Briquetting by Stiff Extrusion vs Sintering
Competition or Synergy?

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Briquetting by Stiff Extrusion vs Sintering

- The smelting of iron and steel, in addition to the well-known negative impact on the environment, is accompanied by the formation of a ***significant amount of iron-containing wastes***, the direct recycling of which is impossible without agglomeration

- Sintering and (indurated) pellet production are the most widespread methods of industrial agglomeration and are based on ***high-temperature processing*** of iron-containing raw materials and lead to emissions of pollutants into the atmosphere (***sintering - up to 20 kg / ton sinter, pellet production - 2 kg / ton pellets***)

- For a long time, cold agglomeration turned out to be uncompetitive in comparison with sintering and pellet production due to ***insufficient productivity*** of briquette equipment and inconsistency of briquette properties which were not meeting the requirements of metallurgical processing

- This has changed with the development of the stiff extrusion technology for briquettes **(BREX)**, which offers a viable alternative, or at the very least which has proven to be a viable and a value adding complementing technology to the first two.

Briquetting by Stiff Extrusion vs Sintering: Comparison criteria

- Metallurgical Properties
- Maximum Equipment Capacity
- Environmental aspects
- Simulation of partial replacement of Sinter by BREX in a large BF
- Could BREX be used as embryos for sinter?

Briquetting by Stiff Extrusion vs Sintering: BREX Hot Strength

- Hot strength of the **BREX** briquette from magnetite concentrate and coke fines in terms of RDI+6.3 (**ISO 4696**) exceeds RDI+6.3 of sinter with a basicity of 1.2–1.6

Agglomerated Products	RDI (+6.3), %
Brex No.4* (basicity 0,75)	96.5
Brex No.2* (basicity 1,93)	61.9
Sinter (basicity 1,2)	64
Sinter (basicity 1,4)	60
Sinter (basicity 1,6)	77

BREX components	Composition by weight, %	
	Brex No.2	Brex No.4
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

** These tests were conducted in a lab in Russia in 2010*

Briquetting by Stiff Extrusion vs Sintering: BREX Hot Strength

Agglomerated product	ISO 13930, %			ISO 4696-1, %		
	LTD +6.3	LTD -3.15	LTD -0.5	RDI +6.3	RDI -3.15	RDI -0.5
BREX #A	89.95	8.68	8.32	94.31	4.67	4.14
BREX #B				93.72	5.93	5.31
BREX #C				91.52	7.67	7.24
BREX #D				95.65	3.64	3.13
BREX #E				95.24	4.02	3.55
Sinter	65.03	13.93	4.47	76.54	7.57	1.32
Pellets #1	94.87	3.78	3.49	97.99	0.71	0.15
Pellets #2	80.7	10.45	7.79	80.49	10.19	5.3
Pellets #3	82.5	13.94	12.29			

BREX (diameter of 19 mm, after curing at a temperature of 24 ° C). Portland cement (from 6.0% to 6.5%) as a binder and sodium bentonite (from 1.0% to 2.0%) as a plasticizer. The density of the obtained briquettes ranged from 2.6 to 2.9 g / cm3.

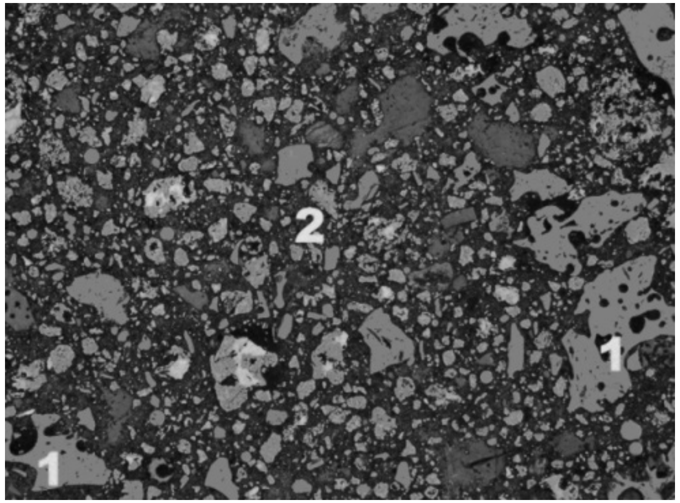
Note: BREX were produced at JC Steele & Sons Lab in Statesville - NC

Briquetting by Stiff Extrusion vs Sintering: BREX Hot Strength

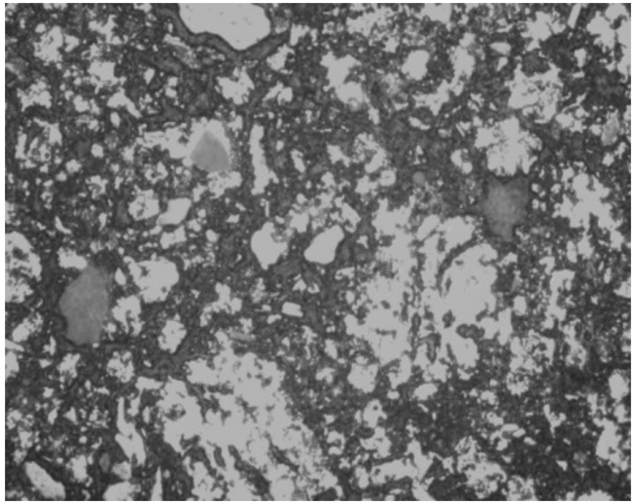
- Samples of BREX were heated to 1000 ° C in a neutral atmosphere (nitrogen) in 2 hours with a temperature gradient of 500 ° C per hour. After reaching 1000 ° C, the furnace was turned off and cooled for 12 hours. The purpose of the test was to determine the mass loss and assess the shape integrity

- The mass loss of the BREX when heated to 1000 ° C in a neutral atmosphere due to the removal of hydration moisture and partial reduction of iron oxides was **8.1%**, the briquette retained its original shape (not destroyed). The cement used as a binder is destroyed at this temperature. The fact that the BREX keeps its shape is due to the formation of a matrix made of iron-calcium olivine.

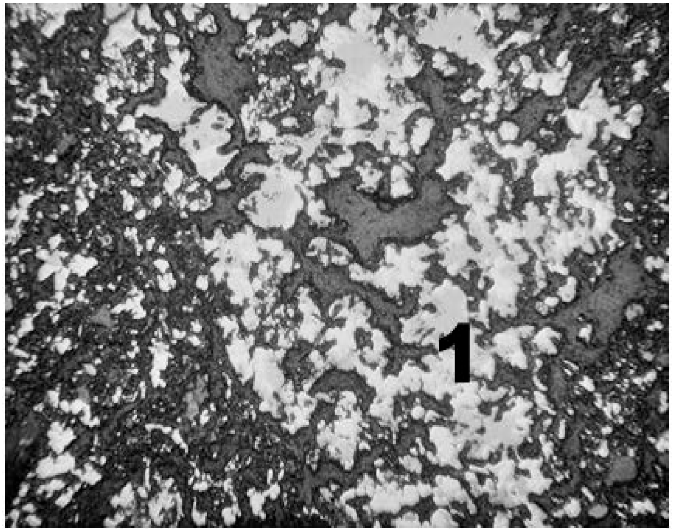
Briquetting by Stiff Extrusion vs Sintering: BREX Hot Strength



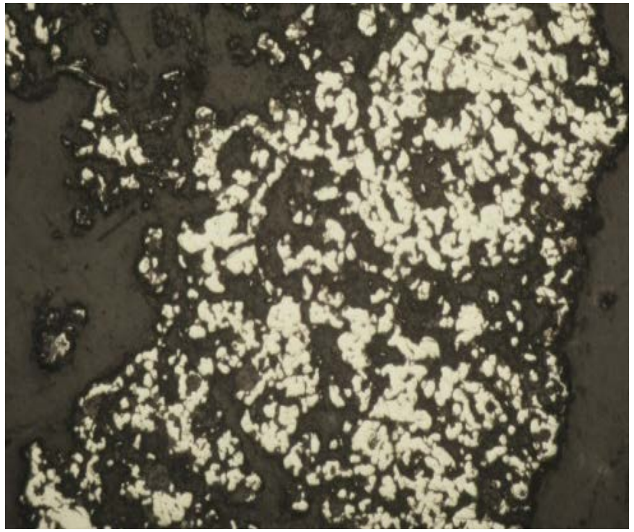
1 – Coke breeze; 2 – Iron ore



Core, 900 °C



1 – Metal shell, 900°C



Shell,   1100 °C

Briquetting by Stiff Extrusion vs Sintering: 100% BREX in BF

BF furnace performance	**100% Iron ore**	**80% BREX**	**100% BREX**
Consumption, kg/t hot metal:			
Iron ore	1,500	372	–
BREX	–	1,425	1,960
Limestone	150	–	-
Dolomite	144	–	29
Scrap	132	–	-
Quartzite	–	–	13
Flushing BREX of Mn ore	–	19	75
Coke	**680**	**530**	490
Iron content in the fluxed burden, %	57.6	50.4	45.5
Furnace output, t/(m^3·day)	**1.9**	**1.62**	2.0
Hot blast temperature, °C	925	900	1,000
Pressure at tuyeres, kPa	50	35-38	38-42

** Test was made in a 50 cu. m. Blast Furnace at Suraj - India*

Briquetting by Stiff Extrusion vs Sintering: 100% BREX in BF

BF furnace performance	**100% iron ore**	**80% BREX**	**100% BREX**
HM chemical composition, %			
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	3.8–3.95
S	0.050–0.060	0.038–0.050	0.038–0.042
Hot metal temperature, °C	1,380-1,440	1,400-1,450	1,410-1,450
Chemical composition of slag, %:			
CaO	34.86	33.12	38–39
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

** Test was made in a 50 cu. m. Blast Furnace at Suraj - India*

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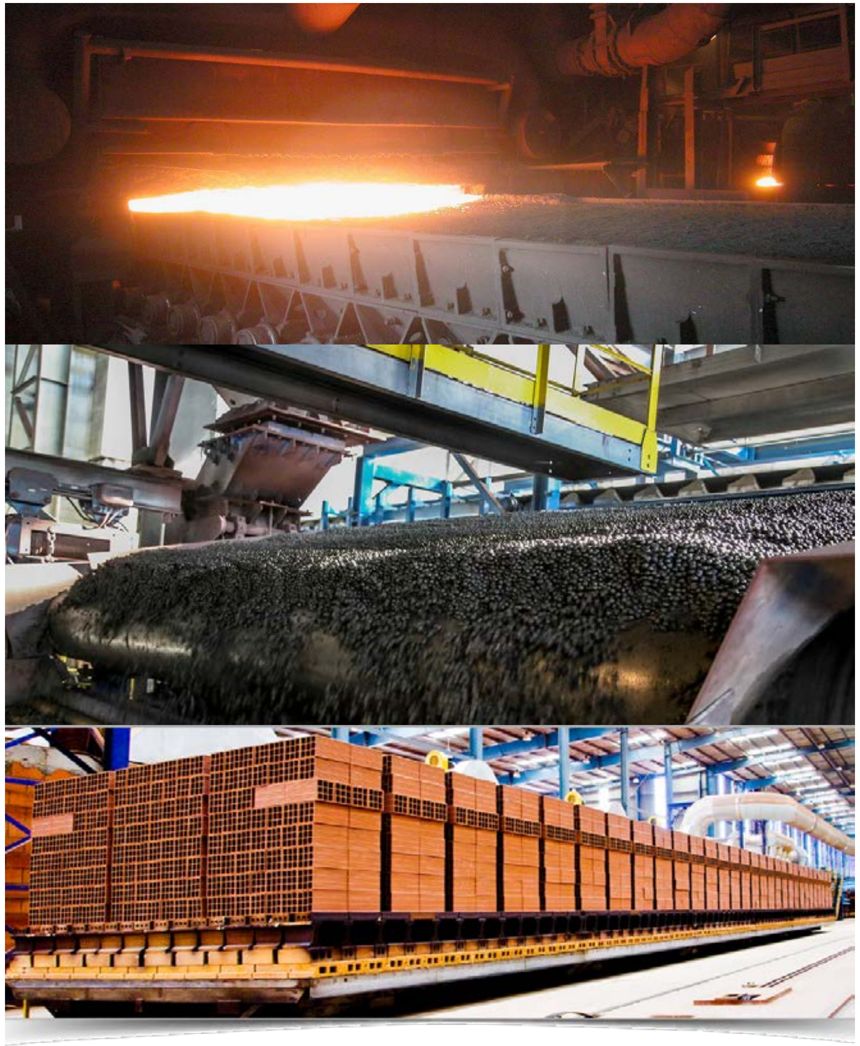
Briquetting by Stiff Extrusion vs Sintering: Maximum equipment capacity

- Capacity of sintering belt: **1,500–10,000** tons per day
- Capacity of roasting machines: **2,500–9,000** tons per day
- Capacity of extrusion plant: **2,000-7,000** tons per day; Saudi Red Bricks Plant, 1 million clay bricks per day.
- NLMK BREX-making Plant: **2,000** tons per day.
- The BREX technology has the advantage of being down-scalable to as low as **80** tons per day and still be economically viable. This is a great advantage when smaller quantities of waste are to be treated



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Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

- The Best Available Technologies (BAT) concept was first time used in 1992 by the OSPAR Convention for the protection of the marine environment of the North-East Atlantic from all types of industrial installations.

- The Best Available Technology must meet a set of criteria:

  - the lowest level of negative impact on the environment per unit of time or volume of products (goods), or work performed, or services rendered;

  - economic efficiency of its implementation and operation;

  - application of resource-and energy-saving methods;

  - specify a period of its implementation;

  - industrial implementation of this technology on two or more projects that are having a negative impact on the environment.

- Regarding the processes for production of agglomerated iron containing materials, the list of the BAT and their technological indicators are presented in the information technology directories of the Best Available Technologies

Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

What about Production of Sinter as a BAT ?

Sinter production, carried out by burning solid fuel in an air flow filtered through a layer of iron ore charge, remains a primary method of agglomeration of iron ore materials to date. As a result of physical and chemical processes in the sintering layer, emissions of pollutants are formed:

- **dust emissions** are caused by mechanical removal of the fines from the sintering layer or formed in the process of destruction of materials (sinter coming off the sintering belt; cooling, crushing and screening of the sinter cake after sintering);
- **carbon monoxide (CO) emissions** which, due to the combustion characteristics of the distributed solid fuel in the sintering layer (incomplete combustion), are technologically unavoidable; **Some CO2 emission** is of course also generated.
- **emissions of sulfur dioxide (SO_2),** depending on the sulfur content in coke fines, which is used as fuel, as well as on the composition of the iron ore charge;
- **emissions of nitrogen oxides (NO_x)** from combustion in internal combustion chamber burners, partially burning solid fuels, as well as due to the emission of "thermal" nitrogen oxides due to nitrogen content in coke fines and iron ore materials.

Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

What about Production of Sinter as a BAT ?

Production	Share of total emissions for various parts of the steel making process, %			
	Dust	**CO**	**SO_2**	**NO_x**
Sinter	31.1	77.8	61.0	26.0
Steel making	19.7	5.4	0.02	6.5
Refractory (lime-burning)	18.4	0.4	0.4	5.4
Blast furnace	17.3	3.5	0.3	3.0
Thermal power station-steam and air blower station	7.4	n/d	36.7	36.6
Coke making	2.0	7.8	1.0	9.1
Rolling production	1.2	n/d	0.2	10.5
Repair	1.0	4.9	0.02	1.5
Other	1.9	0.2	0.36	1.4
Total:	100	100	100	100

Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

What about Production of sinter as a BAT ?

A primary source of emissions during sinter production are the various processes of combustion. To minimize the impact on the environment and reduce the consumption of resources, as mandated by BAT, the following relevant technical solutions in the sinter production are applied:

- reduction of fuel consumption due to **rational charge preparation** (optimization of size distribution of charge components, the components composition of the charge, the size of coke fines, etc.);

- increased height of the sintered layer (in most cases requires some amount of retrofitting of the sintering machine);

- improvement of the combustion conditions of coke fines in the layer by increasing the gas permeability of the charge (**optimization of the pelletizing process**, the introduction of lime, the use of modulators of combustion (water mist));

- recirculation of waste gas heat (depending on the process requirements, different amounts of recirculation are possible, but under the moisture content conditions, it cannot exceed 35%; in any case, the processing of sinter gases requires a mandatory additional supply of air (oxygen); improving the flow of sinter gases is associated with an additional power consumption).

- ✦ The above measures, improving the traditional sintering technology, essentially provide no more than **20%** reduction in emissions; the most radical technical solution (recycling of sinter gases) at the maximum possible amount of recycling reduces emissions to **50%** (and thus leads to a specific emission level of about **10 kg/t** instead of **20 kg/t** of sinter).

Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

Production of indurated pellets as a BAT ?

- Pellets production refers to pyro-metallurgical technologies, since the strengthening of agglomerated granules (raw pellets) requires high temperature (1250-1350 ^oC) firing.
- The emissions generated by the pellets production are due solely to the combustion of natural gas to ensure the heat requirements of firing and the chemical transformation of the components of the charge (oxidation of sulfur compounds):

  - **emissions of NO_x** from the combustion process in heated sections of the induration machine hearth;

  - **emissions of SO_2**, determined by the sulfur content in iron ore material (concentrate);

  - **dust emissions** due to mechanical removal of dispersed particles of raw pellets, indurated pellets during unloading from the induration machine, their sieving, loading;

  - **emissions of CO_2**, due to stoichiometric combustion of natural gas, there is no chemical “under burning”, so carbon monoxide is practically not formed, however a large amount of CO2 is released.
- Measures to reduce emissions of NOx are associated with the use of burners of special design with low formation of nitrogen oxides, or technology of selective catalytic reduction of nitrogen oxides (efficiency up to 60%).
- All considered, we are still looking at about 2 kg/t of pollutants for this technology

Briquetting by Stiff Extrusion vs Sintering: Environmental aspects

Stiff extrusion briquetting as a BAT?

- As mentioned earlier, pyro-metallurgical technologies of agglomeration are associated with the release of substantial emissions.
- The technology of briquetting by the method of stiff extrusion under vacuum conditions doesn’t have such disadvantages. The technology does not require any heat treatment of raw materials or briquettes but still allows to produce a durable material.
- The main sources of environmental impact in the production of BREX is dust at the following stages:
    - warehouse storage of raw materials (unloading operations of charge materials, storage and feed into the technological process);
    - stages of dosing, mixing, extrusion (although very limited due to water addition);
    - BREX unloading, stacking and each handling step (attrition of the fine fraction, shipment to consumers);
- Most of this dust can actually be collected and simply recycled into the process.
- The main component of emissions into the atmospheric air in the production of BREX is inorganic dust. According to various assessments, the specific emission of inorganic dust in the production of BREX does not exceed 0.05 kg/t.

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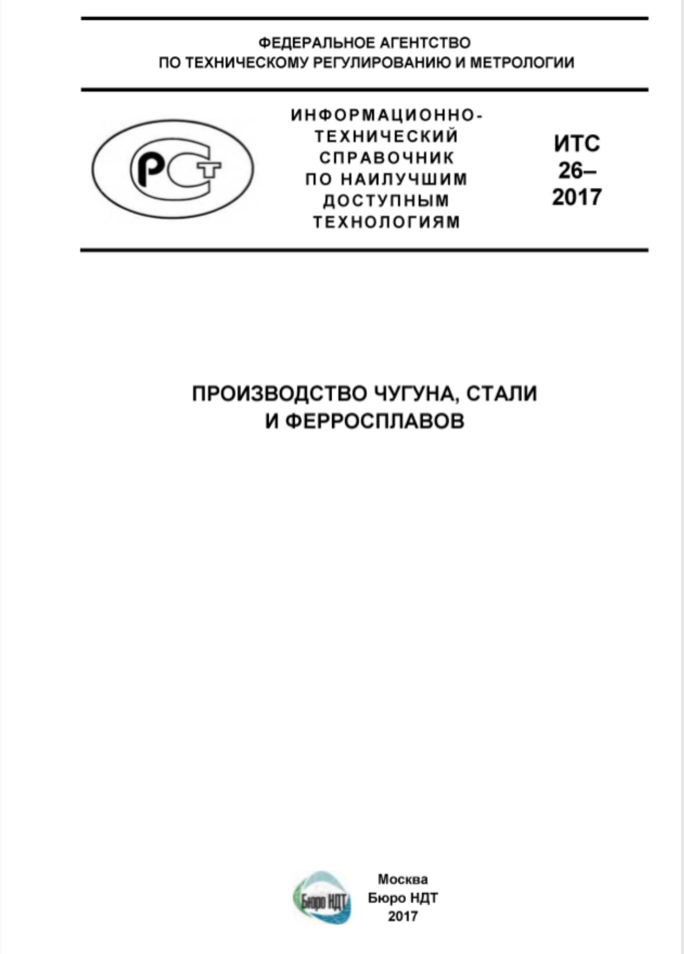
Briquetting by Stiff Extrusion vs Sintering & Indurating: Environmental Aspects Comparison

BAT criterion	Agglomerated iron-containing material		
	Sinter	**Pellet**	**Brex**
1- The minimum level of impact on the environment, kg/t:			
- dust	≤1.2	≤0.6	0.05
- nitrogen oxide	≤0.55	≤0.535	0
- sulphur dioxide	≤4.0	≤0.5	0
- carbon oxide	≤14.0	~0	0
Total emissions, kg / t:	**≤20 (≤10?)**	**≤2**	**≤0.05**
2- Resources consumption:			
- solid fuel, kg/t**	23.6-48.9	0	0
- gaseous fuel, m^3/t	2.45-6.3	9.5-15.0	0
- Electricity, kWh / t	23.0-48.7	29.0-48.5	25.0-35.0

Briquetting by Stiff Extrusion vs Sintering: Comparison of Agglomeration Technologies - Environmental aspects.

In 2017 Stiff Extrusion has been included into the List of Prospective Agglomeration Technologies of Russian Manual of BAT (Chapter 7, p. 7.1)



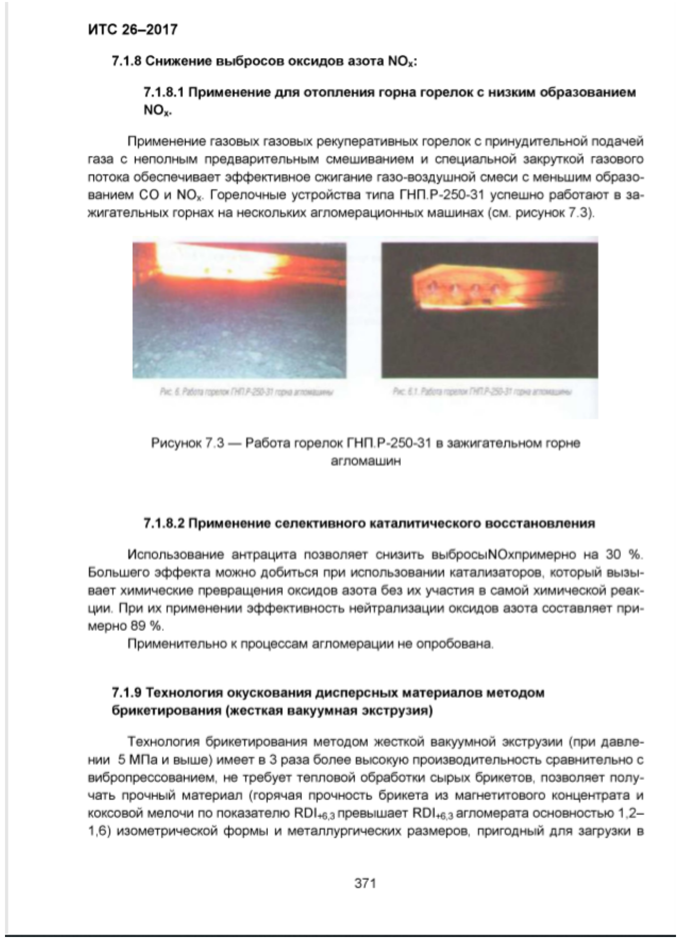
ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ

ИНФОРМАЦИОННО-
ТЕХНИЧЕСКИЙ
СПРАВОЧНИК
ПО НАИЛУЧШИМ
ДОСТУПНЫМ
ТЕХНОЛОГИЯМ

ИТС
26–
2017

ПРОИЗВОДСТВО ЧУГУНА, СТАЛИ
И ФЕРРОСПЛАВОВ

Москва
Бюро НДТ
2017



7.1.8 Снижение выбросов оксидов азота NO_x:

7.1.8.1 Применение для отопления горна горелок с низким образованием NO_x.

Применение газовых газовых рекуперативных горелок с принудительной подачей газа с неполным предварительным смешиванием и специальной закруткой газового потока обеспечивает эффективное сжигание газо-воздушной смеси с меньшим образованием CO и NO_x. Горелочные устройства типа ГНП.Р-250-31 успешно работают в зажигательных горнах на нескольких агломерационных машинах (см. рисунок 7.3).

Рисунок 7.3 — Работа горелок ГНП.Р-250-31 в зажигательном горне агломашин

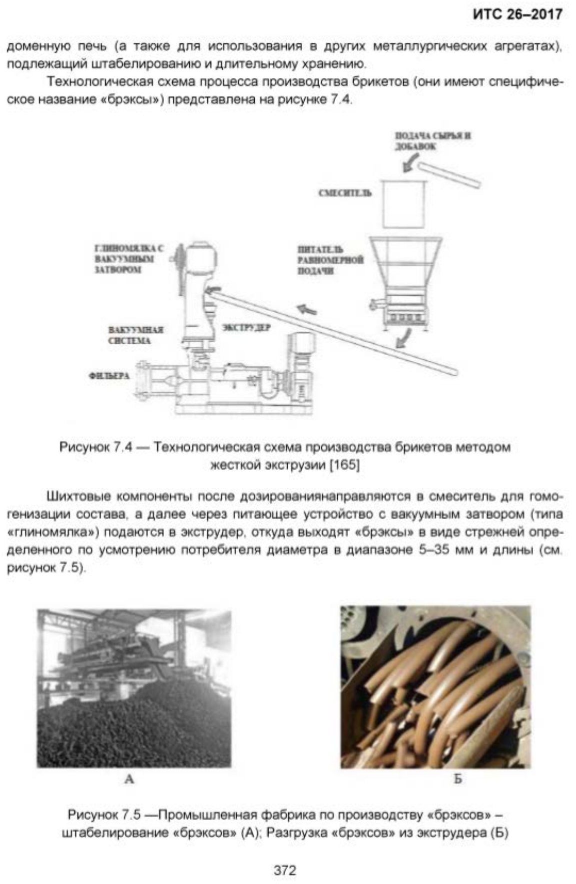
7.1.8.2 Применение селективного каталитического восстановления

Использование антрацита позволяет снизить выбросыNOхпримерно на 30 %. Большего эффекта можно добиться при использовании катализаторов, который вызывает химические превращения оксидов азота без их участия в самой химической реакции. При их применении эффективность нейтрализации оксидов азота составляет примерно 89 %.

Применительно к процессам агломерации не опробована.

7.1.9 Технология окускования дисперсных материалов методом брикетирования (жесткая вакуумная экструзия)

Технология брикетирования методом жесткой вакуумной экструзии (при давлении 5 МПа и выше) имеет в 3 раза более высокую производительность сравнительно с вибропрессованием, не требует тепловой обработки сырых брикетов, позволяет получать прочный материал (горячая прочность брикета из магнетитового концентрата и коксовой мелочи по показателю $RDI_{+6,3}$ превышает $RDI_{+6,3}$ агломерата основностью 1,2–1,6) изометрической формы и металлургических размеров, пригодный для загрузки в



доменную печь (а также для использования в других металлургических агрегатах), подлежащий штабелированию и длительному хранению.

Технологическая схема процесса производства брикетов (они имеют специфическое название «брэксы») представлена на рисунке 7.4.

Рисунок 7.4 — Технологическая схема производства брикетов методом жесткой экструзии [165]

Шихтовые компоненты после дозированиянаправляются в смеситель для гомогенизации состава, а далее через питающее устройство с вакуумным затвором (типа «глиномялка») подаются в экструдер, откуда выходят «брэксы» в виде стрежней определенного по усмотрению потребителя диаметра в диапазоне 5–35 мм и длины (см. рисунок 7.5).

Рисунок 7.5 —Промышленная фабрика по производству «брэксов» – штабелирование «брэксов» (А); Разгрузка «брэксов» из экструдера (Б)

Briquetting by Stiff Extrusion vs Sintering: Partial Substitution of Sinter - Numerical Simulation

- The effectiveness of BREX in the charge of large blast furnaces was estimated by the method of mathematical modeling of blast furnace smelting using the “**DOMNA”** software.
- The blast furnace smelting in a furnace with a volume of 4297 m^3, operating under the conditions of NLMK, was modeled.
- Simulation of blast-furnace smelting was carried out for a mixture consisting of 3 components - **sinter, pellets and BREX**.
- The share of pellets is determined by the capacity of the pelletizing plant (Stoilensky GOK, **6 million tons of pellets per year**).
- The basicity of a BREX made from iron ore concentrate and low coking coal is determined from the content of cement (6%) and bentonite (1%) in the composition of the BREX, themselves based on the results of preliminary testing, and also taking into account the content of coal in the mixture. At the indicated contents of cement and bentonite, the basicity of BREX (B2) is **0.50 - 0.55**.

Briquetting by Stiff Extrusion vs Sintering: Partial Substitution of Sinter - Numerical Simulation

- The required basicity of the sinter is back calculated based on the accepted concept of replacing the sinter with BREX of a certain basicity.

- When replacing 50% of the sinter in the blast furnace charge with BREX, the basicity of the sinter should be between **2.8 and 3.2**.

- It should be noted that with such basicity in the structure of the sinter, the “flux” phases predominate, providing an increase in its strength compared to the sinter with basicity in the range of **1.5–1.7** that is characteristic of the sinter produced at NLMK.

- The coal content in BREX was back calculated by observing at what point the structural composition of BREX after heating in a reducing atmosphere to 1400 ^{o} C and after reaching almost complete metallization, unreacted coke breeze particles remained in the BREX structure due to its excessive content in the mixture for briquetting.

Briquetting by Stiff Extrusion vs Sintering: Partial Substitution of Sinter - Numerical Simulation

- The consumption of carbon-containing material in the charge for briquetting is calculated based on the stoichiometric ratio of oxygen and iron in BREX (O/Fe) by the time they arrive in the cohesion zone, where the temperature exceeds 1100 ° C and reduction takes place only with the participation of solid carbon.

- To simulate the blast smelting mentioned in the previous slide, the calculated compositions of sinters are shown for a basicity of **1.70 and 3.02.**

Materials	**FeO**	**Fe_2O_3**	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	**C**	**SO_3**
Portland cement	-	4.71	20.64	4.98	63.58	1.15	-	2.55
Bentonite	0.5	4.37	59.25	14.27	2.07	3.62	-	0.14
Coking coal	-	1.2	2.7	1.5	0.4	0.1	68.9	0.36
SGOK pellets	1.51	90.31	7.04	0.32	0.22	0.45	-	0.12
SGOK Iron ore concentrate	29.2	62.3	6.62	0.18	0.26	0.1	-	0.05
Sinter (1.70)	11.81	66.0	6.70	0.72	11.37	2.51	-	0.05
Sinter (3.02)	10.0	60.8	6.30	0.7	19.0	3.0	-	0.06
BREX	24.83	53.28	7.67	0.71	4.09	0.19	5.5	0.22

Briquetting by Stiff Extrusion vs Sintering: Partial Substitution of Sinter - Numerical Simulation

BF operation parameters	Base – no BREX	Variant 1	Variant 2
Sinter consumption (B2 = 1.7), kg/t	1109	-	-
Sinter consumption (B2 = 3.0), kg/t	**-**	**557**	**575**
SGOK pellets consumption, kg/t	**546**	**557**	**541**
Brex consumption , kg/t	**-**	**557**	**575**
SGOK iron ore consumption, kg/t	-	17	-
Fe content in charge, %	58.2	57.45	57.15
Coke rate, kg/t	**391**	**354**	**284**
Natural gas consumption, nm^3/t	**125**	**125**	**35**
Pulverized coal consumption, kg/t	**-**	**-**	**160**
Blast rate, m^3/min	7483	7568	7340
Blast temperature, °C	1240	1240	1240
O_2 content in blast, %	30.5	30.5	30.5
Blast humidity, g/m^3	10	10	20
Top gas yield, m^3/t	1545	1540	1470
Top gas pressure, kPa	240	240	240
CO,%	24.4	24.9	26.2
CO_2, %	23.2	22.6	23.9
H_2, %	9.7	9.9	8.2
Slag ratio, kg/t	318	314	323
Slag basicity, B2	1.01	1.01	1.02
Capacity, t/day	12465	12624	12708
Capacity, $t/m^2 \cdot day$	92.48	93.66	94.3
Reduction efficiency,%	94.2	94.2	94.2

- The simulation was carried out for [Si] = 0.4 %; [C] = 4.8 %; $T_{\text{pig iron}}$=1500 ° C;

- The results showed that due to the carbon contained in the BREX, the coke consumption for hot metal production is reduced compared to the base case by **10%**.

- When blowing natural gas with a consumption of 125 m^3/t of hot metal, coke consumption of **354 kg /t** of hot metal is achieved.

- When pulverized coal is injected with a flow rate of 160 kg/t of hot metal, coke consumption of **284 kg/t** of hot metal is achieved.

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Briquetting by Stiff Extrusion vs Sintering: Synergy of both Technologies

- When replacing 50% of the sinter production with the production of briquettes:
  - reduced consumption of iron ore concentrate;
  - eliminated sinter returns, by improving the quality of sinter;
  - limestone consumption increases;
  - increases the consumption of dolomite;
  - the consumption of skip sinter is reduced;
  - reduced consumption of dry skip coke takes place;
  - increases the basicity of the sinter (> **3.0**);
  - reduced the mass fraction of iron in the sinter;
  - 50% reduction in emissions (CO2 emissions by **32%**, dust by **50%**, sulfur dioxide by **43%**).

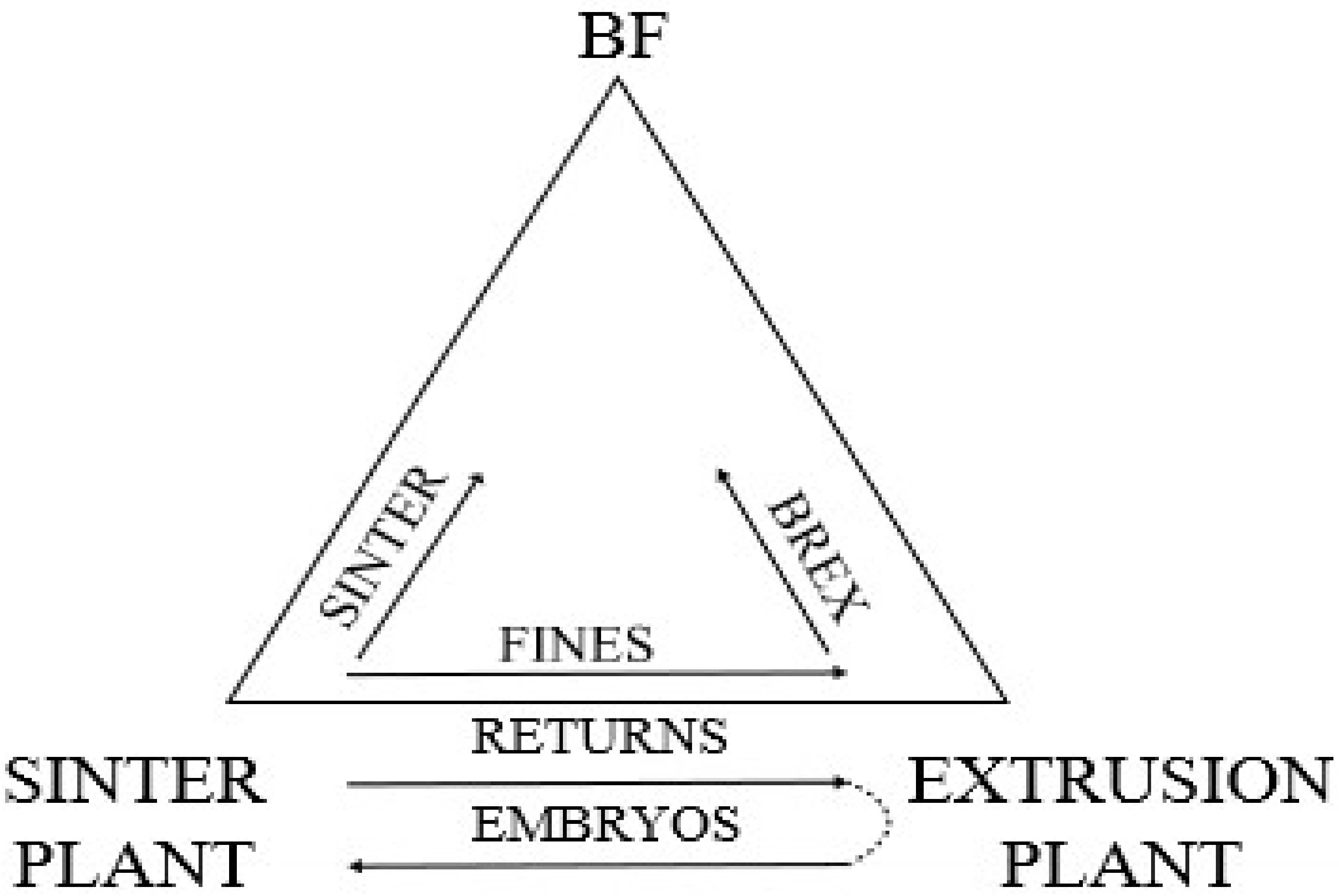
- The cost of production of 1 ton of BREX, with a line capacity of **700 kty**, is comparable to the cost of sinter with a sinter plant productivity of **7 million tons per year**.

Briquetting by Stiff Extrusion vs Sintering: Embryos for Sintering?

Another possible important advantage of extrusion agglomeration is the preference for using extrusion for the preparation of nucleating agents for the production of sinter, revealed in industrial experiments carried out in Ukraine (link below). A number of essential parameters of sintering, including efficiency of sintering process in general, were improved by using embryos prepared on an extruder. According to this research, traditional methods of nucleation - the use of pellets or crushed roll briquettes - are said to be inferior in terms of extrusion efficiency.

Reference: **Pilyugin E.I., Semakova V.B. POSSIBLE APPLICATION OF ADDITIONS OF RECYCLED SELECTED SINTER FINES TO SINTER CHARGE. *Izvestiya. Ferrous Metallurgy*. 2013;56(10):48-49. (In Russ.) https://doi.org/10.17073/0368-0797-2013-10-48-49**

Extrusion vs Sintering - Synergy



Thank You For Your attention

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