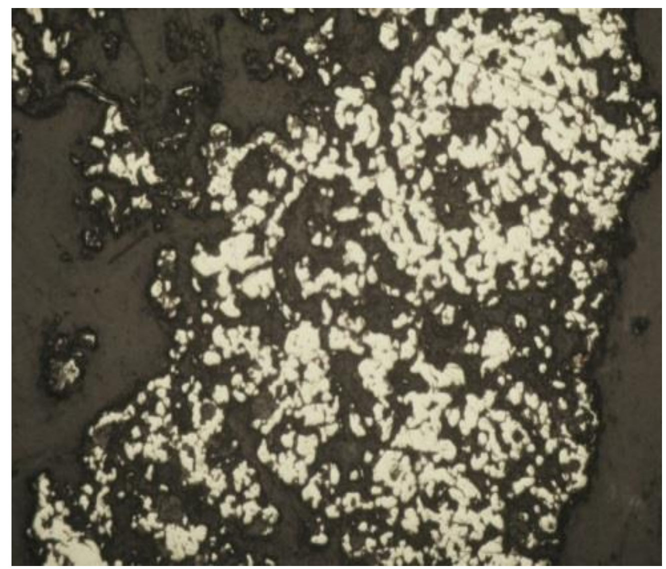
1 – Coke breeze; 2 – iron ore



Core, 900 °C



1– metal, shell, 900°C,



Shell,   1100 °C

Blast Furnace Operation with 100% of Brex

The performance of blast furnace	100 % iron ore	80 % extruded briquettes	100 % extruded briquettes
Consumption, kg/t:			
Iron ore	1500	372	-
extruded briquettes	-	1425	1960
limestone	150	-	-
Dolomite	144	-	29
scrap	132	-	-
Quartzite	-	-	13
Mn ore extruded briquettes	-	19	75
Coke, 15-25mm	680	530	490
$Fe_{total.}$ in fluxed charge, %	57.6	50.4	45.5
Capacity, t/m^3 per day	1.9	1.62	2.0
Blow temperature, ^{o}C	925	900	1000
Blow pressure, kg/cm^2	0.5	0.34–0.38	0.38–0.42
[Si], %	1.0–1.8	1.0–1.5	0.8–1.1
[Mn], %	0.2	0.4–0.5	0.7–0.8
[C], %	3.8–4.0	3.75–3.90	3.80–3.95
[S], %	0.050–0.060	0.038–0.050	0.038–0.042
Hot metal temperature, ^{o}C	1380–1440	1400–1450	1410–1450
(CaO), %	34.86	33.12	38.0–39.0
(SiO_2), %	31.98	30.23	30.0–32.0
(Al_2O_3), %	23.87	17.98	16.0–18.8
(MgO), %	9.46	9.48	8.0–9.5
(FeO), %	1.01	1.26	0.6–1.15
(MnO), %	0.35	0.75	1.3-1.4

Simulation of BF with extrusion briquettes in the charge

Mathematical model of BLAST FURNACE on the basis of software developed in Moscow Institute of Steel and Alloys (DOMNA). Blast furnace volume **4297 m^3**.

Charge of 3-components- **sinter, pellets and brex** The share of pellets is determined by the capacity in pelletizing factory (6 million tons of pellets per year).

Basicity of brex consisting of iron ore concentrate and coal is determined on the basis of the binder share in the mass (6%) and bentonite (1%), basicity of briquettes (B2) is **0.50-0.55**.

Basicity of sinter is determined on the basis of the accepted concept of replacing the sinter by brex and by their basicity. When replacing **50%** of sinter in blast furnace by brex sinter basicity should be between **2.8-3.2**. It should be noted that in the structure of sinter of this basicity dominating are the phases with increased strength compared with sinter with basicity in the range **1.5-1.7** (produced by NLMK at present).

The simulation was carried out for the same composition of hot metal and its temperature ([Si] = 0.4 %; [C] = 4.8 %; T_{iron}=1500 ° C) and for the same reduction efficiency (the degree of approximation to the equilibrium composition of the gas in the wustite reduction zone).

Simulation of BF with brex in the charge

Materials	Fe_{tot}	FeO	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	C	SO_3
Portland cement	3,3	-	4,71	20,64	4,98	63,58	1,15	-	2,55
Bentonite	3.45	0.5	4.37	59.25	14.27	2.07	3.62	-	0.14
Caking coal	0.84	-	1.2	2.7	1.5	0.4	0.1	68.9	0.36
SGOK pellets	64.38	1.51	90.31	7.04	0.32	0.22	0.45	-	0.12
SGOK Iron ore concentrate	66.32	29.2	62.3	6.62	0.18	0.26	0.1	-	0.05
Sinter (170)	55.4	11.81	66.0	6.70	0.72	11.37	2.51	-	0.05
Sinter (3.02)	50.34	10.0	60.8	6.30	0.7	19.0	3.0	-	0.06
Brex-1	56.6	24.83	53.28	7.67	0.71	4.09	0.19	5.5	0.22
Brex-2	54.34	23.84	51.15	7.36	0.68	3.93	0.18	9.5	0.21

Simulation results

BF operation parameters	Basic variant	Variant 1	Variant 2	Variant 3
Sinter consumption B2 = 1.7, kg/t	1109	-	-	-
Sinter consumption B2 = 3.0, kg/t	-	557	575	575
SGOK pellets consumption, kg/t	546	557	541	565
Brex consumption B1, kg/t	**-**	**557**	**575**	**-**
Brex consumption B2, kg/t	**-**	**-**	**-**	**575**
SGOK iron ore consumption, kg/t	-	17	-	-
Fe content in charge, %	58.2	57.45	57.15	56.2
Coke rate, kg/t	**391**	**354**	**284**	**257**
Natural gas consumption, nm^3/t	125	125	35	35
Pulverized coal consumption, kg/t	-	-	160	160
Blast rate, m^3/min	7483	7568	7340	7340
Blast temperature, ^oC	1240	1240	1240	1240
O_2 content in blast, %	30.5	30.5	30.5	30.5
Blast humidity, g/m^3	10	10	20	20
Top gas yield, m^3/t	1545	1540	1470	1466
Top gas pressure, kPa	240	240	240	240
CO,%	24.4	24.9	26.2	26.6
CO_2, %	23.2	22.6	23.9	24.4

Simulation results

The results of the experiment showed that at a brex consumption rate of **557 kg** per ton of hot metal, each **1%** of carbon in brex reduces coke consumption by **6.7 kg/ton**.

The blast furnace that uses brex-1 and 125m^3 of natural gas per ton of hot metal consumes less coke, the amount of which decreases from 391 kg/t to 354 kg/t in comparison with the basic variant. When pulverized coal is injected in an amount of 160 kg/t and 35m^3/t of natural gas is used, brex-1 reduces coke consumption to 284 kg/t

The results of the numerical simulation of blast furnace smelting using brex from iron ore concentrate and caking coal showed a high efficiency of partial (by 50%) replacement of a sinter production which can lead to reduction of coke consumption by 15% and to a 50% reduction of gaseous and dust emissions during sinter production.

Comparison of Main Industrial Agglomeration Technologies

- SINTERING (1400-1500 C^{o})

1. Capacity **4.0-6.5 Mio** tons per year in single units.
2. Source of more than 50% of all hazardous emissions of the integrated steel mill.
3. Not all types of iron ore concentrates could be pelletized and sintered.
4. Granulation of return sinter fines (-3mm) is required.

- PELLETIZATION (1200 C^{o})

1. Capacity of the firing machines – up to **10,000 Mt** per day.
2. Zonal structure of the indurated pellets creation.
3. Agglomeration of iron ores concentrates only.

- STIFF EXTRUSION (ambient)

1. Capacity of the Saudi Brick making plant – 1 Mio pieces per day (**3,500 tons per day**).
2. 2017-2018: NLMK feasibility study of **7 Mio tons** of BREX per year for sinter substitution in BF.
3. Feeding of the extruded granules to the sinter charge leads to the increase of productivity of sintering by 1.0-1.4% for each 10 kg of such granules while maintaining the yield and strength of sinter
4. Successful agglomeration of iron ore concentrates unsuitable for pelletizing and sintering.

CONCLUSIONS

- The cement-bentonite binder in iron ore and sludge brex provides sufficient mechanical strength, which simplifies the transportation of green brex using a conveyor belt to a stacking system without disintegration or fines generation. After 48 hours of strengthening brex is strong enough to be loaded into wagons for further transportation to a blast furnace unit and to be loaded into the furnaces bins without forming fines as well. The viscous-plastic character of brex destruction is maintained during compression tests performed in the course of 4 days of strengthening.
- The level of hot and cold strength of the types of brex that were investigated meets the requirements for the components of a blast furnace charge. The hot strength of brex from anthropogenic raw materials is comparable to the hot strength of fluxed sinter. The hot strength of brex from magnetite concentrate and coke breeze is much higher than the hot strength of fluxed sinter.
- The formation of an iron silicate matrix helps maintain the integrity of sludge brex when heated in a reducing atmosphere to 1150^{o}C. In the brex from iron ore concentrate and coke breeze in addition to the iron-silicate matrix formation a metallic iron surface frame is also formed in the process of reduction.
- Many years of successful operation of a small blast furnace with the charge of 100% of the brex made from a mixture of natural and anthropogenic raw materials with a blast temperature of 1000 ^{o}C and with the coke consumption smaller than 500 kg/t enables a conclusion to be made that brex are a new effective component in the BF charge and can be considered as a partial, or complete alternative to sinter.