Aitber Bizhanov

BRIQUETTING IN METALLURGY.
HISTORY, PROBLEMS AND PROSPECTS.

Modern State-of-Art of Briquetting in Ferrous Metallurgy

Dr. Aitber Bizhanov

What is a briquette?

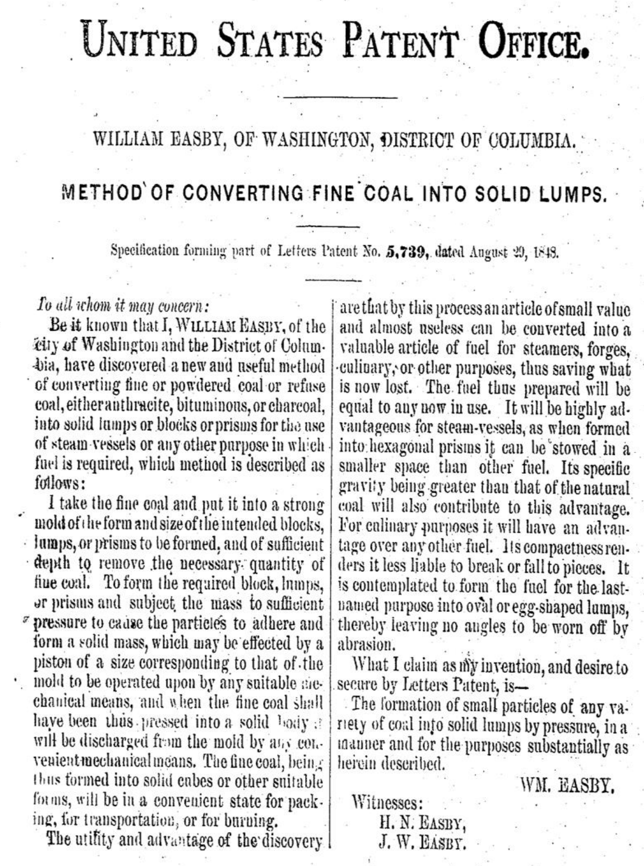
- Acquaintance with briquetting could begin with reference to the most extensive modern information resource - to Wikipedia. In the English version, the use of briquette in metallurgy is not paid attention at all, and in the Russian version there is only 15 lines on briquetting in ferrous metallurgy.
- In the Cambridge Dictionary (https://dictionary.cambridge.org), the word briquette is explained as - *a small block of coal dust or peat, used as fuel*. No mention of metallurgical briquetting applications. Here echoes of the Second World War are heard, when in England briquettes from a mixture of coal dust and cement, molded into blocks of 15x15x5 cm, were used for heating homes.

What is a briquette?

- The word briquette (from the French "brique" - brick) means a pressed product.
- The history of briquetting is closely intertwined with the production of bricks and some other construction materials.
- The first commercially successful project of briquetting iron ore fines for blast furnaces was based on the equipment used at that time for the production of bricks.
- Following Pink Floyd one call briquette as … another brick …
- Not to be confused with Briquet syndrome - a serious mental illness, characterized by multiple vague, recurring somatic complaints that cannot be fully explained by any known general medical condition; it usually begins before age 30 and persists for several years (☺).

History of Industrial Briquetting in Ferrous Metallurgy

- For the first time, the idea to use a press to produce briquettes was expressed by the **A.V. Veshnyakov** (Russia) in application to the briquetting of charcoal and hard coal. With the priority of **July 7, 1841**, he was granted a "privilege" for a new type of fuel, called "**carbolyne**". He proposed to subject the charcoal (coal, coke) to grinding and sifting, then add vegetable or animal oil to it, load the resulting mass into bags (made of bast or strong canvas), tightly wrapped with ropes or strong canvas and compress them in a hydraulic press. The obtained pieces were proposed to be further dried. Later, Veshnyakov proposed replacing the bags with cast-iron boxes with holes.
- A year later, in **1842**, **Marsais**, a Frenchman, invented a coal-fuel briquette with coal tar as a binder.
- In **1843**, a similar patent was granted to **Wylam** in the UK . The first patent for coal briquetting in the United States was issued in **1848** by **William Easby**.



UNITED STATES PATENT OFFICE.

WILLIAM EASBY, OF WASHINGTON, DISTRICT OF COLUMBIA.

METHOD OF CONVERTING FINE COAL INTO SOLID LUMPS.

Specification forming part of Letters Patent No. **5,739**, dated August 29, 1848.

To all whom it may concern:

Be it known that I, WILLIAM EASBY, of the city of Washington and the District of Columbia, have discovered a new and useful method of converting fine or powdered coal or refuse coal, either anthracite, bituminous, or charcoal, into solid lumps or blocks or prisms for the use of steam-vessels or any other purpose in which fuel is required, which method is described as follows:

I take the fine coal and put it into a strong mold of the form and size of the intended blocks, lumps, or prisms to be formed, and of sufficient depth to remove the necessary quantity of fine coal. To form the required block, lumps, or prisms and subject the mass to sufficient pressure to cause the particles to adhere and form a solid mass, which may be effected by a piston of a size corresponding to that of the mold to be operated upon by any suitable mechanical means, and when the fine coal shall have been thus pressed into a solid body it will be discharged from the mold by any convenient mechanical means. The fine coal, being thus formed into solid cubes or other suitable forms, will be in a convenient state for packing, for transportation, or for burning.

The utility and advantage of the discovery are that by this process an article of small value and almost useless can be converted into a valuable article of fuel for steamers, forges, culinary, or other purposes, thus saving what is now lost. The fuel thus prepared will be equal to any now in use. It will be highly advantageous for steam-vessels, as when formed into hexagonal prisms it can be stowed in a smaller space than other fuel. Its specific gravity being greater than that of the natural coal will also contribute to this advantage. For culinary purposes it will have an advantage over any other fuel. Its compactness renders it less liable to break or fall to pieces. It is contemplated to form the fuel for the last-named purpose into oval or egg-shaped lumps, thereby leaving no angles to be worn off by abrasion.

What I claim as my invention, and desire to secure by Letters Patent, is—

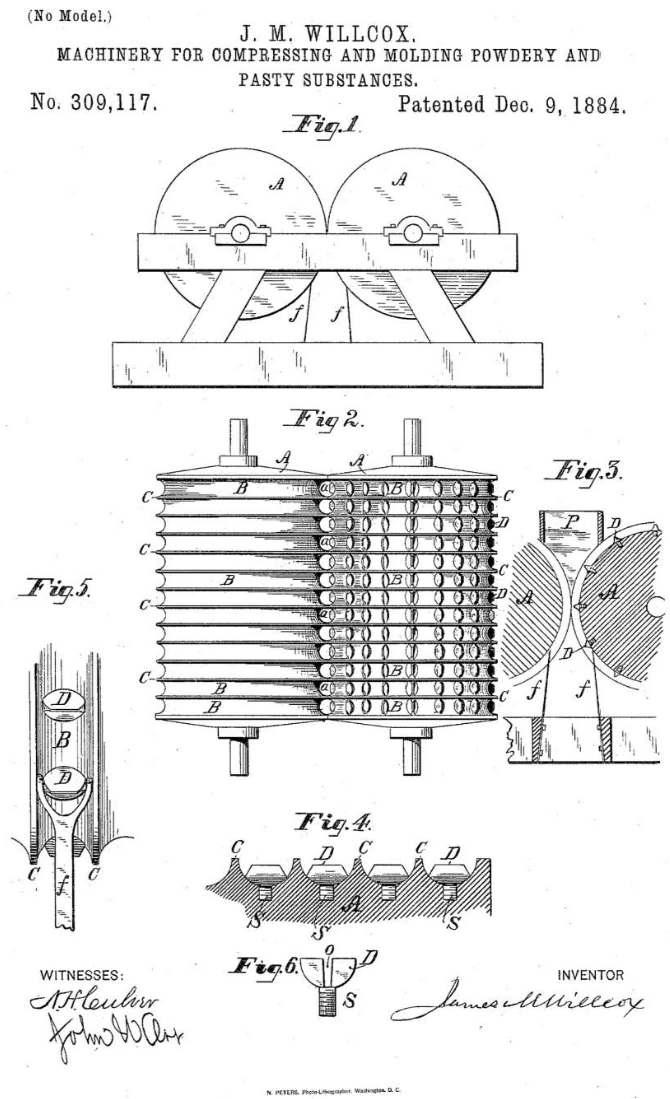
The formation of small particles of any variety of coal into solid lumps by pressure, in a manner and for the purposes substantially as herein described.

WM. EASBY.

Witnesses:
H. N. EASBY,
J. W. EASBY.

History of Industrial Briquetting in Ferrous Metallurgy

In **1859**, the first coal briquette factory was built by SAHUT-CONREUR in Raismes in France, where in **1860** a roll press was used to produce coal briquettes. The essence of the concept of such briquetting was forming with the help of two cast-iron rolls, the surface of which was covered with submerged ellipsoidal cells, which, while simultaneously rotating the rolls, should ideally coincide with each other, forming a container for forming the briquetted mass held in it. One of the first patents for the design of a roller press was obtained only in **1884** by **J.M. Wilcox** in the USA.



History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

Gröndahl Johan Gustav (Sweden)

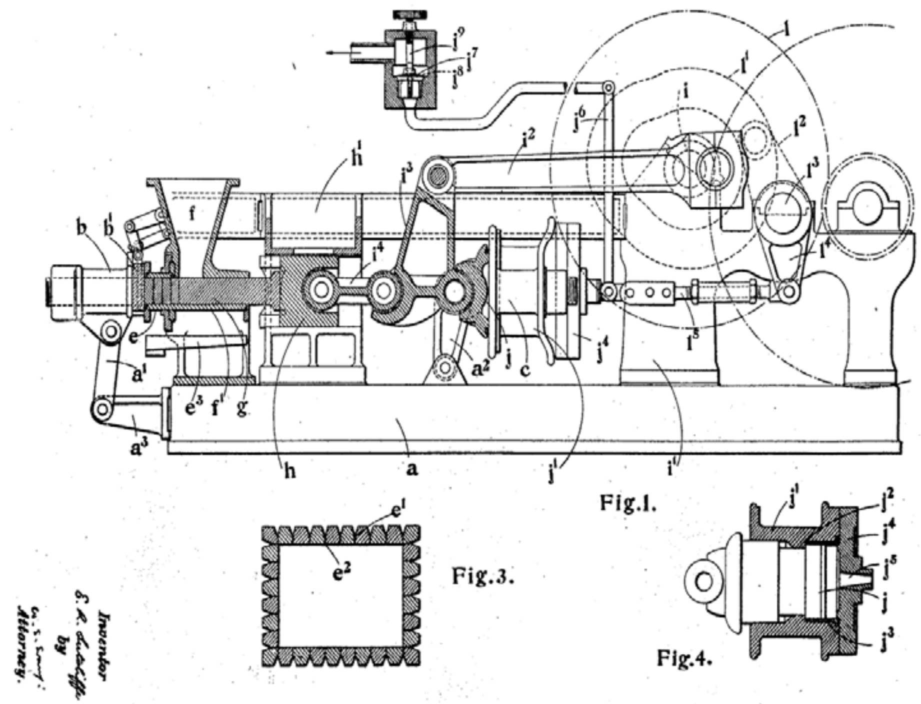
February 11, 1859 - March 16, 1932

- His energy and inventive talent in metallurgy began to emerge with the beginning of his work in 1880 as an engineer at the Pitkäranta Copper-Tin Plant on Lake Ladoga in Finland near the Russian border.

- He invented new methods of enrichment of iron ores, which were previously considered unsuitable for processing. These methods included magnetic separation, **briquetting**, new kiln designs.

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

To produce briquettes, stamp presses of **Sutcliff** design with a pressure of **30–50 MPa** were used. A patent for such a press was received by Edgar Sutcliffe from Lancashire (England) on **March 31, 1925**. The patent number 1531631 was issued in the United States on May 31, 1925 and was called **"Press for the production of bricks, briquettes, blocks, and the like."**



The design of the Sutcliff stamp press for the production of bricks and briquettes:
a - base plate; b, c - parts of the crank-slider mechanism, e-mold (mold), f - receiving funnel, g - plunger, h - slider).

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

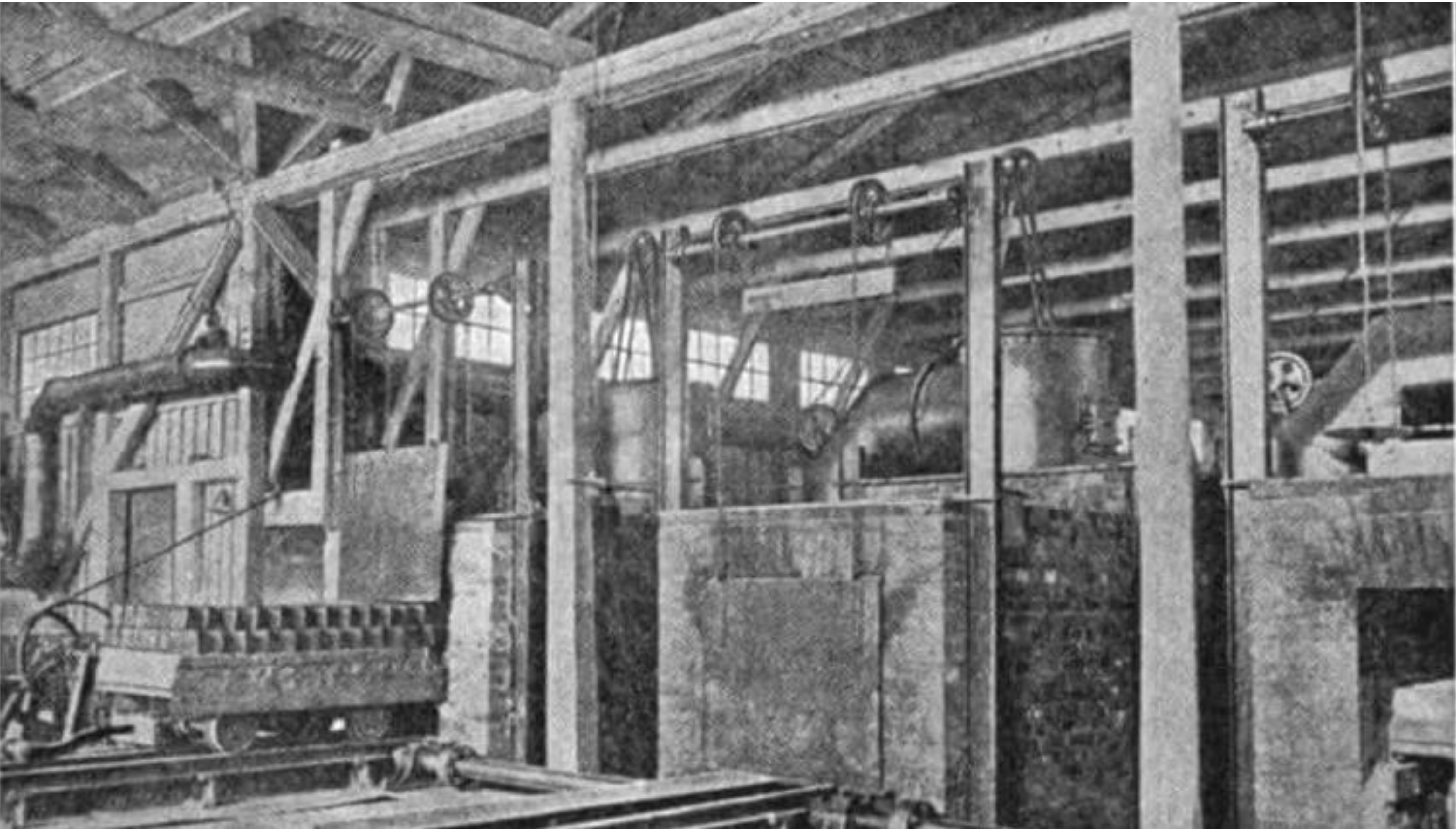
- The fine concentrate was pressed into briquettes **without the use of a binder material**, the moisture content in the concentrate was adjusted to obtain briquettes with strength enough to remove them from the press and load them on special carts for delivery to **Gröndahl kiln**.

- The necessity of burning briquettes to give them the strength required for blast-furnace smelting was due to several reasons:
  - Achieving the required mechanical strength without binder and roasting would require the application of ultrahigh pressures (over 200 MPa), which made it possible to obtain dense and durable briquettes, whose porosity, however, didn’t contributed to their reducibility;
  - Adding organic binders also did not solve the problem. Firstly, most of the known organic ligaments were very expensive, and secondly, when heated, the organic material burns out or undergoes pyrolysis, which negates its astringent effect. The use of inorganic ligaments, in addition to the effect of "dilution" - reducing the iron content in the charge, significantly affects the composition of iron and slag, increasing the yield of the latter.

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

- The **Gröndahl** kiln was in the form of a tunnel, with a track leading down the center and a combustion chamber in the middle. The air required for combustion enters the gas-tight platform at the feed end of the furnace, and, having passed the discharge end, returns above the platforms of the carts loaded with briquettes. The cold air circulating under the platform keeps the wheels and carriage frame cool, heats up as it simultaneously cools the baked briquettes and enters the combustion chamber hot; hot gases, in turn, heat the briquettes and cool themselves to exit the furnace.
- Such heat recovery increased the efficiency of the furnace. Coal consumption averaged 7% of the briquette mass, the main heat loss was associated with evaporation of water in briquettes. The temperature in the combustion chamber when burning gas reached **1300 ° or 1400 ° C**, and with this heating the particles were sintered enough to create a strong, solid briquette.
- It is important that during briquette roasting their **desulfurization** was achieved. The time spent on the operation depended on the type of ore and the required degree of desulfurization. When the total iron content in the ore is **38%**, it contained **68.3%** in the concentrate, and **68%** in the briquette. For sulfur content, these values were, respectively, **0.066%**, **0.026%** and **0.006%**.

History of Industrial Briquetting in Ferrous Metallurgy
(Beginning of the 20th century - the 20s of the 20th century)



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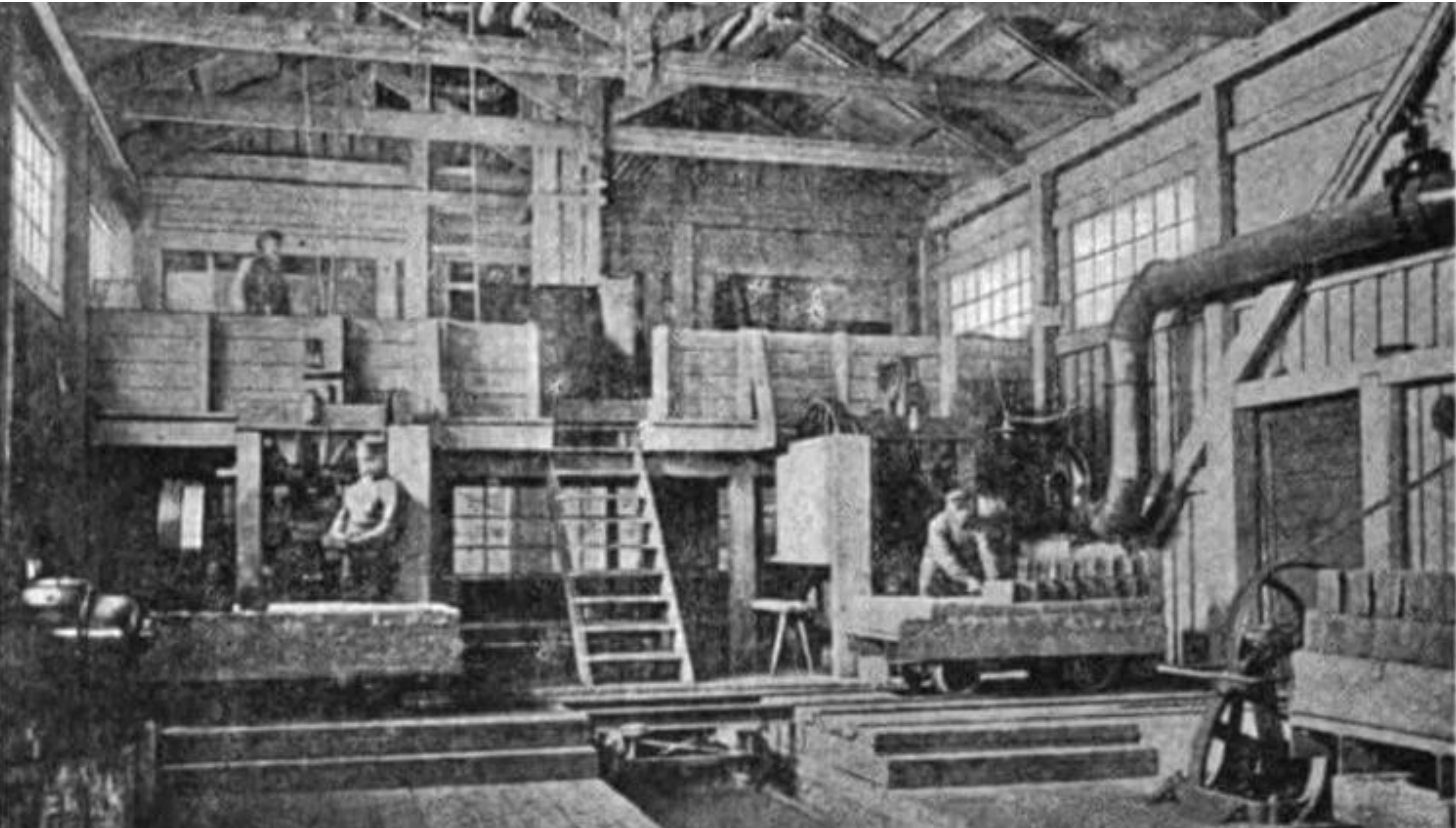
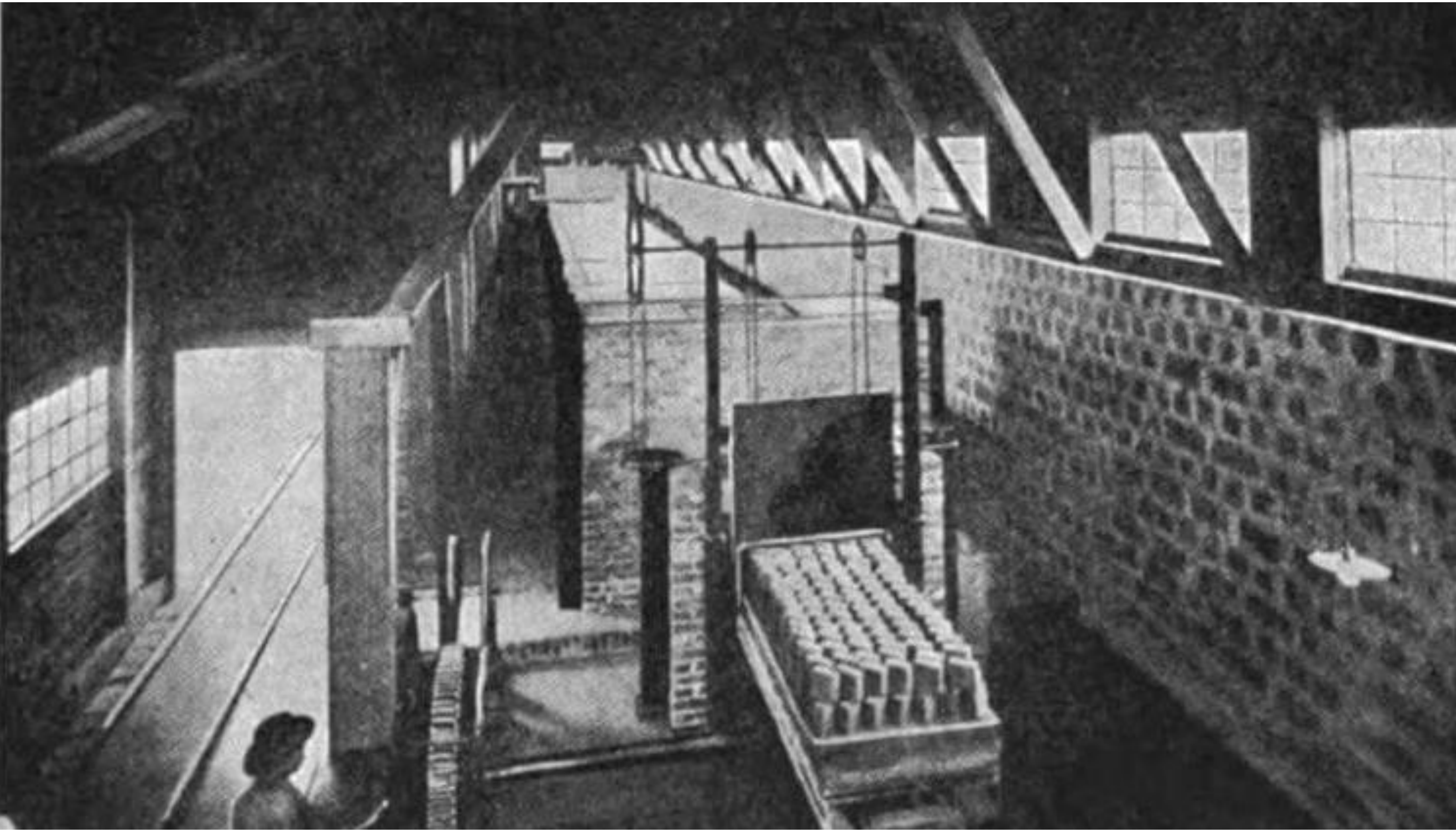


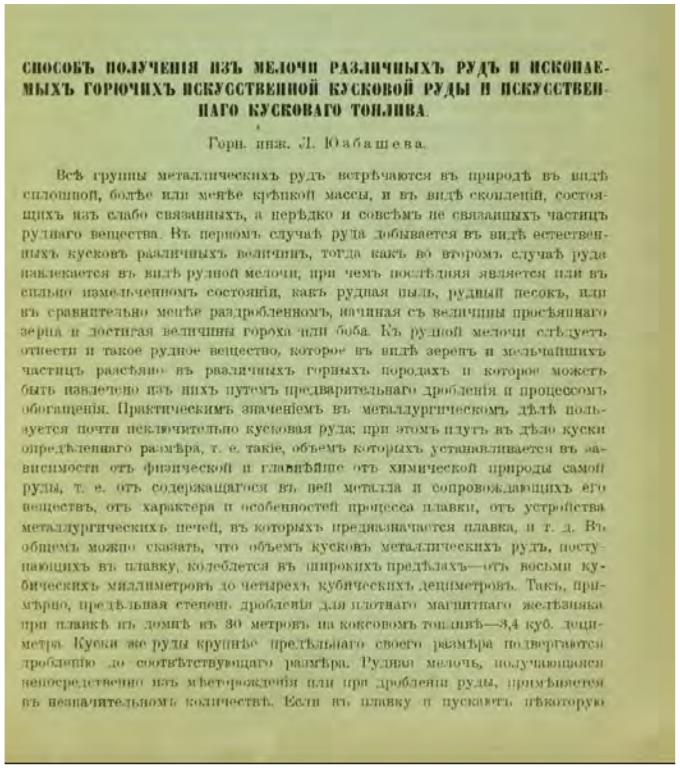
History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

- Briquettes were made using the Gröndahl technology and at a lower temperature due to the use of various binding materials. For example, in Pitkäranta (Finland), lime was used as a binder (3-5% of the mass of the briquette). After two weeks of curing, the briquettes were additionally heated to 800 ° C for subsequent hardening. At a briquette factory in Edison, USA, resinous substances were used as a binder. The cost of briquette at this factory was about 45 cents per ton. Interestingly, the equipment for iron ore dressing at this plant was designed by Thomas Edison himself.
- A factory with a capacity of 60 thousand tons of briquettes per year was soon built in Guldsmedshyttan. Factory staff was only 14 people.

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)



History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)



СПОСОБЪ ПОЛУЧЕНІЯ ИЗЪ МЕЛОЧИ РАЗЛИЧНЫХЪ РУДЪ И ИСКОПАЕМЫХЪ ГОРЮЧИХЪ ИСКУССТВЕННОЙ КУСКОВОЙ РУДЫ И ИСКУССТВЕННАГО КУСКОВАГО ТОПЛИВА.

Горн. инж. Л. Юзбашева.

Всѣ группы металлическихъ рудъ встрѣчаются въ природѣ въ видѣ сплошной, болѣе или менѣе крѣпкой массы, и въ видѣ скопленій, состоящихъ изъ слабо связанныхъ, а нерѣдко и совсѣмъ не связанныхъ частицъ руднаго вещества. Въ первомъ случаѣ руда добывается въ видѣ естественныхъ кусковъ различныхъ величинъ, тогда какъ во второмъ случаѣ руда извлекается въ видѣ рудной мелочи, при чемъ послѣдняя является или въ сильно измельченномъ состояніи, какъ рудная пыль, рудный песокъ, или въ сравнительно менѣе раздробленномъ, начиная съ величины просѣяннаго зерна и достигая величины гороха или боба. Къ рудной мелочи слѣдуетъ отнести и такое рудное вещество, которое въ видѣ зеренъ и мельчайшихъ частицъ разсѣяно въ различныхъ горныхъ породахъ и которое можетъ быть извлечено изъ нихъ путемъ предварительнаго дробленія и процессомъ обогащенія. Практическимъ значеніемъ въ металлургическомъ дѣлѣ пользуется почти исключительно кусковая руда; при этомъ идутъ въ дѣло куски опредѣленнаго размѣра, т. е. такіе, объемъ которыхъ устанавливается въ зависимости отъ физической и главнѣйше отъ химической природы самой руды, т. е. отъ содержащагося въ ней металла и сопровождающихъ его веществъ, отъ характера и особенностей процесса плавки, отъ устройства металлургическихъ печей, въ которыхъ предназначается плавка, и т. д. Въ общемъ можно сказать, что объемъ кусковъ металлическихъ рудъ, поступающихъ въ плавку, колеблется въ широкихъ предѣлахъ—отъ восьми кубическихъ миллиметровъ до четырехъ кубическихъ дециметровъ. Такъ, примѣрно, предѣльная степень дробленія для плотнаго магнитнаго желѣзняка при плавкѣ въ домнѣ въ 30 метровъ на коксовомъ топливѣ—3,4 куб. дециметра. Куски же руды крупнѣе предѣльнаго своего размѣра подвергаются дробленію до соотвѣтствующаго размѣра. Рудная мелочь, получающаяся непосредственно изъ мѣсторожденія или при дробленіи руды, примѣняется въ незначительномъ количествѣ. Если въ плавку и пускаютъ нѣкоторую

The operating experience of the first briquette factories showed that the potential for agglomeration without bonding materials is limited due to the insufficiently high strength of raw briquettes and the need for costly roasting. In **1901**, the Russian mining engineer **L. Yuzbashev** proposed to do without firing and use hydraulic cement as a binder for briquetting ore fines.

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

V. Schumacher’s Method (Autoclaving)

At the very beginning of the last century, V. Schumacher (Germany) proposed to use crushed quartz sand (1-5% by weight of the briquette) and quicklime (3-10% by weight of the briquette) as a binder. This powder was thoroughly mixed with ore after wetting, and then pressed at a pressure of 40-70 MPa. Briquettes were strengthened by steam treatment at a pressure of 1 MPa for 2-4 hours in an autoclave at a temperature of 174 ° C .

By the way, Schumacher is credited with the authorship of the very principle of autoclaving - the processing of the material at a pressure above atmospheric and at a temperature above 100 ° C. With this steaming, a new binder of calcium hydro silicates ($CaO \cdot SiO_2 \cdot nH_2O$) was formed, which was obtained by the reaction $Ca(OH)_2 + SiO_2 + (n-1) H_2O = CaO \cdot SiO_2 \cdot nH_2O$. The compressive strength of such briquettes reached a value of 10-13 MPa.

History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

- Thus, by the twenties of the last century, the achievement of the strength of briquettes required for smelting iron was mainly provided by firing or other temperature treatment (steaming), and the productivity of briquette factories was limited by the productivity of equipment used at that time to make bricks.
- The performance of such equipment did not meet the growing needs of blast-furnace production for agglomerated raw materials. Briquetting was quickly replaced by the sintering technology developed by that time. High performance and manufacturability of the process, the possibility of utilization in it of the inevitable in the smelting of iron and steel dispersed iron-containing materials, led to its rapid spread. Sintering practically supplanted briquetting from ferrous metallurgy. Thus, for example, by **1923** almost all the above-mentioned **Gröndahl briquette factories were replaced by sinter plants**.
- The use of roller presses for briquetting natural and anthropogenic raw materials that began in the 20s of the last century did not save the situation with briquetting. Roller briquettes at the beginning of the 20th century found sufficient application in low-shaft blast furnaces and in blast furnaces of small volume. Briquettes were made from iron ore fines, limestone and coke dust. In the blast furnaces of the Kushvinsky plant, the proportion of briquettes in the charge reached **25%**. Briquettes in the amount of up to 100 thousand tons per year were used in the charge of the Kerch blast furnace (the capacity of the briquette factory in 1915 was 35 thousand tons of briquettes) and Taganrog metallurgical plants (the capacity of the briquette factory in 1906 was 30 thousand tons of briquettes).

History of Industrial Briquetting in Ferrous Metallurgy
30-50s of the 20th century

Yarkho Method

- Another noteworthy attempt to carry out briquetting without firing was undertaken in 1936 at the Krivoy Rog briquette factory. Briquettes were made from ore fines of rich hematite ore. To the ore fines were added 5-10% of crushed iron shavings and 0.5-1.0% NaCl in the form of a solution, which accelerated the process of formation of iron oxide hydrates. Hardening briquettes was achieved as a result of corrosion and hydration of iron shavings.
- The hardening of briquettes for some ores was completed within a few hours after their production. For most ores, the curing period was **20–40 hours**. Briquettes did not need drying or firing.
- However, this generally successful method did not become a landmark in cold agglomeration. An obvious disadvantage of the method was the high cost of the additives used and the content of alkaline compounds made in this way, the briquettes of alkaline compounds, which are extremely undesirable.

History of Industrial Briquetting in Ferrous Metallurgy 30-50s of the 20th century
Yarkho Method for BOF Briquettes

- In 1957-1958, a series of full-scale testing with briquettes was carried out in Ukraine. Briquettes were made according to the method of Yarkho at the Krivoy Rog briquette factory.
- The composition of the mixture - iron ore concentrate, limestone, bauxite and iron shavings (0-3 mm). Raw briquettes gained strength during the week in a warmed warehouse. The supply of briquettes that gained strength was carried out along the path of bulk materials with the first addition of charge materials. Briquettes were also loaded into the BOF during purging. In total, over 100 heats were held. In the first 60 heats, the content of calcium oxide in briquettes was 21.5%, and the missing amount of fluxes was injected into the converter in the form of lime.
- The melts performed confirmed the possibility of using ore-limestone briquettes to control the temperature of the metal bath. The process with briquette was more intensive, but emissions were not observed. The slagging process has improved. For the next series of heats, the limestone content in briquettes was increased to 35.45% to achieve the required basicity ($CaO / SiO_2 = 10.74$).

History of Industrial Briquetting in Ferrous Metallurgy
30-50s of the 20th century
Averkiev and Udovenko Method

- In **1932**, Averkiev and Udovenko suggested to apply “liquid glass” - an aqueous alkaline solution of sodium silicates $Na_2O(SiO_2)_n$ – as the binder. Dissolved liquid glass was added to the briquetted ore, the wetted mass was thoroughly mixed and pressed. The consumption of liquid glass for briquetting, for example, flue dust was at least **15-18%** of the mass of the briquette.
- Compressed briquettes were dried and baked at **400–500 ° C**, after which they acquired good strength and water resistance.
- The disadvantages of the method were revealed already at the first experimental meltings. Briquettes could not withstand high temperatures, differed low porosity. Liquid glass product is very expensive, which, together with its substantial consumption, markedly reducing the iron content in the briquette, made such briquetting economically unjustified and technologically inefficient because it required additional flux consumption and increased the amount of slag in the blast furnace smelting.

History of Industrial Briquetting in Ferrous Metallurgy
30-50s of the 20th century
Fonyakov's Method

- A method that allowed a significant reduction in the consumption of liquid glass for briquetting was soon proposed by **A.P.Fonyakov**.
- The method was based on the binding properties of silicic acid gels of the general formula $nSiO_2 \bullet mH_2O$, which fall out of the liquid glass solution when treated with a weak solution of calcium chloride. To obtain such a gel, the ore was processed, before pressing, in succession with two solutions — first with a 1-2% solution of liquid glass, then with a 1.5-2% solution of calcium chloride, and then pressed.
- Freshly formed briquettes were dried and then burned at a temperature of **500–600 ° C** to dehydrate the resulting silica gel. The finished briquettes had high strength (**18-22 MPa**), porosity up to 21% and met the requirements for BF briquettes. The consumption of liquid glass in terms of the SiO_2 content decreased markedly (to 1.0-2.5%), but this decrease was compensated for by the need for costly roasting. And this method is not widespread too.

History of Industrial Briquetting. 60-70s of the 20th century

- Interest in briquetting resumed in the 60–70s. of the last century due to the complicated environmental situation in the areas of metallurgical production, associated mainly with harmful emissions from sinter plants.
- In the 1960s – 1970s, briquette factories at the Alchevsk and Magnitogorsk plants and the KMAruda plant were also commissioned.
- In 1961, the Donetsk Briquette Factory was built in the city of Donetsk (Ukraine).
- At Magnitogorsk Metallurgical Plant, mill scale was briquetted along with lime using a roller press, and the resulting briquettes were **dried in a tunnel kiln**.
- At the KMAruda combine, magnetite concentrate (Fe-59.68%, SiO_2 - 5.5-14.0%) was briquetted together with quicklime. Raw briquettes were **autoclaved** at a pressure of 8 atm. and a temperature of **174 ° C**.

History of Industrial Briquetting. 60-70s of the 20th century
Weber’s Method

- In the second half of the twentieth century, several experimental and industrial briquetting units for ore-fuel charges according to the Weber method were operating in the FRG.
- Ore fines mixed with carbonaceous reducing agent (high-volatile coal and tar) and a binder (sulphite-alcohol stillage concentrate - 5%, hydrogenated coal tar or acetylene sludge - more than 20%) are mixed and briquetted in a roll press (**20–70 MPa**). Raw briquettes were dried at **250 ° C**, and then subjected to semi-coking for one hour in retorts of the Humboldt company, where sand with a temperature of **700–800 ° C** was used as a heat carrier. Briquettes were used to smelt iron in low-shaft furnaces with a capacity of up to 120 tons per day.
- The production of ore-fuel briquettes became widespread in the GDR. At the Max Hutte enterprise, briquettes were produced from fines of poor iron ore (53% of the mass of the briquette, fraction 0-2 mm, total iron content from 23 to 33%) with the addition of coke breeze (5% of the mass of briquette, 0-2 mm). Acetylene silt (42% of the mass of the briquette) was used as a binder, which also served as a fluxing additive. Briquettes were made with a roller press with a pressure of 50-70 MPa. Raw briquettes were **carbonized** by blowing off the exhaust gases from the Cowper of blast furnace at a temperature of **120–150 ° C** for 30– 120 min. The compressive strength of briquettes increased from 6-9 MPa to 15-17 MPa after such processing.

History of Industrial Briquetting. 60-70s of the 20th century Carbonization

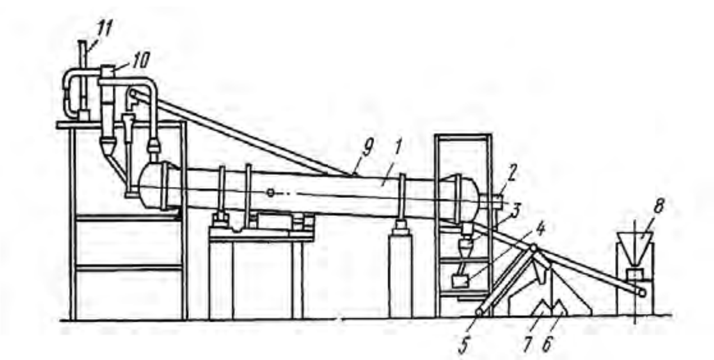
- The essence of the carbonization process as applied to briquetting is that calcium hydroxide (Ca (OH)2), the basic mineral of slaked lime, loses crystalline moisture when heated to **530-580 ° C**, as a result of which the binding properties are lost, and the briquettes lose strength. Carbonization proceeding according to the scheme:

$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$.

leads to the formation of secondary limestone, which is characterized by a dissociation temperature in the range of **860–920 ° C**, which determines the higher strength of the briquettes.

- Air carbonization is an extremely slow process and may require briquettes from a week to a month or more to achieve the required strengths. To accelerate the carbonization process, the **Weiss** method is used, which consists in a two-stage treatment of briquettes with carbon dioxide under pressure. At the first stage, briquettes are treated with cold gas, and at the second stage, heated to a temperature of **90-100 °**

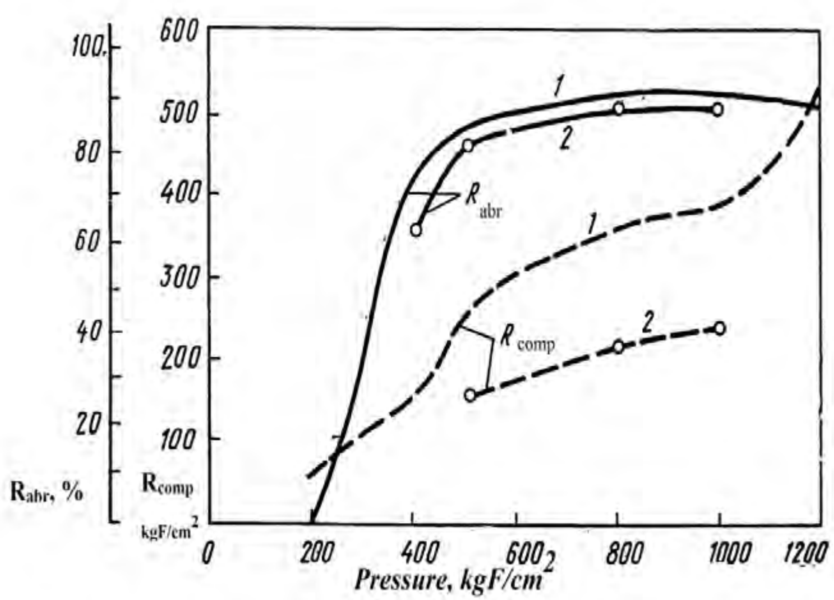
History of Industrial Briquetting. 60-70s of the 20th century. Hot briquetting



(1 - rotary kiln, 2 - burner, 3 - intermediate bunker, 4 - roll press, 5 - elevator, 6 - briquettes, 7 - screening of briquettes, 8 - iron ore bunker, 9 - secondary air supply, 10 - cyclone, 11 - exhaust pipe)

- One of the first successful projects of hot briquetting, was implemented in the UK in the mid-60s.
- In a blast furnace with a volume of 1798 m3, briquettes were used, which were made of iron ore concentrate by hot briquetting on a semi-industrial plant.
- The hot briquetting unit was located at the Steel of Wales company (now **Tata Steel**) in Port Talbot. It consisted of a rotary metallization furnace with a length of 25.6 meters and a roller press.
- The share of briquettes in the blast furnace charge was **25%**. The total number of the melted briquettes was 12 thousand tons. The operation of a large blast furnace did not deteriorate with the introduction of briquettes into the mixture.
- However, coke consumption in the experimental period increased and amounted to **567 kg per ton of pig iron versus 547 kg** when operating without briquettes. Iron smelting also decreased from 2281 tons per day when operating without briquettes to 2234 tons with 25% of briquettes in the charge.

History of Industrial Briquetting. 60-70s of the 20th century. Thermal briquetting



Influence of pressure on the mechanical strength of thermal briquettes (1 - briquettes with peat, 2 - briquettes with coal, R_{abr}- abrasion resistance, R_{comp} - compressive strength).

- The basis of the method known from the practice of continuous coking is the formation of a solid from coal of plastic mass upon reaching a certain temperature level. For example, hard coal is plasticized at **350-460 ° C**, peat - at **300-400 ° C**.
- Iron ore concentrates were used with an iron content of 65-68% and mixed with peat or black coal. The prepared mixtures, with or without addition of fluxes (from 5 to 15% hydrated and quicklime), were heated in electric molds to **300-430 ° C**.
- The quality of thermo-briquettes was mainly influenced by their fuel component. The chemical composition of iron ore concentrates practically did not affect the quality of thermal briquettes. An increase in the pressing pressure from **20 to 120 MPa** led to a noticeable increase in compressive strength and a less pronounced increase in abrasion strength.

History of Industrial Briquetting. 60-70s of the 20th century.
Ferro Alloys production

- The first industrial experience of using briquettes based on manganese ore concentrates in the charge of the ore-smelting furnace was obtained in **1961**: 160 t of roll briquettes made of manganese ore concentrate (30.9% Mn; 4% Fe; 0577% P; 26, 95% SiO_2; P / Mn = 0.0018; 0.33% S; 1.9% CaO; 4.05% BaO) were used in the charge in a 2500-kVA furnace of the Zestafoni Ferroalloy Plant. The results of the heats showed that this type of charge component is quite effective.
- In **1966**, pilot-industrial studies on the smelting of ferrosilicon manganese in industrial ore-smelting furnaces were carried out at the same plant using ore briquettes of manganese concentrate from the Chiatura deposit. For industrial experiments, briquettes were obtained on a roller press with a capacity of **5 tons per hour** from ore with a particle size of 5–0 mm on a binder of sulphite-alcohol bards (SAB) with a density of 1.2 g /cm3.
- Heat treatment required because the binding properties of SAB are caused by polymerization, leading to the formation of long chains of molecules in the body of the briquette. The polymerization reaction in the presence of manganese is most fully realized at temperatures of **160-180 ° C**. For iron ore briquettes, the polymerization temperature reaches **200 ° C**. Thus, the achievement of the required strength values of briquettes required their drying at temperatures of **50-300 ° C**.
- On the charge with ore briquettes, silicomanganese was smelted in a three-phase open ferroalloy furnace with a capacity of 16.5 MVA. The furnace worked normally and stably, the gas permeability of the charge was good, the flame was distributed evenly throughout the furnace. After 112 hours of experimental melting, it was concluded that sufficiently strong briquettes can be obtained from manganese ore of this size suitable for use in the mixture of ferroalloy furnaces. When working on ore briquettes, the furnace productivity increases, the power consumption is reduced, the reducing agent consumption is reduced.

History of Industrial Briquetting. 60-70s of the 20th century.
Ferro Alloys production

- In **1970** at **Nikopol Ferroalloys Plan**t (Ukraine) for briquetting the mixture of concentrates of a fraction of 10–0 mm was ground to a size of **3–0 mm**. Briquettes were made on a semi-industrial roller press at a pressure of 500 kg/cm2, the binder was a mixture of **bitumen, fuel oil and SAB** in an amount of **10%** by weight of the charge. The mixture was prepared in tanks with steam heated (to activate the polymerization of the SAB).
- Briquettes of two compositions were prepared and melted:
  - with an **excess of reducing agent** (coal) in the amount of 50%, introduced to create a skeleton in the briquette and increase its strength (mixture of concentrates - 54.5%, river sand - 9.1%, coal - 27 , 3%, a mixture of bitumen and fuel oil — 3.6%, SAB — 5.5%),
  - with a **stoichiometric amount** of reducing agent necessary to reduce silicon and manganese (a mixture of concentrates –60.6%, river sand — 10.1% , coal - 20.2%, a mixture of bitumen and fuel oil - 3.6%, SAB - 5.5%). Laboratory tests showed that the physical properties of raw briquettes were superior to those for baked briquettes, so they refused to burn the briquettes. The values of mechanical strength and heat resistance were higher for raw briquettes.

History of Industrial Briquetting. 60-70s of the 20th century.
Ferro Alloys production

- Commodity silicomanganese was decided to be smelted on raw briquettes.
- Semi-industrial smelting on briquettes of the above composition and on sinter was carried out in a three-phase open ore recovery furnace with a capacity of 1.2 MVA.
- Briquettes with **an excess of reducing agent** had a high electrical conductivity and when penetrating they gave a significant increase in the current load, which led to the rise of the electrodes and the opening of the top. To eliminate this phenomenon, 10% of manganese concentrate was added to the briquette sample. In this way, 14 tons of briquettes with an excess of reducing agent, 1.2 tons of concentrate and 200 kg of dolomite were melted.
- The smelting of silicomanganese on briquettes containing a **stoichiometric amount of reducing agent**, took place without any complications. The load was steady;
- Comparative analysis of different charges (briquettes, sinter) showed that smelting of silico-manganese on **briquettes should be preferred to smelting on sinter**.

History of Industrial Briquetting. 60-70s of the 20th century. Ferro Alloys production

- The results of the pilot heats formed the basis for the construction and commissioning in **1976** of a briquette factory at the site of the Zestafoni Ferroalloy Plant.
- Manganese ore briquettes with the addition of gas cleaning dust and without it were produced by roller presses of **Sahut Conreur** (France). However, this first industrial experience was unsuccessful. Due to the increased wear of the sleeves of roller presses, their high cost and the impossibility of their independent production, this briquette factory was closed.
- Briquetted charge was used for smelting ferrosilicon. At the Zaporizhia plant of ferroalloys briquetted sand, coking coal and iron ore concentrate. The mixture was heated and stirred in a steam mixer and then pressed with a roller press. Raw briquettes were burned at a temperature of **600-800 °** C for 10-13 hours to achieve a reduction degree of 70-80%. The smelting of ferrosilicon on the briquetted charge was carried out in a 3.5 MVA furnace.
- Briquettes were also used for smelting carbon black ferrochrome and ferrosilicochrome, ferromanganese. When working on briquettes, the furnace productivity increased, the power and reducing agent consumptions decreased. The smelting of ferroalloys from briquetted charge became widespread in the United States, France, Japan and Germany.

History of Industrial Briquetting.60-70s of the 20th century. Summary

- Summarizing the contribution of the 60-70s to the development of briquetting technology, it can be said that **heat treatment** of the charge or raw briquettes (in one form or another) remained in most of the implemented projects of briquette factories as a mandatory component of briquetting.

- The use of roller briquettes in blast furnace production did not lead to an increase in the scale of the industrial use of this technology in the iron and steel industry. The main reason for the low competitiveness of briquetting in those years was the **low productivity of roller presses** compared to the performance of sintering (1500–10000 tons per day) and indurating machines (2500–9000 tons per day).

- In the ferroalloy sub-industry, where the requirements for productivity and for the strength of briquettes are much lower than in the blast furnace production, an increase in briquette production was observed. As a result, by the mid-70s, the production of briquettes was already about 2% of the total agglomeration in ferrous metallurgy.

History of Industrial Briquetting. 80s - the end of the 20th century

- In the last two decades of the last century, one of the main incentives for the development of briquetting technology was still the difficult **environmental situation** in the regions where metallurgical plants are located, primarily due to harmful emissions from sinter plants (more than 50% of all harmful emissions).
- In addition, it turned out that not all types of fine technogenic materials of ferrous metallurgy can be considered as a full-fledged charge material for sinter production. First, this applies to BF and BOF sludge. The presence of zinc and lead in such materials prevents their use in agglomeration. The use of dusts and sludge from electric furnaces to produce sinter also poses serious difficulties due to fluctuations in the chemical composition of such materials, high dispersion, low iron content, the presence of non-ferrous metals, etc.
- The “capricious” charge for agglomeration is also the **flue dust** due to its poor lumpiness due to the presence of carbon in its composition. Much of the flue dust is carried away with sinter gases and re-passes to the sludge.
- A similar problem turned out to be relevant for another sintering technology - pellet production. Metallurgists are faced with the need to utilize fines of pellets. This problem was faced by metallurgists in Sweden, where by the end of the last century blast furnaces worked exclusively on pellets. The last Swedish sinter plant ceased to exist in **1995**.

History of Industrial Briquetting. 80s - the end of the 20th century

- The limited or inability to use the above materials for sinter production, the accumulation of reserves of iron-rich pellet fines together with the increased cost of waste disposal (up to **$10–15 per ton of waste**) in the early 90s justified efforts to find effective methods of briquetting such materials.
- Briquetting was destined to become recycling technology - the “assistant” of sintering and pellet production. The search for ways of recycling of zinc-containing materials and pellets fines led to the emergence in the arsenal of briquetting a new method of forming briquettes - **vibropressing**.
- In **1988**, the first vibropress briquette factory with a capacity of **110 thousand tons** of briquettes for ferrochrome smelting was built at Vargön Alloys in Sweden.
- Since **1991**, this method of briquetting has been used in France by Eurometa SA for the agglomeration of the ferroalloys fines. Briquettes from screenings of ferroalloys were used in the foundry business.
- According to this method, briquettes are produced at low pressures (**0.02–0.1 MPa**) and simultaneous exposure of the compression mixture to vibration (frequency **30–70 Hz**, amplitude 0.2–0.6 mm). The manufacturing cycle lasts no more than **30 seconds**. Cement was used as the only binder.

History of Industrial Briquetting. 80s - the end of the 20th century

- In Germany, the technology for utilizing zinc-containing dusts and sludge from sintering, blast-furnace and steel-making industries with a high zinc content known as **"Oxy-Cup"** was developed which is bade on f vibropressing to produce carbon-containing self-reducing briquettes (C-Brick).
- The components of the briquette were dust and sludge from the blast-furnace production, converter and electric-smelting production, oily mill scale, magnetic slag fractions after desulfurization, and other iron-containing materials. Carbon-containing components - coal, coking, anthracite, petroleum coke.
- Briquettes mixed with large-sized (up to 1 m in diameter) metallurgical slag scrap were then melted in a special cupola operating on an oxygen-rich blast. The share of briquettes in the cupola charge is up to **70%**.
- In **1999**, a pilot cupola with a capacity of **210 thousand tons** per year was built in Duisburg (Germany).
- The satisfactory metallurgical properties of the briquettes produced by this new method contributed significantly to the commercial success of the Oxy-Cup process, which today is rightly regarded as providing a solution to the problem of recycling zinc-containing dusts and sludge. In the period from **2005 to 2011**, 6 Oxy-Cup process furnaces with briquette factories were built in the world (three each in Japan and in China).
- However, the high cost of the main equipment and engineering of Oxy-Cup and the insufficiently high performance of the vibropress (up to 20 tons per hour) restrain its further wide distribution.

History of Industrial Briquetting
80s - the end of the 20th century

- One of the first industrial briquette lines of vibropressing was put into operation at the SSAB plant in Oxelösund (Sweden) in **1995**.
- Briquettes **60x60 mm** in size, hexagonal in cross-section, are used as a component of the blast furnace charge (**60–100 kg** of briquettes per ton of iron. The limitation for the proportion of briquettes in the blast furnace blast furnaces of SSAB is the zinc content in the sludge.
- The composition of the briquette is 25% top dust, 50% mixture of scrap metal, desulfurization scrap, converter sludge, pellet screening and 5-8% aspiration dust. Binder - Portland cement (10–12%), moisture content of briquettes 5–8%.
- The particle size of the briquetted mixture is 0–5 mm.

History of Industrial Briquetting. 80s - the end of the 20th century

- The most important event of the last two decades of the last century in briquetting was the entry into the market of companies specialized in providing briquetting services for ferrous metallurgy materials on a so-called "give-and-take" basis, when briquettes are made by the manufacturer at their own expense from the raw materials provided by the metallurgical enterprise .
- The pioneer of such a business in briquetting was the company NRS (National Recovery System, USA), which in the early 70s began to search for a solution to the problems of utilization of oxide materials of ferrous metallurgy by briquetting. Several formulations of briquetted fluxing additives and briquettes from screenings and mill scale were added by adding scrap as an alternative to scrap and a method for processing the accumulated stocks of materials with high iron content.
- These briquettes began to be widely used in the US recycling practice in the 90s of the last century. Since the end of the 80s, the NRS has been looking for efficient and inexpensive binders for briquetting in blast furnaces. The combined binder of molasses and non-gypsum cement, for which the patent was obtained, was used in the production of 15,000 tons of experimental blast-furnace briquettes for smelting on blast furnace No. 8 by US Steel at Gary Works. To achieve the required hot strength in blast furnace smelting, from **14 to 19.5%** (mass.) of such a binder was added. For the composition consisting of mill scale (41%), steelmaking slag (19%) and top dust (40%), 11.5% of cement and 8% molasses were required, which considerably diluted the mixture.

History of Industrial Briquetting. 80s - the end of the 20th century

- The briquetted charge had to be dried to a moisture content of **3%**, since it is impossible to form a wet mass using a roll press. Cold strength of briquettes (ISO 3271-1985 E) was not less than **70%**
- The share of briquettes in the blast furnace charge reached **10%**. This level was quite enough for recycling anthropogenic materials.
- The success of the pilot campaign allowed the NRS to build four briquette factories in the USA and one in the UK at the Port Talbot. In early 1993, US Steel began working at the Edgar Thomson plant, the Bethlehem Steel company in Pennsylvania, and the Inland Steel Company. The fourth factory in the United States began operations in 1996 at the National Steel Corporation's plant. In 1997, she earned a factory in the UK.
- Briquette factory at Edgar Thomson's US Steel plant was designed to produce **200 thousand to**ns of briquettes per year. Productivity of the pressing equipment is **40 tons** of briquettes per hour.
- A patented composition of molasses and cement was used as a binder and it caused the smells emanating from the blast furnace gas cleaning system because of a protein that got into the system with molasses. It was decided to switch to a purely inorganic binder, as a result of which odors ceased.
- By **1998**, up to **10%** of briquettes were used in the blast furnace charge. For the converter briquettes, a combined binder from a mixture of lime and molasses was also used, but no odor problems were noted.

History of Industrial Briquetting
80s - the end of the 20th century

- In **1993**, the Bethlehem Steel commissioned a briquetting line based on **stiff vacuum extrusion** (SVE), a technology widely used in the United States to produce bricks. The factory was intended for the agglomeration of converter dust.
- Briquettes were used as a component of the blast furnace charge. The capacity of the line is **100 thousand tons** of briquettes per year. The performance of the extruder supplied by J.C.Steele and Sons reached **20 tons per hour**. Cement was used as a binder.
- The cost of manufacturing ton of briquettes ranged from **11 to 14 US dollars**. In total, the line produced about 70 thousand tons of briquettes and was dismantled in 1996 after the liquidation of Bethlehem Steel.
- Disputes about the feasibility of liquidating the company have not ceased so far, and the blast furnace shop where the extrusion line was located is a gloomy monument to the once successful enterprise.
- The equipment of this line **still functions** as part of a Texas Industries briquette plant.

History of Industrial Briquetting
80s - the end of the 20th century

In **1996,** one of the largest briquette factories in the history for production of extruded briquettes from laterite nickel ore fines and gas cleaning dust of electric furnaces with a capacity of **700 thousand tons** of briquettes per year (three extruders Steele-90) was put into operation in Colombia at the ferronickel production plant.

A characteristic feature of the process is the possibility of obtaining solid briquettes without a binder. The main equipment of extrusion lines has been operating for **23 years** without replacement.

History of Industrial Briquetting. 80s - the end of the 20th century

- Important results were obtained in the process of developing and commercializing technologies for producing dust briquettes and smelting manganese ferroalloys from them at the Zestafoni ferroalloy plant.
- It has been established that to obtain mechanically strong briquettes (specific crushing force of **8–12 MPa**), the optimum briquetting parameters are: moisture content of the charge 4–6%, binder content (SAB) **6–8%**, amount of the fine component (**dust, sludge**) **30%** and minimum pressure of **19.6 MPa**.
- The comparative kinetics of the reduction of sludge-dust briquettes and manganese sinter was investigated. It was found that briquettes gave the greatest degrees of reduction at different temperatures. The results of high-carbon ferromanganese heats showed that the capacity of the furnace in the case of using briquettes increased from **73.33 to 75.67 tons / day**, and the specific consumption of electricity decreased by **90 kWh/ton**.
- Coke consumption decreased by **34 kg/ton**. For ore briquettes with SAB, the softening interval, according to the authors, is **750–850 ° C**.
- An important task was the development of current-resistant briquettes that would not be destroyed at the furnace top since cause of the destruction of briquettes of a mono charge can be a high current density. With an increase in the content of carbonaceous reducing agent in a briquette, the permissible critical current density also increases. For example, with an increase in the content of coal in a briquette from 10 to 35%, the critical current density increased from 2.15 to 14.6 A/sq.cm.

History of Industrial Briquetting. 80s - the end of the 20th century

- An equally important event in the history of briquetting in the ferroalloy industry is the development of technology for smelting low-phosphorous carbon ferromanganese with 100% briquetted charge.
- In 1987 in the USSR under the leadership of Victor Dashevsky an experimental and field test of such a technology was carried out in the conditions of the Nikopol Ferroalloy Plant in comparison with traditional technology. As a melting unit, a three-phase 3600 kVA ore-thermal furnace with coal lining was used.
- The essence of the technology was the smelting of carbon ferromanganese with the required low phosphorus content by the flux-free method on a charge, the ore part of which, in addition to graphite concentrate, contains a concentrate obtained by chemical enrichment of sludges. The low phosphorus manganese slag obtained by smelting carbon ferromanganese by the flux-free method is used as a feedstock for the smelting of low phosphorous silicomanganese, refined ferromanganese, and metallic manganese.
- An analysis of the results of experimental smelting of 100% briquettes showed that the briquetted mixture provided an economically acceptable solution to the problem of smelting high-quality ferromanganese from high-phosphorous manganese ores.

History of Industrial Briquetting. 80s - the end of the 20th century

Parameter	Traditional Technology	Briquetted Charge
Mass Share in Metal, %		
Mn	78,10	80,55
C	5,26	5,24
Si	3,34	1,37
P	0,140	0,053
S	0,013	0,019
Mass Share in Slag, %		
Mn	11,66	40,16
SiO_2	33.01	25,26
CaO	39,70	15,90
Slag Basicity CaO/ SiO_2	1,20	0,63
Slag Ratio	2,21	1,15
Mn Distribution,%		
in metal	65,75	55,38
in slag	21,77	32,88
loss	12,48	11,74
Useful Mn Utilization,%	65,75	88,26
Capacity, b.t per day	4,10	6,44
Specific Power Consumption, kWh/b.t	5556,5	3485,5

History of Industrial Briquetting. 80s - the end of the 20th century. Summary

- By the end of the last century, the main competing industrial technologies of briquetting were defined: **roll briquetting, vibropressing and stiff extrusion**.
- The market of manufacturers of equipment and services of briquetting has been formed.
- Briquetting has become firmly established in all branches of the steel industry.
- The success of technological developments was largely ensured by specialized scientific institutions (universities and laboratories).
- The role and importance of the **Institute for Briquetting and Agglomeration** (IBA) has increased, which contributed to bringing together the efforts of scientists, metallurgists, equipment manufacturers.

History of Industrial Briquetting. Nowadays

- NRS continued to dominate the briquetting market. In 2004, another factory was built in the United States at the site of AK Steel, and since December 29, 2005, the NRS became a structural unit of **Harsco Metals**.
- By 2011, Harsco Metals already owned a dozen briquette factories around the world. Without exception, briquette factories used to produce briquettes roller pressing.
- Seven briquette factories, of which five with the capacity from 150 to 250 thousand tons of briquettes a year, worked in North America at the sites of the company's customers and two more with a capacity of 100 thousand tons of briquettes per year were located at the sites of Harsco Minerals. Several briquette factories operated in Europe and in Asia
- Briquettes were used in the charge of blast furnaces and oxygen converters. BF briquettes were produced in five factories. Briquette charge included mill scale, blast furnace and converter sludge, bag filter dust.
- The share of briquettes in the blast furnace charge averaged from **3% to 6%** (the maximum value is 12%).
- The share of briquettes in the charge of BOF is 1%.
- The briquette factory in Ugine (France) produced 10 thousand tons of mill-scale briquettes and aspiration dust for arc steel-smelting furnaces.

History of Industrial Briquetting. Nowadays

- The business of Harsco Metals was promoted by the changed prices for charge materials. When comparing the prices of coke and iron ore fines in the late 80s and by 2011, it was clear that the briquette began to be a **valuable component of the charge of metallurgical aggregates**, and not just a means of recycling waste materials. The cost of coke breeze increased over this period from **45-60 to 350-400 US dollars per ton** (almost 8 times), the cost of iron ore fines - from **20-25 to 170-180 US dollars per ton** (more than 7 times), while the cost of waste disposal increased from **10-15 to 30-35 US dollars per ton** (twice). The total volume of briquettes produced by Harsco Metals exceeded **1.5 million tons per year in 2011.**
- In 2010, the company tried to enter the market of briquetting services in Russia. It was planned to carry out a project to produce almost 800 thousand tons of briquettes for blast furnaces from a mixture containing top dust, aspiration dust, converter and blast furnace sludge and sinter fines. A mixture containing additives developed by Harsco Metals was recommended as a binder (the composition was not disclosed). The proportion of binder in the briquette mass exceeded **17%**, which would lead to a substantial “dilution” of the blast furnace charge. This project was never implemented.
- A similar picture began to take shape at other briquette factories of the company, which led to the fact that Harsco Metals completely ceased production of blast briquettes, and the production of briquettes for converters was preserved only in the factories in Fort sur Mer (France) and in both factories in Great Britain. The Harsco Metals briquette factory in Kosice (Slovakia) changed owners in 2015 and is currently manufactured by the Phoenix Services service company.
- Thus, roller compaction was almost completely superseded from the BF segment of the briquetting market.

History of Industrial Briquetting. Nowadays

- Nowadays, one more application of roller briquetting is the agglomeration of dispersed oxide and metallized materials of DRI production processes.

- In 2002, POSCO launched a rolling briquette factory to produce 500 thousand tons of briquettes per year from coal fines as a replacement for expensive coking coal in the FINEX process.

- In 2011, a roller briquette factory was built in Brazil as part of an industrial demonstration plant operating according to the **Tecnored** process. Briquettes are used as an alternative to unburned pellets. In 2015, the plant successfully reached a design capacity of 75 thousand tons of pig iron per year.

- In 2016, Qatar Steel put into operation a roller factory equipped with a South Korean roller-press (Jeil) to agglomerate metallized dusts and sludges formed during the direct production of iron in the Midrex reactor. By 2018, the factory produced 200 thousand tons of briquettes, which were successfully smelted in the company's electric furnaces.

History of Industrial Briquetting. Nowadays

- Primetals completed a series of studies that confirmed the viability of using roller briquettes as components of the Midrex process charge and in 2015 announced plans to build a briquette factory in Corpus Christi (Texas, USA) as part of a direct reduction reactor construction project (Midrex). The factory, commissioned in 2016, produces 160 thousand tons of briquettes from dust, sludge and pellet fines per year.
- Emirates Steel has announced the construction of a mill to produce briquettes from metallized and oxide materials generated in the Midrex process. Briquetting services will be provided by Phoenix Services.
- Another interesting application of roller briquetting is associated with the **PIZO (Pig Iron Zinc Oxide)** process developed by Heritage Technology Group, in which briquettes from a mixture of electric furnace dust and carbon were melted in induction furnaces. A pilot plant was built at the site of the Nucor plant in Blytheville (USA). The briquettes are fed into the molten iron bath, in which the reduction of iron oxides by the carbon of the briquettes takes place. Volatile metal oxides (zinc, lead, cadmium, etc.), evaporate at the operating temperature of the furnace (**1300-1500 ° C**) and are collected by bag filters. The zinc-rich material obtained in this way can then be used as a raw material in zinc plants. The zinc content in this material reaches 67%. Commodity products of the PIZO process are, in addition, cast iron and slag. Since the construction of the pilot plant in 2006, neither the technology developer company nor the customer have announced a transition to the full-scale project stage.

History of Industrial Briquetting. Nowadays

- For briquetting in iron metallurgy, until 2011 the lion's share of blast-furnace briquettes was produced by the method of vibropressing.
- In Russia, the first vibropressing factory was commissioned at the enterprise OJSC Tulachermet in 2003. (8,000 tons of briquettes per month). Briquettes of two types were produced and used as a component of the blast furnace charge: iron-carbon-containing (3 compositions) and flushing (2 compositions). The design strength of compression briquettes should have been at least **6.0 MPa**. After drying, its values were **3.83 MPa**, after **heat and humidity treatment - 6.9 MPa**.
- In total, over 52 thousand tons of briquettes (about 50 thousand tons of iron-carbon containing and 2700 tons of washing briquettes) were produced during the existence of the line. The maximum values of briquette expenses were - for BF № 1 - **32 kg/t** of pig iron, for BF № 2 - **56 kg/t** of pig iron.
- The consumption of dry skip coke decreased by **14.4 kg / t** of pig iron, which corresponded to the coke-fines replacement rate of coke breeze in the briquette 1 kg / kg.
- After two years of operation, the briquette factory ceased to exist due to changes in economic conditions that affected the availability of carbon-containing materials suitable for briquetting (coke breeze of the required particle size distribution).

History of Industrial Briquetting. Nowadays

- A series of campaigns on the use of vibropressed briquettes of different component composition on a cement bond in a **1000 m^3** blast furnace charge was carried out in **2003 at NLMK**.
- At the first stage a batch (2500 tons) of briquettes (65% converter sludge, 20% coke breeze and 15% Portland cement) was smelted. Briquette consumption ranged from **50–70 kg/t** of hot metal in the first 5 days to **190 kg/t** of hot metal in the last 24 hours and averaged **121 kg/t** of hot metal.
- At the second stage, a batch of 2475 tons of briquettes made of a mixture of iron ore concentrate, coke breeze and Portland cement was smelted, with a gradual increase in the share of briquettes in the charge (**122, 198, 303 kg/ton of hot metal**). The results of the heats confirmed that such briquettes are a complete self-reducing component of the blast furnace charge, the use of which ensures a reduction in coke consumption in the blast furnace smelting, proportional to their consumption. The share of such a component in the blast furnace charge is only marginally limited to a decrease in the furnace productivity due to a decrease in the iron content in the charge and can reach 50% or more.

History of Industrial Briquetting. Nowadays

- At the third stage, a batch (2560 tons) of vibropressed briquettes from a mixture of blast-furnace sludge (59%), mill scale (20%), coke breeze (10%) and cement (11%) were smelted in a blast furnace of **2000 m^3**. When unloading briquettes from bunkers, their increased bridging was observed. The average consumption of briquettes for the period amounted to **62 kg/t** of hot metal, with fluctuations in days from 36 kg / t of iron to 81 kg / t of hot metal.
- According to the results of the campaigns, the following main conclusions were made:
  - vibropressing can provide the required values of the strength values of the briquettes from oxide technogenic and natural iron-containing materials for compression when using a cement bond with a content of at least **10–12%** by weight of the briquette.
  - for most briquettes, the value of compressive strength was not less than **30 kgF/cm^2** and ensured their safety during handling and transportation with fines output (-10 mm) no more than 5–7%.

History of Industrial Briquetting. Nowadays

Currently, commissioning of the NLMK stiff extrusion briquette factory with a capacity of 700 thousand tons per year of blast furnace briquettes is underway.

History of Industrial Briquetting. Nowadays

- In 2010, the Kosaya Gora Iron Works commissioned a vibropressing factory with an annual capacity of 120,000 tons to produce briquettes from a mixture of iron ore concentrate, ore fines, top dust and a binder - Portland cement (not less than 10% of the mass of the briquette). The briquettes are processed in the steam chamber is for **36 hours**. Compressive strength limit - not less than **3.5 MPa**, moisture - not more than 9%. The share of briquettes in the ore part of the blast furnace charge is **100 kg per ton of hot metal**. It was noted bridging when loading. Since October 2015, the factory is not in operation.
- In **March 2012**, a vibropressing line to produce briquettes for blast furnaces was put into operation at the SSAB plant in Finland (Raahe Works). The decision to build a briquette line was taken after the **closure of the sinter plant in 2011**.
- Briquettes are made from a mixture of iron ore fines, coal dust, mill scale and scrap using **at least 12%** binder (a mixture of 60% quick-hardening Portland cement and 40% slag Portland cement). The briquette size is **60x60 mm, weight 475 g**.
- After **48 hours** of drying, the cold strength of the briquettes according to ISO 4696 drum sample was 74% (the proportion of pieces with a size of more than 6.3 mm).
- With the consumption of briquettes in the blast furnace charge in the amount of **120–130 kg** per ton of iron, a reduction in coke consumption was achieved (6%) due to the carbon contained in the briquette.

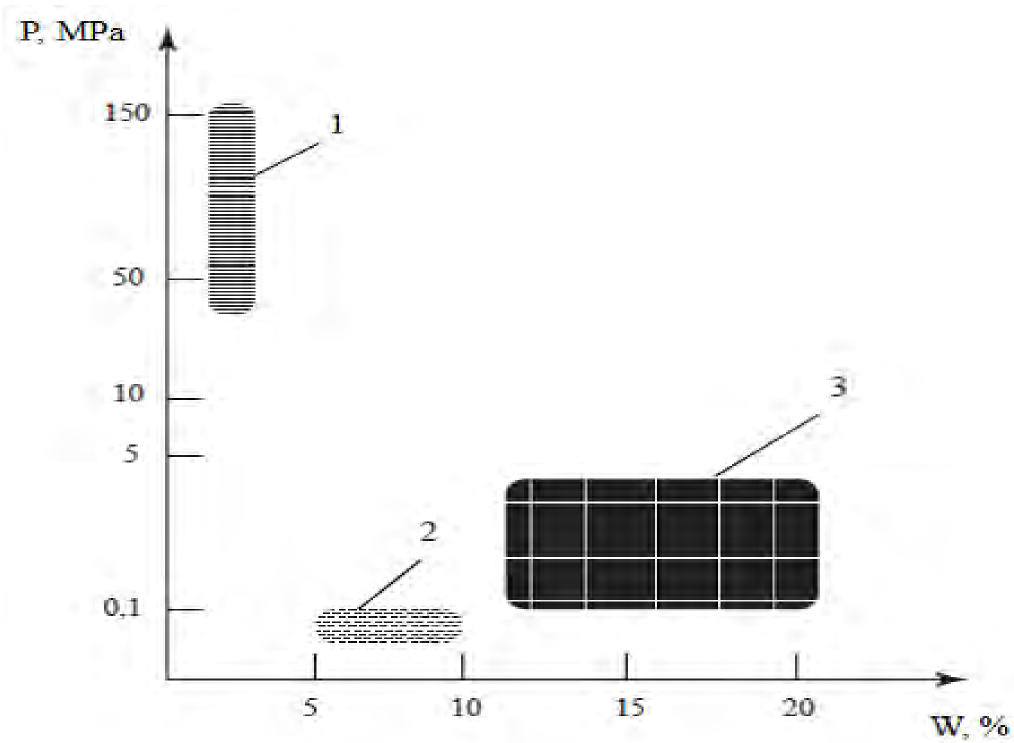
History of Industrial Briquetting. Nowadays

- The results of experimental-industrial tests and practical use of vibropressing briquetting technology show the fundamental possibility of achieving the required level of metallurgical properties of agglomerated products. However, this method of briquetting creates some significant technological limitations, overcoming of which is either difficult, or leads to a significant increase in the cost of briquette (see PPT #2).
- In 2006 vibropressing plant was commissioned by Siberian Mining Metallurgical Company (Russia) for production of Mn ore fines briquettes. The factory soon closed without reaching its design capacity.
- In 2008, vibropressing factory was built at the United Metallurgical Company, which was also unable to produce briquettes from EAF dusts of good quality and was soon closed.
- In 2010, the vibropressing factory was built at the Serov Ferro Alloys Plant (Russia), which was also soon closed because of the increased income of Sulphur to the briquettes for the Ferrochromium production.
- 2018, Ukrainian company start using Chinese vibropress which produce briquettes only with 20% of Portland cement at least.
- In 2011 Xstrata in RSA failed to commission 5 vibropressing briquetting plants.
- **As of the beginning of 2016, briquettes in this way in industrial volumes are not produced in Russia**.

History of Industrial Briquetting. Nowadays. Comparison of Briquetting Technologies

Process characteristics and properties of briquettes	Briquetting units and their characteristics		
	Vibropress	Roller-press	Stiff Extrusion
Maximum performance	20 t/h	+50 t/h	+100 t/h
Service life (cost of parts to be replaced, US $ / ton)	1 year (n/d)	1 year (1.5)	1.5 year (1.0)
Compaction pressure	0.02-0.10 MPa	40-150 MPa	3.5-4.5 MPa
Cement share in briquette,%	Not less than 12	15-16	4-9
Heat treatment of raw briquettes	80 °C (10-12 hours)	Drying of charge	Not required
Returns	absent	30 % of production	absent
Briquettes shape	Prism, cylinder	pillow	Any shape
Briquette size, mm	Up to 80x80,	30x40x50	5-50
Charge moisture content,%	less than 5 %	less than 10 %	12-18 %
The ability to store raw briquettes in a pile	absent	possible	possible
Utilities: Electricity Natural gas Heat Compressed air	 42.6 kWh/t 47 m^3/t 0.3 GCal/t 90 m^3/t	 45.0 kWh/t 0 0 0	 33 kWh/t 0 0 0

History of Industrial Briquetting. Nowadays.
Comparison of Briquetting Technologies



History of Industrial Briquetting. Summary

- Interest in briquetting as a cost-effective and environmentally friendly method of using natural and anthropogenic raw materials of ferrous metallurgy has increased significantly.
- The market of briquetting services and the market of commodity briquettes with a tendency towards globalization have been formed and are developing. The market of briquetting services has the character of oligopoly.
- The main industrial technologies of briquetting are roll briquetting, vibropressing and stiff vacuum extrusion. Marked specialization technology briquetting.
- Stiff vacuum extrusion, due to its high productivity and economic efficiency, is currently the only technology capable of competing with sintering.

THANK YOU FOR ATTENTION!

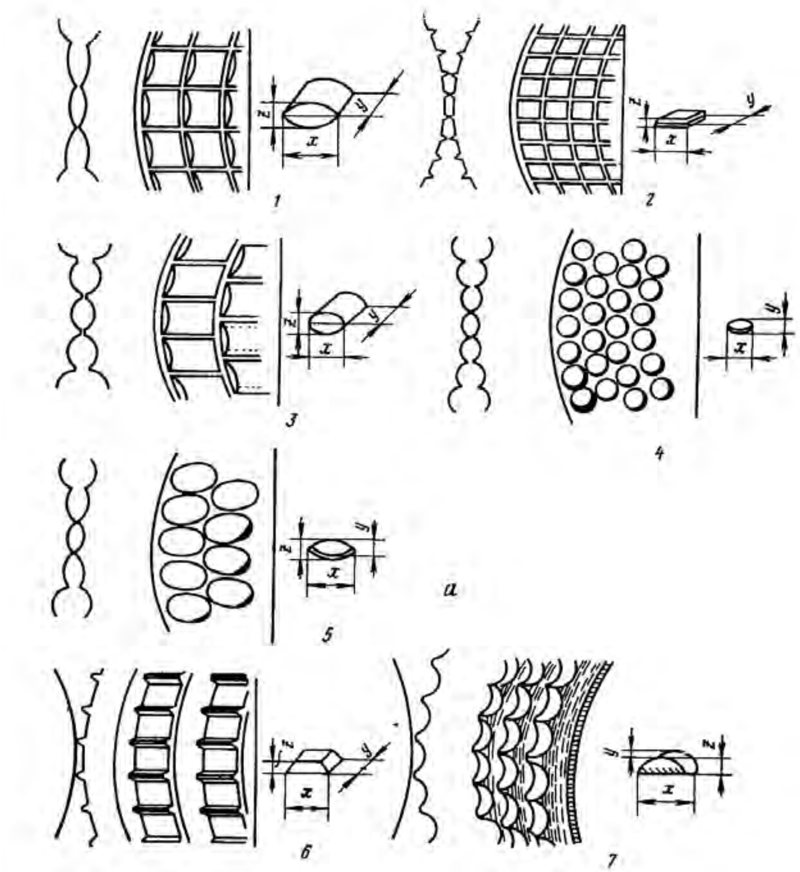
Main Types of the Briquetting Technologies in Ferrous Metallurgy

Dr. Aitber Bizhanov

Roller-Press Briquetting

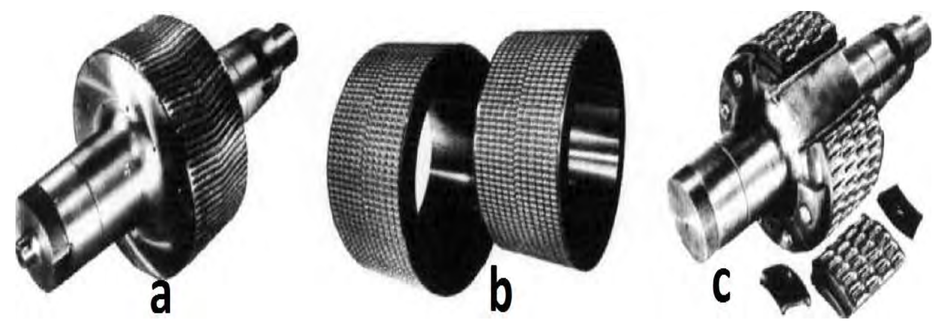
- The principle of operation of such presses is that the briquetted mixture is fed into the gap between two rolls rotating towards each other, on the surface of which symmetrically located cells in the form of semi-briquettes are arranged in a checkerboard pattern.
- During the rotation of the rolls, there is a convergence of cells, the capture of the material and its sealing compression.
- The briquetted material is subjected to bilateral compression, which contributes to a more uniform distribution of its density by volume.
- Then, as the rolls rotate, the cells diverge, and the briquette drops out of the cell under its own gravity.

Roller-Press Briquetting



Different types of cells of the roller press sleeves

The shape and size of the roller briquettes, determined by the geometry of the cells of the sleeves, are important for the processes of storage, transportation and subsequent metallurgical processing.



Designs of rolls of roller presses: a - one-piece solid roll; b - sleeve rings; c – segmented roll.

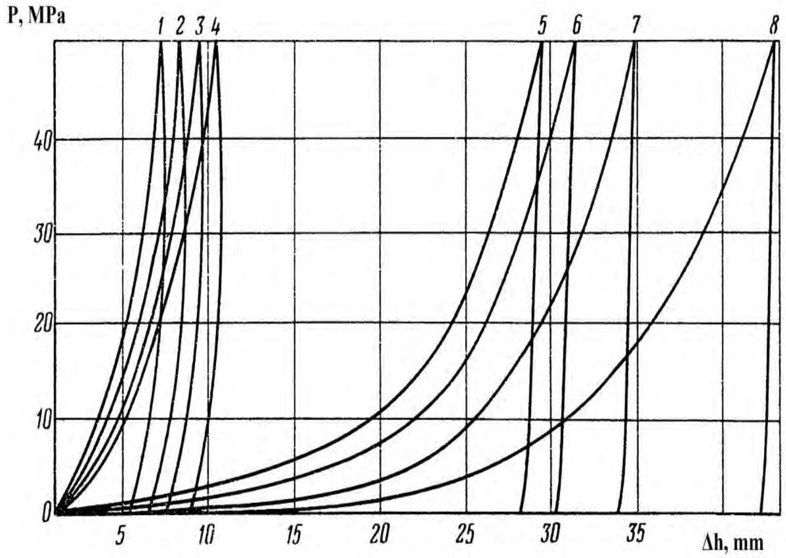
Roller-Press Briquetting

- The processes occurring in the briquetted mass in a roller press can, to a certain degree, be described by methods of the general pressing theory.
- The compaction process can be divided into three stages.
  - The first stage is the reorientation of particles without changing their shape and size.
  - In the second stage, the deformation of the soft and the destruction of brittle particles of material take place.
  - At the last stage, plastic changes in the structure of the material occur, and its compaction occurs.
- The strength of briquettes produced in this way depends on several factors:
  - the particle size and component composition of the briquetted material,
  - the magnitude of the applied pressing force;
  - the moisture of the charge;
  - the duration of the pressing process;
  - the shape and size of the cells of the sleeves and friction coefficients.

Roller-Press Briquetting

- The factor limiting the effectiveness of compaction is the presence of air, which is **"trapped"** inside the material during compression and is released after the external pressure ceases.
- The amount of pressed air can be **30-70%** of the initial volume of air in the material. To avoid this phenomenon, it is necessary to ensure maximum **removal of air from** the briquetted mixture.
- Air removal can be facilitated by a reduction in the rate of material compression itself, facilitating the release of air from a decreasing pore space.
- During **vibropressing and in stiff vacuum extrusion** the removal of air from the briquetted mass is an important component of the technology and is achieved by displacing the air as a result of high-frequency vibrations in the vibropress and the complete removal of air from the stiff extruder's working chamber.
- The maximum particle size for roller briquetting usually does not exceed **5-6 m**m.
- Multi-fractionality is a factor favoring briquetting efficiency, since in this case the space between large particles is filled with smaller particles, which contributes to the displacement of air from the material.

Roller-Press Briquetting

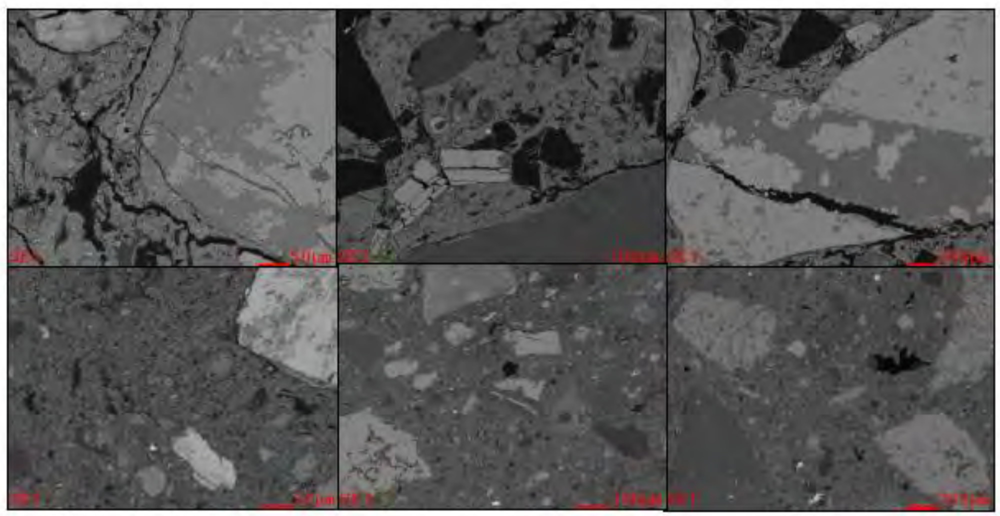


The degree of compaction of the mixture with coal and peat components depending on the compression load (1-4 - manganese ore fines and coal in proportions of 70:30, 60:40, 50:50 and 40:40 respectively; 5-8 - manganese ore fines and peat in proportions of 70:30, 60:40, 50:50, and 40:40, respectively

When briquetting multicomponent mixtures, one should also consider the difference in the manifestation of the elastic-plastic properties of the individual components, leading to a significant difference in the degrees of compaction. Figure illustrates the degree of compaction of roll briquettes based on manganese ore fines with the addition of various carbon-containing materials (coal or peat). It is seen how significantly the degree of compaction of the mixture varies depending on the physical-mechanical properties of the components of the mixture.

Roller-Press Briquetting

- The structure of the material pressed in the rollers undergoes changes due to elastic and irreversible deformation, destruction of the particles of the pressed material and the formation of cracks in it (at pressures above 10 MPa).
- Figure shows the structure of a **roller-pressed brique**tte (manganese ore fines -47.6%, dust of the gas cleaning system - 38.1%, coal - 9.5% and lignosulfonate as a binder – 4.8%) in comparison with the structure of **extrusion briquette** (manganese ore fines -66 %, gas cleaning dust - 28%, cement -5% and bentonite -1%). As a result of high pressure (up to 100 MPa), the briquette structure is characterized by the presence of many large cracks and low porosity. The occurrence of such cracks may be due to elastic expansion after the finished briquette leaves the cells, which leads to a decrease in its strength.



Roller-Press Briquetting

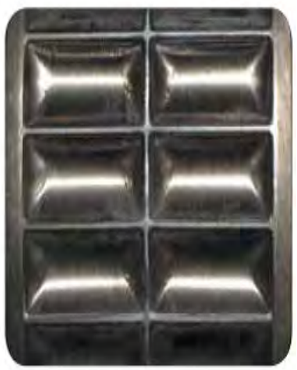
- A feature of roller briquetting is the limitation on the **moisture content** of the charge material (not higher than **5-10%**).
- Roller presses in ferrous metallurgy allow briquetting a wide class of natural and anthropogenic materials with a range of bonding materials. However, restrictions on the moisture content of the briquetted charge create difficulties in using Portland cement, which has become widespread, as a binder. The required proportion of cement in the mass of the briquette can reach 8-12%, which is comparable with the content of this binder in the vibropressed briquettes, but two times higher than that required in stiff extrusion briquettes.
- The strength of the briquettes is significantly affected by the duration of the pressing process. For example, the duration of pressing for rolls with a **diameter of 1.1 m** at a frequency of rotation of **8-11** revolutions per minute is only **0.29-0.38** seconds. Exposure of the briquette under pressure allows not only more fully to force out the air from the narrowing pore space without the formation of pressed "air pockets", but also to reduce the amount of elastic deformations that can lead to its softening. The increase in pressing time is achieved by restrictions on the speed of rotation of the rolls. For iron ore briquettes, usually no more than **6-8** revolutions of rolls per minute are recommended

Roller-Press Briquetting. Main Producers. Köppern

- One of the largest manufacturers of roller presses used for briquetting natural and anthropogenic raw materials in the steel industry, is the company **Köppern**, which since **1950** supplied 450 roller presses for cold briquetting and 143 presses to produce hot briquetted iron. Figure shows one of the company's first roller presses, used in the **1920s** for coal briquetting and a modern briquette press.
- An important design feature of the company’s roller presses is that the gap between the rolls is controlled automatically by a hydraulic station depending on the requirements of a process, which ensures that the entire feed material passes through the gap between the rolls under the same process conditions.

Roller-Press Briquetting. Main Producers. Köppern

- Köppern is also known for its work in improving durability of materials used in the construction of roller presses.
- Cells of sleeves for the formation of briquettes are manufactured by electrochemical processing technology (**ECM –Electro Chemical Machining**) since 1965. Electrochemical treatment consists in removing the metal from the surface of the workpiece by electrolytic dissolution to achieve the desired shape and size.
- Köppern has also developed the **HEXADUR® anti-wear system** - the patented technology to produce briquetting sleeves with high-wear-resistant metal-powder surface - **RESIDUR®**.
- The design of the rolls consists of two parts: the base (core) of the roll and the wear-resistant band fixed on the base by means of a shrink fit, which makes it possible to reuse the core of the roll at the end of the life of the band. Figure presents for comparison the degree of wear for the same time of operation of fragments of the regular sleeve and a sleeve made using the RESIDUR® technology.

Roller-Press Briquetting. Main Producers. Köppern

- The company's experience in briquetting hot plastic materials, high performance presses (up to 100 tons per hour), their reliability and high wear resistance of sleeves led to the fact that today Köppern is the world leader in hot briquetting technology.
- The Köppern roller briquetting technology allows to convert sponge iron directly after it exits the direct reduction reactor at a temperature of 750 ° C into a form that is more convenient for transportation and storage - into hot briquetted iron (**HBI**). Such pressing makes it possible to effectively prevent the occurrence of pyrophoric sponge iron during its transportation and storage, due to compaction and reduction of porosity.

Roller-Press Briquetting. Main Producers. Komarek.

- Komarek, a Köppern group of companies, is also the largest producer of roller briquetting presses.
- The company has been on the briquetting market for more than a century, starting, like Köppern, with coal briquetting.
- Since **1968**, the company has put on the market more than **600** presses for briquetting, pelletizing and compaction in more than 40 countries of the world.
- For the first time, Komarek began to use segment bandages with replaceable elements

Roller-Press Briquetting. Main Producers. Komarek.

- The maximum capacity of Komarek presses is 54 tons of briquettes per hour (Model DH 500- 28x2). This model is designed for coal briquetting.

- For briquetting metal oxides, ore fines and sludges, press Komarek DH500 with a capacity of up to 45 tons per hour is used. The design features of this press consist in:
  - the use of continuous or segment bandages,
  - in the vertical flow of the charge by gravity or using a screw feeder,
  - in the vacuum deaeration of the fine powder components of the charge, which, as we noted above, is very important for roller briquetting,
  - the use of engines with the ability to control the speed of rotation of the rolls and the screw,
  - in the use of materials from resistant alloys, etc.

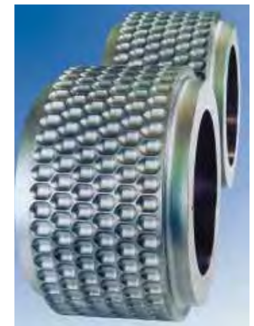
- Roll diameter 710 mm, roll width 229-508 mm, pressing force up to 3000 kN. The drive power of the rolls 200 kW, the drive feeder 22 kW. Press weight - up to 33 tons

Roller-Press Briquetting. Main Producers. Euragglo.

- In 2001, Komarek acquired a controlling stake in EURAGGLO, which is currently the European division of Komarek.
- The maximum productivity of roller presses EURAGGLO reaches 65 tons per hour (model E92).
- The model is designed for briquetting at medium and high pressures. The pressing force - 4200 kN, roll diameter 1200 mm, width - 300-460 mm, roll power drive 500 kW.

Roller-Press Briquetting. Main Producers. Hosokawa-Bepex.

- Hosokawa-Bepex is one of the largest manufacturers of roller briquetting presses. For briquetting with the use of high pressure, roller presses of the MS series are used, suitable for processing also abrasive and hot materials.
- A special feature of the design of Hosokawa-Bepex presses is the possibility of their work in an inert gas atmosphere, as, for example, when working with materials that require the exclusion of contact with oxygen. In this case, the casing of the roller presses of the MS series are made in a gas-tight version.
- The surface of the rolls can be smooth, profiled or with grooves. For presses of the MS series there are rolls suitable for a variety of applications (segmented, for highly abrasive materials and high temperatures; with an external sleeves, for moderately abrasive materials and temperatures up to 450 ° C; solid rolls).
- The pressing force of presses of the MS series is in the range from **360 to 6000 kN**. Roll diameters - from 300 to 1100 mm.

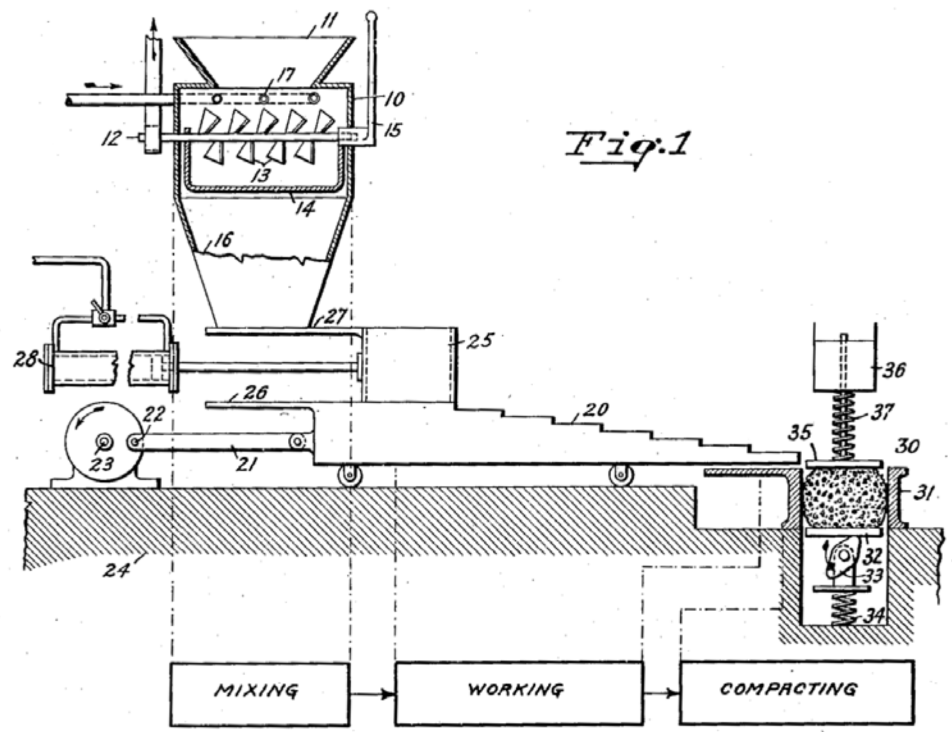



Roller-Press Briquetting. Main Producers. Sahut-Conreur.

- The largest French manufacturer of roller presses for briquetting coal and ore concentrates is Sahut-Conreur, one of the oldest briquette companies in the world.
- The roller presses of this company have been used for briquetting since **1860**.
- The performance of modern roller presses companies from 500 kg to 100 tons of briquettes per hour. The pressing force reaches values of 10-50 kN per linear centimeter of roll width. The roll diameter is 250 - 1400 mm. The presses are equipped with a system of hydraulic compression of the rolls and a system for automatically controlling the frequency of their rotation.
- As well as Köppern, Sahut-Conreur produces briquetting roller presses for hot briquetting.
- The company is also the developer of the patented concept of “cold briquetted iron and carbon” (Cold Briquetted Iron and Carbon, CBIC). The raw material for such briquetting is the so-called cold direct reduced iron and carbon. The largest producer of such iron is Iran. The method proposed by Sahut-Conreur serves the same purpose as Köppern presses for hot briquetting - passivating pyrophoric sponge iron.

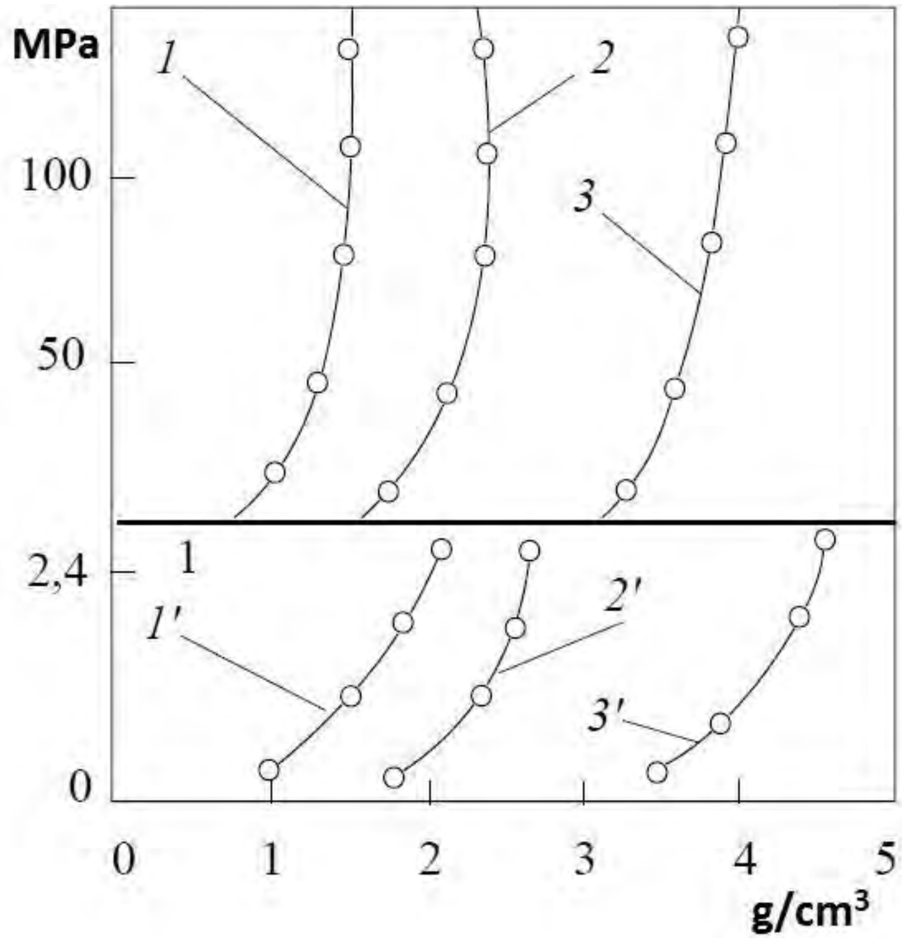
Vibropressing Briquetting

- The possibility of using vibrations for agglomeration was known as early as 1902.
- Vibration was used in the United States in the production of concrete, and in 1927 in France a patent was issued for a method of vibrating concrete compaction.
- In the same year, a method for producing agglomerated masses using vibration was patented in the USA.



Vibropressing Briquetting

- The very first experience in powder metallurgy at the end of the 40s of the last century showed that the use of vibration when filling powder into a mold or in the process of compaction allows significantly reducing the required pressure and homogenizing the distribution of its density by volume.
- It was found that when vibrations with a frequency exceeding 50 Hz, the bonds between the particles in the compacted dry powder are destroyed and the internal friction in the compressible mass sharply decreases, which facilitates the convergence of particles and compaction of the mixture.
- In this case, a higher degree of compaction is achieved at lower load values than during compression.



Comparison of the degree of compaction of the material during static pressing (1-3) and vibropressing (1’-3’). 1, 1’ - boron carbide; 2, 2’ - silicon carbide; 3,3’ – titanium carbide

Vibropressing Briquetting

- The process that occurs when vibration is applied to a formable mass containing gel phases is the so-called **"thixotropy"** - a decrease in viscosity (liquefaction) under mechanical action and thickening in state of rest.
- Manifestations of thixotropy underlie the process of vibration compaction of concrete. Under the influence of vibration, the cement gel transforms into a sol, simplifying the movement (convergence) of solid aggregate particles under the action of its own gravity, which leads to compaction of concrete.
- Similar processes take place during briquetting with the use of cement binder, when, due to the reversible transformation of a cement gel into sol when exposed to vibration, at the stages of its liquefaction, particles of the briquetted charge approach each other under the action of their own gravity, which contributes to compaction of the briquette, and the air displaced by the approaching particles is released on the surface of the compressible mass in the form of bubbles.
- The thixotropy of the gel and the reduction of internal friction due to the oscillatory movements of the particles caused by vibration lead to the fact that the briquetted mass acquires some properties of the liquid, which simplifies the molding.

Vibropressing Briquetting

- It is clear that thixotropy plays a key role in vibropress briquetting.
- It is no coincidence that almost all known vibropressing briquette factories use cement as a binder. That is why the moisture content of the charge components plays an important role in briquetting with vibropressing. Its quantity should be enough to preserve the properties of the cement gel and for further hydration hardening of the cement.
- Usually its content in the briquetted mixture is limited to 5-8% by weight of the briquette. The cycle of vibratory compaction lasts less than 30-40 seconds, which is obviously not enough for the cement to “set”.
- As a result, newly formed vibropressed briquettes have a very low mechanical strength, which does not allow them to be transported and stacked like roll briquettes or BREX.
- Therefore, the equipment of the vibropressed briquetting factories include special mechanisms to transport and accumulate finished products on pallets.
- In addition, to speed up the curing of briquettes, their “steaming” is used - heat and moisture treatment at a temperature of **70-95 ° C** in an atmosphere of saturated steam. Movement of moisture and steam in a briquette that has not yet become strong may lead to its softening.

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

- The process of vibropressing consists of several stages.
- The pallet is mounted on the vibrating table.
- The briquetted mixture prepared in the mixer with the addition of a binder is poured into a replaceable mold tooling - a matrix.
- Next, the mixture is compressed by the punch, a kind of “mirror” reflection of the matrix, ideally entering it exactly like a piston in a cylinder, and the vibration of the whole unit is turned on.

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

- The duration of the vibration cycle is 15-40 seconds.
- At the end of the molding cycle, the vibration is automatically turned off, the pressure in the hydraulic system decreases, the matrix rises, and the formed briquettes remain on the process pallet.
- The appearance of the briquetting vibropress is shown in Figure.
-

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

- The low strength of freshly formed briquettes does not allow them to be delivered to the zone of curing by the conveyor.
- Preserving the integrity of freshly formed briquettes requires special measures. Briquettes are transported, remaining on technological pallets.
- Pallets with freshly formed briquettes along the conveyor are fed to a special hoist drive, from where a stack of pallets is delivered to the heat treatment zone.

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

- After accumulating the required number of pallets on the pallet stacker, they are removed and further transportation to the heat treatment chamber is carried out by an automatic stacked cart moving along the rails.
- It is possible to transport a stack of pallets to the heat treatment zone and with the help of a transborder consisting of transfer and dispensing carts, which ensures the accuracy of the installation of pallets in the heating chambers.
- The duration of heat treatment can reach 24 hours or more. The temperature in the chamber is **70-95 ºC**. The cost of heat treatment chambers can exceed **20%** of the cost of equipment and engineering costs.

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

- After heat treatment, the briquettes on the pallets are moved to the stacker and further using a hydraulic pusher to the finished product conveyor for further unloading to the warehouse or loading onto a vehicle.
- The pallets freed from briquettes are returned to the vibropress.
- With a briquette line capacity of up to **130 thousand tons** of briquettes per year, the number of formable pallets can exceed **one million pieces**. The cost of technological pallets may exceed the cost of the vibropress itself.
- In general, the cost of special mechanisms and devices for automatic lines of vibropressing, allowing ensuring the preservation of raw briquettes intact until delivery to the heat treatment chambers and the return of pallets can **double the cost of vibropress**. In the absence of automation of these procedures, the capacity of the briquetting plant will be **not exceeding a few tons per hour**. The cost of automation can be up to **50% of the cost of the vibropress**.
- In connection with the specifics of vibropressing, the productivity of a vibropress is usually understood as the number of units of products produced during an hour or eight-hour shift. First of all, productivity depends on the degree of automation, which affects the rate of removal of pallets with raw briquettes from the working area.
- Equipment productivity essentially depends on the sizes and volume of briquettes. Therefore, the performance is sometimes offered to compare the number of pallets filled in a certain period. According to the results of operation of the known automated vibropress briquette factories, their productivity does not exceed **20-30 tons** of briquettes per hour.
-

Technology of Vibropressing, Transportation, Heat Treatment and Storage of Briquettes

The size of briquettes is **60-100 mm**; the most widely used form is a hexagonal prism. Such a size of vibropressed briquettes can lead to their “**bridging**” when unloaded into the bunker. The smaller the size of the briquette produced, the lower the performance of the vibropress.

Technology of Vibropressing. Main Producers

- The largest manufacturers of equipment for the production of briquettes by the method of vibropressing are the companies **Hess and Masa** (Germany).
- Hess supplies to the vibration molding market a series of **MULTIMAT** concrete molding machines, which can also be used for briquetting in ferrous metallurgy.
- The machine MULTIMAT RH 2000-3 MA is shown at the Figure.

Hess concrete forming machine MULTIMAT RH 2000-3 MA

Technology of Vibropressing. Main Producers

- The dimensions of the technological pallet are 1400x1300 mm, the area of molding is 1300x1250 mm, the cycle time is 10 seconds.
- The productivity of the machine in the production of paving stones (10x20x6 cm) is 352 m2 of such coverage per hour.
- A special feature of Hess vibropresses is the patented VARIO TRONIC vibrosystem, which allows to set vibration parameters (frequency and amplitude) individually for each type of vibration and achieve optimal compaction using eight vibrators, with minimal wear on equipment components.
- The company supplies the market with automatic briquetting lines, which, in addition to vibropresses, include special devices for transporting pallets with raw briquettes to the heat treatment area and finished briquettes to their shipment points to consumers (pallet conveyors, storage hoists, transborder, multiformes, cameras for heat treatment, briquette dumpers, etc.).
- Figures depict the components of the technological vibration lines of the company Hess, designed to transport and accumulate pallets for heat treatment.

Technology of Vibropressing. Main Producers

- Masa manufactures high-performance XL 9.1 and XL 9.2 stone-forming machines.
- The productivity of the machine XL 9.2 reaches 2938 m3 of rectangular paving slabs with dimensions of 200x100x80 mm, with the standard size of the technological pallet 1400x1300 mm.
- The company supplies complete briquetting lines on a turnkey basis.
- The main equipment, as well as Hess, includes special devices and mechanisms ensuring the safety of raw briquettes until delivery to the heat treatment chambers for curing

Stiff Vacuum Extrusion Briquetting Technology

- Extrusion is a process used to create objects with a fixed cross section profile. The material is pushed through the die of the desired cross section. This method has found a great distribution in the industry of the production of ceramic bricks. Vacuum is maintained in the working chambers of modern brick-making extruders, which contributes to achieving greater uniformity and density of the product. Stiff vacuum extrusion (SVE) technology is applied in the production of ceramic bricks in **64** countries around the world, including the United States, Britain, Germany, South Korea, and South Africa. The world's largest brick factory in Saudi Arabia produces a million bricks per day using SVE technology.
- In accordance with brick industry terminology, the word "stiff" is used to describe the process of extrusion, which is carried out at pressures ranging from **2.5 to 4.5 MP**a and moisture contents ranging from **12-18%**.

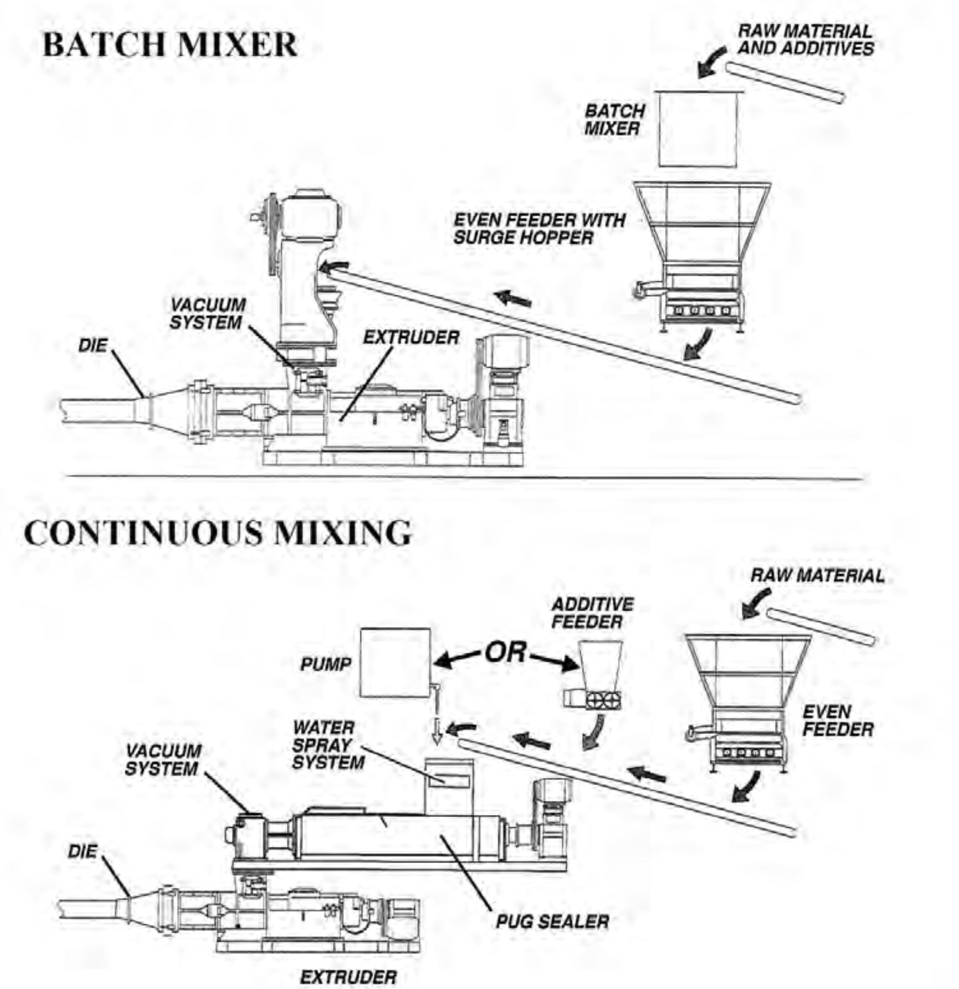
Type of extrusion	Low-pressure extrusion	Medium-pressure extrusion	High-pressure extrusion	
Designation used in structural ceramic industry	Soft extrusion	Semi-stiff extrusion	Stiff extrusion	
Extrusion moisture, % on dry	10-27	15-22	12-18	10-15
Extrusion pressure, MPa,	0,4-1,2	1,5-2,2	2,5-4,5	Up to 30

Stiff Vacuum Extrusion Briquetting Technology

- Unlike a roller-press and vibropress briquetting, shear stress plays an important role in SVE agglomeration. Shear stress occurs when the mixture is processed in the screw feeder, in pug mills, and then in the extruder.
- Based on a comparison of coal briquette porosity values in various pressing options (compression and its combination with torsion), it was found that more dense briquettes (less porous) are formed in the combined pressing option (under identical values of applied pressure).
- With full compression, a significant proportion of energy is expended on the elastic deformation of the particles themselves, while, in the presence of shear stress, the convergence of particles on the surface forces activation distance is more effective.
- In full compression of close-packed particles, each particle only comes into contact with its immediate neighbors and is subjected to compression load.
- Under shear stress, the particles of the adjacent layers are subjected to abrasion due to contact with irregular surfaces, which can lead to crushing, the opening up of new surfaces, and, hence, to an increase in the number of contacts between particles of the mixture.

Stiff Vacuum Extrusion Briquetting Technology

Typical layouts of the SVE briquetting line



Stiff Vacuum Extrusion Briquetting Technology

The mixture of raw materials is fed by a front loader to a Steele E Series Even feeder (Figure), equipped with wear-resistant spiral cast-iron auger elements made of a chromium alloy.

Stiff Vacuum Extrusion Briquetting Technology

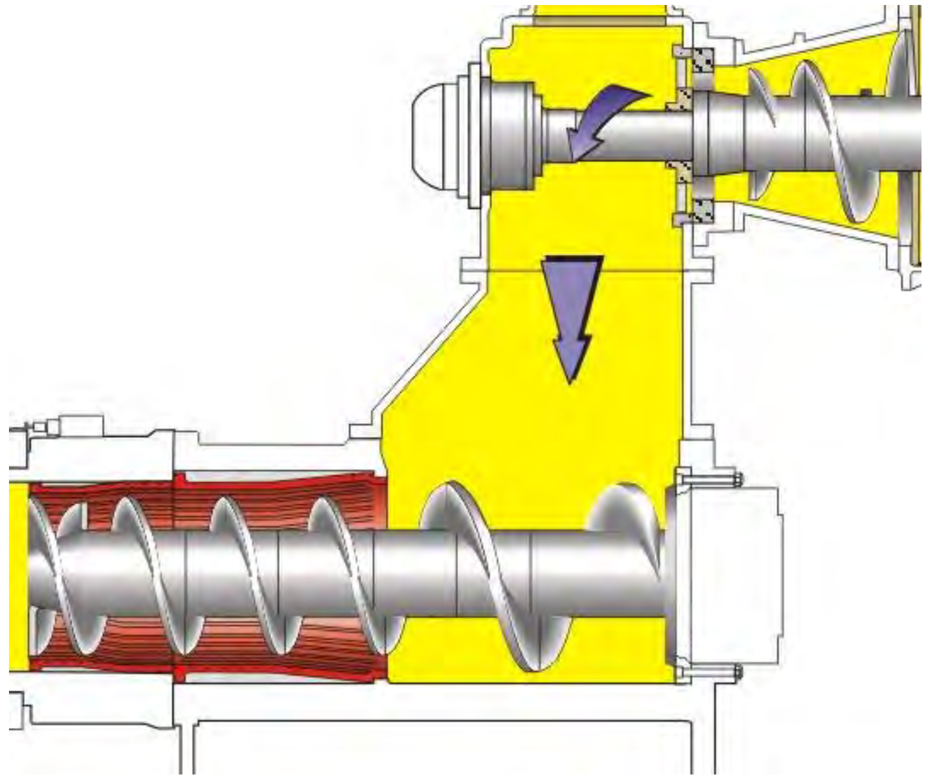
- Next, the prepared mixture with added binder and plasticizer is fed for mixing in the pug sealer.
- The line can also contain primary open pug-mill.
- The pug sealer consists of a large open part and the sealing node. The open part consists of a trough and blades for mixing.
- The blades are fastened to the steel rod shaft by bolted clamps, making it possible to rotate the blades to adjust the angle at which the processing takes place and, thereby, change the machine's performance.
- The pug sealer is combined in a single unit with the extruder and is positioned above it.

Stiff Vacuum Extrusion Briquetting Technology

- The mixture enters the vacuum chamber partially agglomerated and due to the high vacuum inside the chamber the pieces of the mixture immediately crumble into isolated particles, which fall on the blades of the auger.
- It is known that air adsorbed by the surface of particles of plastic material in the form of polymolecular layers held by van der Waals forces slows down their wetting with water, prevents the mass from being evenly compacted, contributes to an increase in elastic deformations during plastic molding, forming delamination as well as micro-cracks.
- Filling the pores, the air also prevents the penetration of moisture into them, separates the particles of the mass, acting as a leaner.
- Vacuum leads to the removal of air from the pores and promotes closer contact of the particles.

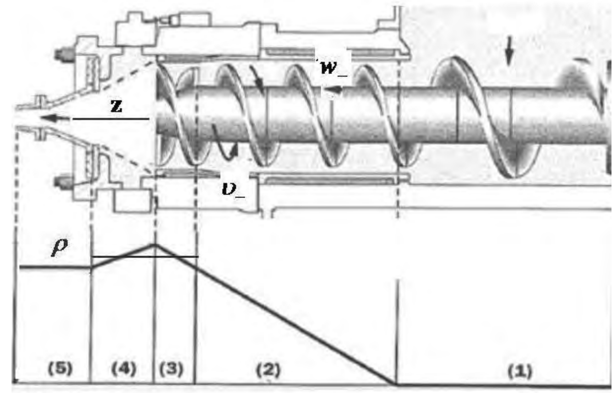
Stiff Vacuum Extrusion Briquetting Technology

- The vacuum is maintained throughout the working volume of the extruder up to the die.
- The pressure of the vacuum is at least 100 mm Hg (in absolute value).
- The combination of mechanical pressure and vacuum in the working extruder chamber helps to remove almost all compressible air from the material before densifying,
- In addition, as is well known, the vacuum slightly decreases the viscosity of the cement paste, which facilitates its uniform distribution in the briquetting mass and improves its interaction with water.
- This circumstance in combination with a higher density of the briquetting mass, due to the removal of air from it, leads to a decrease in the consumption of cement binder.



Stiff Vacuum Extrusion Briquetting Technology

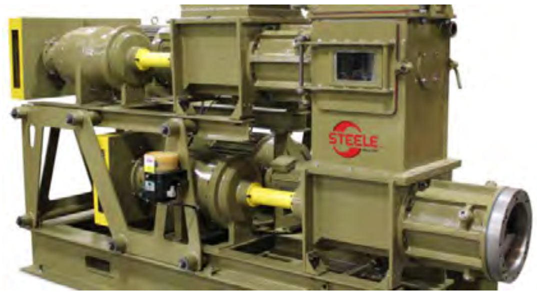
- Due to rotation of the auger blades in the working chamber of the extruder, formable mass performs translational and rotational motion, which is slowed by the walls.
- Stages of densifying in the working zone of the extruder.1 – conveying, 2 – densifying, 3 – metering, 4 – pressure distributing, 5 – die.
- In the conveying zone, material is loose and moves along the barrel without densification. Bulk density remains unchanged. Zone 2 is the densifying region where the loose material is compacted. In zone 3, metering is achieved by way of the special geometry of the wings of the point auger. Zone 4 serves the purpose of distributing the pressure generated by the metering zone more evenly over the die, thus tending to yield a more even flow through it.
- In zone 5, the brex are squeezed out of the holes in the die, which completes the process of their formation.



Stiff Vacuum Extrusion. Main Equipment

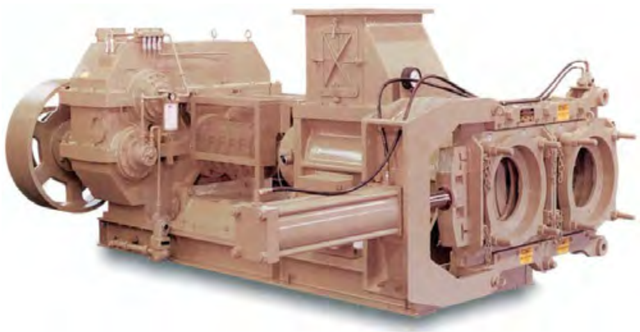
- The first successful attempts to deaerate the mixture before it was fed to an extruder were made in the USA in 1920, and from 1932 such a procedure was used in Europe. The first stiff extrusion experience also took place in the USA at the end of the 19th century and was associated with **J.C.Steele & Sons, Inc.** founded in **1889**. But for the first time on an industrial scale, stiff extrusion was implemented in England in **1960**, and then in Germany in **1967** by **Haendle**, which today is part of the J.C.Steele & Sons, Inc. group of companies. It is the company Haendle has combined vacuum and stiffness of the mixture in extrusion.
- J.C.Steele & Sons, Inc. Is the creator of the modern Stiff Vacuum Extrusion technology and the world's largest supplier of extruders for stiff extrusion.
- As noted above, shear stress plays a significant role in SVE. It is this effect that the briquetted by this method is subjected to at all stages of agglomeration, starting with feeding and mixing in so-called even feeders “J.C.Steele & Sons, Inc.”.
- The company manufactures feeders with two, four and eight augers. Solid augers only serve the mixture, and the split augers, in addition to the feed, carry out loosening, grinding and crushing. The performance of uniform feeders from **30 t / h to 200 t / h**. Knives pugs made of alloy with 28% of chromium.

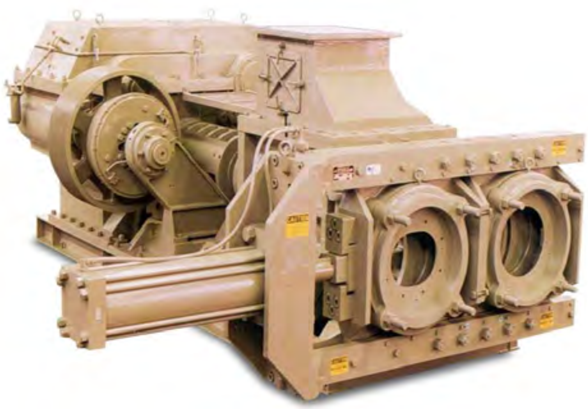
Stiff Vacuum Extrusion. Main Equipment



- J.C.Steele & Sons, Inc. produces several extruder types with different capacities.
- The smallest rated output of this company's extruders is **5 tons per hour** (extruder **HD-10**). The actual performance is determined by the density of the briquetted mass.
- In the range of capacities from **20 to 50 tons per hour**, the company supplies the **25th and 45th** series Steele extruders.

Stiff Vacuum Extrusion. Main Equipment





- Extruder Steele 75 allows to produce up to **54 tons** of briquettes per hour.
- The company's most high-performance extruder is the Steele 90 extruder, designed for production of **80-90** tons per hour. The 45, 75 and 90 series extruders can be equipped with a hydraulic die change mechanism that performs this procedure almost instantly.
- All units and parts of the machines are designed for significant overloads, especially bearings and powerful shafts made of one-piece forging. All elements of the extruder body, the vacuum chamber and the pug mill assembly are molded from ductile iron. In the design of the extruder and the vacuum chamber of the clay mill, welding is not used. All parts in contact with the processed metal are made of 28PC alloy (28% chromium and other alloying additives.)
- Extruders and pug mills are designed for a long service life (30 years or more) and are characterized by ease of maintenance and operation.

Stiff Vacuum Extrusion.

Company	Country	Extruder (quantity)	KTY	Purpose
Bethlehem Steel (1994-1997)	USA	Steele 25	80	BF
Suraj PL (2011)	India	Steele 25	100	BF
Сталелитейная компания*(2010)	NDA	Steele 25 (1) + Steele 90 (2)	1000	BF
NLMK (2019)	Russia	Steele 45 (3)	700	BF
CAP Steel (2018)	Chile	Steele 25	100	BF
J.C.Steele/TMS (2017-н.вр.)	USA	Steele 25	100	BF
BHP Billiton (1997)	Columbia	Steele 90 (3)	700	RKEF, Ferronickel
Vale (2014)	Brazil	Steele 90 (3)	700	RKEF, Ferronickel
Ferro Alloys Co. (2017)	NDA	Steele 45	200	Ferromanganese
ОАО ЧЭМК (2018)	Russia	Steele 45	200	SiMn
ОАО Казхром (2017)	Kazakhstan	Steele 25	80	Ferrochromium
BREXTIME (2019)	Ukraine	Steele 90	200	Ferronickel

CONCLUSIONS

- **The methods of roller pressing, vibropressing and stiff extrusion are most widely used for briquetting natural and anthropogenic materials.**
- **Moisture limits for roller briquetting require retrofitting of briquetting lines with dewatering and/or drying areas and limit the use of cement binder.**
- **Production of roller briquettes is characterized by the formation of up to 30% of recycled waste in the form of small fractions of the briquetted mixture.**
- **Maintaining the operational capacity of roller presses is associated with the need to purchase and replace expensive parts, as they wear out.**
- **The share of roller briquettes, in cases of their use in the charge of modern blast furnaces, is limited to several tens of kilograms per ton of iron. In this case, the required strength of the briquettes is achieved due to the increased consumption of the binder.**

CONCLUSIONS

- **In addition to the actual formation of briquettes, the vibropressing briquetting technology also includes techniques for ensuring the integrity of raw briquettes by transporting them on pallets to a heat and moisture chamber.**
- **This requires the organization of a complex system for transporting briquettes from the vibrating table to the hardening chamber, from the chamber to the production warehouse and returning the pallets to the vibrating table, which increases the cost of briquettes and reduces the reliability of the briquetting line.**
- **The disadvantage of the vibropressing technology is the directly proportional dependence of the line capacity and the inversely proportional dependence of the cost price and the recoverability of the briquettes on their size. Large hexagonal briquettes in cross section (60x60x60 mm and more) make it difficult to unload them from bunkers when loaded into blast furnaces because of bridging.**
- **The metallurgical properties of vibropress briquettes satisfy the requirements of the blast furnace process (except for their size) and can be considered as components of the blast furnace charge, but the high content of cement binder increases their cost and adversely affects the viscosity of the primary slags.**

CONCLUSIONS

- **The results of the operation of the SVE factories for the agglomeration of lateritic nickel ores and dust of the aspiration systems to produce ferronickel showed the possibility of achieving high levels of productivity of briquetting lines at low capital costs.**
- **The results of the operation of the SVE factories for the agglomeration of BF production fine materials confirms the economical feasibility of using extruded briquettes (BREX) in the BF charge.**
- **The capacity of SVE and good metallurgical properties of BREX allows to consider this technology as a possible alternative for sintering.**
- **The results of a comparative analysis of the technical and economic indicators of the modern industrial briquetting technologies allow quite reasonably to choose the SVE technology as the main technology of briquetting anthropogenic and natural raw materials used in the processes of extractive metallurgy of ferrous metals.**

THANK YOU FOR ATTENTION!

Materials for Briquetting and Testing of Metallurgical Properties of Briquettes

Dr. Aitber Bizhanov

Basic Materials for Briquetting

- The most important metallurgical properties of the briquettes are: **cold strength, porosity, reducibility and softening, hot strength**.
- **Cold strength** allows the briquettes to maintain integrity and not to collapse with the formation of fines during transportation, handling and loading into the furnace.
- **The porosity** of briquettes affects the reaction surface of the interaction of the oxides of its components with a gaseous reducing agent.
- **Reducibility** - the ability of the components of the briquette to give oxygen to the gaseous reducing agent. Good reducibility of briquettes allows to reduce the degree of development of direct reduction and the specific consumption of coke for iron smelting.
- **Softening** of briquettes can affect the gas permeability of the charge column in the furnace, therefore, the higher the temperature of the beginning of the softening of the briquette, the less the contribution of this part of the charge to the increase in resistance to gas flow. The metallurgical value of briquettes increases with a decrease in the temperature difference between the beginning and the end of their softening.
- **Hot strength** - the ability of briquettes to preserve integrity as much as possible without destruction in the process of heating and phase transitions.

Basic Materials for Briquetting. Mining and Enrichment of Ores

- For most furnaces and reactors of ferrous metallurgy used today, there is a lower limit for the size of the charge components. For blast furnaces, the allowable size of the charge pieces is at least **10–12 mm**.
- With the extraction and further enrichment of brown iron ore and hematite iron ore, the yield of fractions larger than **10 mm** does not exceed **30%** and the formation of a fine fraction is large, with particle sizes less than **0.05 mm**, which makes the direct use of such materials in the charge (without preliminary agglomeration) economically meaningless due to the gas flow from the working space of furnaces and ore particles reactors.
- Iron ore fines and concentrates are suitable charge components for briquetting. Depending on the iron content, there are **rich iron ores** (Fe content **57-65%**), ores with **average** iron content (**45-57%**) and poor ores (less than **45%**). With increasing iron content in the briquette, its metallurgical value also grows. It is known that with an increase in the iron content in the blast furnace charge by **1%**, the productivity of the blast furnace increases by **2-2.5%**, and the specific coke consumption decreases by **1-1.5%.**

Basic Materials for Briquetting. Mining and Enrichment of Ores

- The composition of gangue of iron ore fines and concentrates may include iron-free quartz minerals, aluminosilicates, garnets, pyroxenes, calcite, etc. The main components of the gangue are silica (SiO_2), alumina (Al_2O_3), lime (CaO) and magnesium oxide (MgO). When melted in a furnace, gangue forms slag, whose properties are largely determined by the so-called basicity - $(CaO + MgO) / (SiO_2 + Al_2O_3)$.
- Impurities, which are usually found in iron ores, can significantly affect the properties of briquettes. It should be noted that, in contrast to sintering and the production of pellets, which imply mandatory high-temperature processing of iron-containing materials, which allow to remove harmful impurities, in cold briquetting the chemical composition of the charge remains unchanged. Harmful impurities include - S, P, As, Zn and Pb. Mn, Cr, Ni, V, W, Mo and other elements are considered useful.

Basic Materials for Briquetting. Sinter and Pellets Production

- Disperse materials of interest for briquetting are formed in the processes of sinter and pellet manufacturing, crushing, handling and transportation. These include dust and sludge from sinter production and induration machines and sinter and pellets fines.
- The specific yield of dusts from sintering machines can be from **10 to 24 kg per ton of sinter**. At the preparatory sites 9 kg of dust per ton of sinter is formed. The output of dust in the production of pellets reaches 7-9 kg per ton of pellets, in the preparatory areas - 5-16 kg per ton of pellets.
- **Dust** consists of particles of sinter (pellets) and particles of raw materials for such industries (ore, coke, coal, limestone). The typical chemical composition of dust of sintering machine: iron content - 45-55%; SiO_2 - 5-10%; sulfur - 6-10%; CaO - 10-20%; Al_2O_3 - 1-2%. Particle shape is spherical with a granular surface (magnetite) or oblong (hematite). More than 46% of such dust particles have a size in excess of 40-50 microns. The size of the dust particles of roasting machines is smaller. About 40% of particles are larger than 40-50 microns.
- **The small fraction of the sinter** (the fraction of the finished sinter with size smaller than 5 mm) is formed when it comes off the sintering belt, after sieving the return from the cooled sinter and when it is loaded into the skip of the blast furnace. This material has the chemical composition and mineralogical composition of the finished sinter.
- **The indurated pellets fines** are formed during classification, transportation, unloading, storage and subsequent loading of pellets into the blast furnaces and metallization reactors. The typical granulometric composition of pellets fines - 8% of particles are larger than 6.30 mm, 60% have sizes in the range of 0.15 - 6.30 mm and 32% of particles are smaller than 0.15 mm. The iron content in the pellets fines is 65% on average. Some features of the mineralogical composition of iron-containing phases of pellet screening can lead to an abnormal swelling of briquettes on a cement binder when they are heated in a reducing atmosphere.

Basic Materials for Briquetting. Blast Furnace Production

- The most promising dispersed BF materials for briquetting -**flue dust, wet gas cleaning sludge, sludge and dust generated in the sub-bunker rooms of blast furnace**.
  - Flue gas dust is formed as a result of the abrasion of pieces of the blast furnace charge during its movement in the shaft of the furnace.
  - Dust in the sub-bunker rooms are formed during transportation and handling of the charge components.
  - Sludge - as a result of hydraulic cleaning and wet cleaning of emissions of aspiration systems.
- The total generation of flue dust and sludge is about **64 kg per ton** of HM. The output of sludge of wet gas cleaning of blast furnace gas - **26 kg / t** of HM. The output of top dust is on average **38 kg / ton** of HM.
- About 30% of flue dust particles have a size in the range of **150-250 microns**. The iron content varies widely (**40-50%**). Flue dust has noticeable amount of **carbon (+30%)** introduced by particles of unreacted coke, which makes this material a promising component of **self-reducing briquettes**. **Hematite, magnetite and calcium ferrite** are the main iron-containing phases of flue dust. Iron ore grains have an irregular shape with sizes ranging from **0.5 to 150 microns**. Fragments of coke are relatively large (**from 350 microns to 1mm**).
- The iron content in the sludge of the wet gas cleaning of blast furnace gas varies widely (**20-55%**), there may be a significant presence of undesirable impurities such as zinc and lead.
- Iron content in sludge of sub-bunker rooms of blast furnace is **33-35%** and its composition is close to the composition of the sinter charge. The granulometric composition of such sludge is close to the composition of the dust of sinter plants.

Basic Materials for Briquetting. Steelmaking

- **Main materials for briquetting: converter sludge, dust and sludge from Electric Arc furnace (EAF)**. In some cases, steelmaking slags can also be added to the briquette mixture, however, due to their low iron content, their use in briquetting is limited.
- In the exhaust converter gases, the dust content is very high (**30-60 g/cub.m)** The main minerals of such dust are **maghemite, magnetite and wustite**. The material itself is a black powder with spherical particles. The average particle size is **0.08 microns**; **10-15%** of the particles are larger than **10 microns**. Large fractions of dust are particles of the charge materials, droplets of slag and the shell of carbon monoxide bubbles carried by the gas stream.
- Sludge is formed during wet gas cleaning of converter gases. In such materials sludge granules are formed, on the surface of which there is a tricalcium silicate ($3CaO \cdot Si0_2$), the granular structure of which prevents the strong adhesion of particles with cement gel during briquetting, which leads to low mechanical strength of briquettes based on converter sludge. Such material should be briquetted together with blast-furnace sludge or top dust.

Basic Materials for Briquetting. Steelmaking

- The specific yield of the EAF dust is on average **8–10 kg per ton** of steel (20 kg/t with oxygen blowing). Dust is formed in the zone of arcs and is a vapor of metal condensing in the cold parts of the tract, condensed vapors of slag and particles of the charge removed from the bath by a stream of exhaust gases. The content of **Fe_2O_3** in such dust is **10-50%**. The dust particles are predominantly spherical in shape. The bulk of the dust particles in the EAF dust have a size in the range of **0.2 to 20 microns**.
- A distinctive feature of EAF dust - high content of zinc oxide (ZnO), which can exceed **20%** of the mass of the material, which is unacceptable for blast furnace briquettes..
- The structural features of the particles and the particle size distribution of the EAF dust create some difficulties in its briquetting by vibropressing with cement as a binder associated with significant values of the specific surface of the particles (16000 cm^2/g), which leads to a noticeable manifestation of the capillary effect and dewatering the briquette. Due to the lack of moisture, the hydration of the cement stone is impeded, and the briquette does not gain strength.
- Such a feature of the EAF dust is not an obstacle for its briquetting by a stiff vacuum extruder.

Basic Materials for Briquetting. Rolling Production

- During the hot rolling process, scale is formed on the outer surface of the plates, sheets and profiles. The output of mill scale of rolling production is about **2%** by weight of the finished product. The shape of the particles is scaly. The size of the main mass of particles does not exceed **0.2 mm**. The chemical composition of scale is close to pure magnetite (**65-72% Fe**).
- The scale may be contaminated with lubricating oils and cutting fluids (coolant) as a result of their leakage from the lubrication system of rolling mill equipment. The presence of oil determines the high hydrophobicity of the particles of scale surface.
- The hydrophobicity of the surface of particles of oily scale reduces the effectiveness of the use of cement as a binder during its briquetting. The de-oiled scale can be used to produce so called washing BF briquettes.

Basic Materials for Briquetting. Ferroalloys Production

- **Dust and sludge, ore fines, fines of pellets and sinter, fines of crushing of ferroalloys**). In the ferroalloy industry, dry(open and semi-closed ore smelting furnaces) and wet systems(closed and sealed furnaces) are used. Open and semi-closed ore-reducing furnaces are equipped with a dry gas cleaning, closed and sealed furnaces are equipped with a wet gas cleaning.
- The specific dust emissions of ferroalloy furnaces are **8-30 kg** per ton of alloy. The total formation of dust in the areas of preparation of raw materials, warehouses of charge materials and finished products reach a total of **1.1 kg/t** of alloy. Particles of large fractions (about 10%) have an irregular shape, since they were formed outside the arc zone in the absence of phase transitions. Such dust contains particles of charge materials (ore raw materials, fluxes and coke). The size of almost **90%** of the dust particles of gas cleaning of ferroalloy furnaces does not exceed **10 microns**. The particle shape is predominantly spherical.
- The content of manganese oxides in dusty gas cleaning systems in the production of silico-manganese is **21-34%** (mass) and in the production of ferromanganese is **20-25%** (mass). The content of chromium oxides in the dust during the smelting of ferrochrome can reach **22-45%** (mass). The content of microsilica in the dust of gas cleaning production of ferrosilicon reaches **98%**.

Basic Materials for Briquetting. Ferroalloys Production

- As well as BF flue dust, gas cleaning dust of ore smelting furnaces may contain a significant amount of carbon (**10-20% and higher**). The use of such dusts as components of the briquette mixture can help reduce coke consumption in the smelting of ferroalloys.
- Dust containing microsilica can exhibit binding properties, resulting in lower consumption of binder materials.
- Before shipment to consumers, ferroalloys are subjected to crushing and sieving on mechanized sieves to obtain the size of pieces required by the technology.
- When crushing using, for example, a jaw crusher with a slit width of 100 mm, up to **10-15%** of the fines of ferroalloys with particle sizes less than **3 mm** can be formed, direct recycling of which in the form of a charge component of the ore smelting furnace is impossible.
- The fine fraction of fines of crushing of ferroalloys and dust, captured by systems of aspiration of sites of fractionation of ferroalloys, are promising components of the briquette mixture due to the high content of the metal phase.

Basic Materials for Briquetting. DRI Production

- Sources of sludge formation in direct iron production processes: **flue gas treatment systems (Venturi tubes); briquette cooling system; hydraulic washing of belt conveyors of the finished product transportation system; de-dusting scrubbers of the briquetting system.**
- Moisture content of sludge reaches values of **30-40%**. The total iron content in sludge can exceed **55%** , metallic iron content - **22%**.
- Metallized fines are formed in the process of briquetting at the breaking of the briquette tape, at the destruction of HBI. In part, it is represented by pellets that have not fallen into the gap between the sleeves of the roller press. The proportion of particles of such a metallized material with a particle size of less than **4 mm** exceeds **92%**. The total iron content in HBI fines exceeds **87%**.
- The variety of materials suitable for briquetting is not limited to the above list, which contains a brief description of the materials widely used in practice as components of industrial briquettes in ferrous metallurgy.

Test Procedures. Mechanical Strength

- In a metallurgical furnace or reactor, the briquette must withstand the pressure of the overlying layers of the charge and maintain integrity until the desired level of metallization is achieved. In accordance with this, a set of methods for testing briquettes for mechanical strength includes methods for the quantitative determination of **impact strength, abrasion resistance, and compression strength**.
- The **impact strength** of briquettes is determined by repeatedly **dropping** a briquette from a certain height onto a metal or concrete surface. In accordance with GOST 25471-82, in order to determine the drop strength, as well as for iron ores, agglomerates and pellets, a triple drop from a height of 2 meters is used.
- According to the UK standards, 20 kg of briquette samples are dropped from a height of 2 meters 4 times and the content of the fraction with dimensions less than 5 mm will be determined. In practice, a modification of this method is used, assuming at least 4-5 drops, and the strength of briquettes for blast-furnace production is considered acceptable if such a test results in no more than 5-10% fines (pieces with sizes less than 5 mm).

Test Procedures. Mechanical Strength

- The impact strength of a briquette is also determined simultaneously with its abrasion in the so-called “tumble” testing in accordance with GOST 15137-77 “Iron and manganese ores, agglomerates and pellets. Method of determining the strength in a rotating drum ".
- The method is based on the testing of briquettes in a rotating steel drum (diameter 1000 mm, length, 500 mm, 200 turns) and the subsequent determination by sieve analysis of changes in the grain size distribution of the sample (with dimensions less than 0.5 mm, from 0.5 mm to 6.3 mm and over 6.3 mm), characterizing the ability of briquettes to resist impact and abrasion during transportation and overloads. The relative fraction of the fraction with particle sizes less than 0.5 mm characterizes the resistance of the briquette to abrasion, and the fraction of the coarse fraction (+ 6.3 mm) - its impact strength.
- A similar test procedure for iron ore, sinter and pellets is provided for by ISO 3271: 2015 and IS 6495: 2003. The quality of the sinter is considered satisfactory if its impact strength by this method is not lower than 70%. For pellets, the impact strength in the drum sample exceeding 90% is considered optimal, and the abrasion resistance is not higher than 5%.
- For briquettes, the permissible impact strength values start at 60%, and the abrasion resistance should be no more than 15%. We will discuss the reasons for this difference in PPT#5.

Test Procedures. Mechanical Strength

- The compressive strength of the briquette determines the ability of the briquette to maintain integrity under load during storage in the stack and its response to the pressure of the overlying layers of the charge in the furnaces prior to softening as a result of reduction processes.
- In relation to pellets, such a test is carried out in accordance with GOST 24765-81 “Iron ore pellets. Method for determining the compressive strength”. The method assumes the presence of a special machine that includes a device for creating a compressive load (with registration of its size) and satisfies the following requirements: the working parts of the sample holder plates, between which the pellets are placed during testing, should be flat, made of hardened steel and installed in mutually parallel planes, the speed of movement of the compressive support should be not less than 5 and not more than 75 mm/min, the maximum compressive load on the pellets should be 500 kg. This GOST corresponds to the standard ISO 4700: 2015.

Test Procedures. Mechanical Strength

- The value of the compressive strength of the pellet larger than 150 kgF per pellet is accepted for BF. The choice of such a dimension of pellet strength is due to the sphericity of its shape, which implies that the crushing force is applied at a single point.
- The compressive strength of the briquette is measured in kgF/cm^2 (or in MPa), since the applied crushing force is distributed over a part of the surface of the briquette and may vary depending on the shape of the briquette and how the load is applied.
- For cylindrical briquettes, it is necessary to separately consider options for applying a crushing load in a test machine to the load on a vertical stand and on a briquette lying on the side surface.
- In the first case, the strength of the briquette for axial compression is measured, in the second, the tensile strength when splitting. Compressive strength is determined from the ratio $R = F/A$, the tensile strength at splitting is described by the formula $R = 2F/\pi A$, where F is the compressive force, A is the area of the working section of the sample.

Test Procedures. Mechanical Strength

- Acceptable values of compressive strength depend on the type of metallurgical furnaces and reactors.
- For BF briquettes, the lower permissible compressive strength is **5.8-6.0 MPa**. Approximately such strength is enough for the briquette to withstand the pressure of the overlying layers of the charge **30 meters** or more in height.
- The internal standards of some major iron producers adopted a compressive strength of **6.0 MPa**.
- Several publications indicate overestimated compression strength criteria for BF briquettes of **150 kgF /sq.cm** and higher, which is a consequence of the incorrect analogy with the above minimum pellet compressive strength (150 kgF per pellet). Incorrectness is associated not only with different dimensions of the compressive strength of pellets and briquettes, but also with the difference in the structure of these agglomerated materials.
- Practical experience of BF operation with briquettes shows that for some briquette compositions the compressive strength did not exceed **35 kgF /sq.cm** and their use in the charge did not lead to an increase in dust extraction.
- The compressive strength requirements for briquettes for ferroalloy and steel-making, as well as for briquettes used in the production of direct reduced iron, are lower than for blast briquettes (**30-50 kgF / sq.cm**).

Test Procedures. Reducibility and Hot Strength

- To determine the reducibility using the reducibility index according to **ISO 4695: 2015**, a briquette sample weighing 500 grams is heated in an inert atmosphere to 950°C, then its isothermal reduction in an atmosphere of gases consisting of CO (40%) and N (60%) N_2 begins. The flow rate of the gas mixture is 50 liters per minute. Tests continue until the weight loss of the sample is stopped. Then the sample is cooled to room temperature in an inert atmosphere. The degree of recovery is determined by the formula (below). According to ISO 11258: 2015, the degree of reducibility and metallization of briquettes, which are components of the charge of direct reduction reactors, can be determined.
- The degree of recovery after a time (Rt) relative to iron (III) in percentage is calculated by the formula:
- $R_t = \left[\frac{0{,}111W_1}{0{,}430W_2} + \frac{m_1 - m_2}{m_0 * 0{,}430W_2} * 100\right]100$

- where: $m_0$is the mass of the sample
- m_1 is the mass of the sample immediately before the start of recovery, g
- m_2 - weight of the sample after 4 h of recovery
- W_1 - mass fraction of iron (II) oxide in the control sample prior to the study and calculated by the mass fraction of iron (II) by multiplying it by a factor of 1.286
- W_2 - mass fraction of total iron (II) in the control sample before the study,%

Test Procedures. Reducibility and Hot Strength

- The hot strength of briquettes after low-temperature recovery in a rotating drum is determined according to **ISO 4696-1: 2015 and ISO 4696-2: 2015**.
- According to ISO 4696-1: 2015 a sample of a test briquette is dried in an oven at a temperature of **105 °C± 5 °C** for two hours. Further, before testing it is cooled to room temperature. In accordance with the standard, the size of the pieces of briquettes is from **10 to 12.5 mm**.
- The test sample (500 g) is placed on porcelain pellets in a recovery tube. A thermocouple is placed in the center of the test. The tube is filled with an inert gas (argon consumption 20 l/min), and the test sample is heated until **500 °C**. Next, the sample is flushed with a reducing gas for 1 hour (composition: CO - 20%, CO2 - 20%, H2 - 2%, N2 - 58%) at a flow rate of 20 l /min, and then cooled to a temperature below **100 °C** with an inert stream gas.

Test Procedures. Reducibility and Hot Strength

- The test sample is removed from the recovery tube, its mass (m_o) is determined and placed in a tumbling drum in which the sample is subjected to destructive loads due to the rotation of the drum at a speed of **30 revolutions per minute for 10 minutes**. After that, the sample is removed from the drum and sieved by hand on sieves with a cell diameter of **6.3 mm**; **3.15 mm** and **500 microns**. Strength is determined by the results of at least two tests.
- The index of hot strength (index of damage during restoration) RDI-1 is calculated as follows:
- RDI - 1 is calculated from the following equalities:
- $\mathrm{RDI} - 1 = \frac{m_1}{m_o} 100$
- $\mathrm{RDI}\ - 1_{-3,15} = \frac{m_o - (m_1 + m_2\,)}{m_o} 100$
- $\mathrm{RDI}\ - 1_{-0,5} = \frac{m_o - (m_1 + m_2 + m_3)}{m_o} 100$
- Where m_o is the mass of the test after recovery, but before rotation in the tumbling drum, g
- m_1 is the mass of the oversize fraction remaining on the sieve with a 6.3 mm cell, g
- m_2 is the mass of the oversize fraction remaining on the sieve with a 3.15 mm cell, g
- $m_3$is the mass of the superlattice fraction remaining on the sieve with a 500 µm cell, g

Test Procedures. Reducibility and Hot Strength

- According to **ISO 4696-2: 2015**, the preparation of briquette samples is carried out similarly to the first part of the standard, with the only difference that the size of briquette samples is **16 to 20 mm**. Heating of the sample to a temperature of **550 °** C is carried out in an inert atmosphere with a gas flow rate of 15 l/min.
- After reaching the specified temperature, the sample is flushed with a reducing gas (CO - 30%, N2 - 70%) at a flow rate of 15 l/min for 30 minutes and then cooled with an inert gas to a temperature of less than 100 ° C. The cooled sample for 30 minutes is subjected to breaking loads in the drum, rotating at a speed of 30 revolutions per minute. After removing the material from the drum, it is sifted by hand on a sieve with **2.8 mm** diameter holes. At least two tests are carried out with each sample.
- The hot strength index **RDI– 2.2.8** is calculated as:
- $\mathrm{RDI} - 2_{-2,8} = 100 - \frac{m_1}{m_o} 100$
- *Where m_o is the mass of the test portion after recovery and before rotation in the drum, g*
- m_1 is the mass of the oversized product; retained on the sieve 2.8 mm g

Test Procedures. Reducibility and Hot Strength

- The ISO 13930 standard describes a technique for dynamically determining the parameters of low-temperature disintegration of iron ores as components of a blast furnace charge and can be used to test blast briquettes. The tests of briquettes are carried out in a rotating pipe at a temperature of 500 **°C** in the atmosphere of a mixture of gases CO (20%), CO_2 (20%), H_2 (2%) and N_2 (58%). The flow of reducing gas, preheated to 500 **°C**, is maintained at 20 liters per minute. After one hour, the gas supply and pipe rotation is stopped, the material is cooled to temperatures below 350 **°C** when an inert gas is supplied to the pipe with the same flow rate 20 l/m. Then the gas supply is stopped, and the material is cooled to 100 **°C** and scattered into three fractions as well as the method according to ISO 4696 standard.
- Low-temperature disintegration indicators are calculated using the formulas:
- $LTD_{+6.3} = \frac{m_1}{m_0} * 100$
- $LTD_{-3.15} = \frac{m_0-(m_1+m_2)}{m_0} * 100$
- $LTD_{-0.5} = \frac{m_0-(m_1+m_2+m_3)}{m_0} * 100$
- Where m_o , the mass of the material after the test, including the mass of dust in the dust collector, g;
- m_1, the mass of particles of the sample with dimensions greater than 6.30 mm, g;
- m_2, the mass of particles of the sample with dimensions of more than 3.15 mm, g;
- m_3 is the mass of particles in a sample with dimensions greater than 0.5 mm, g;
- $LTD_{+6.3}$ - disintegration strength parameter;
- $LTD\text{-}_{3.15}$ - disintegration index;
- $LTD_{-0.5}$ - index of disintegration abrasion.

Test Procedures. Reducibility and Hot Strength

- The ISO 7992: 2007 standard describes a method for testing iron ore materials for blast furnace smelting for reducibility under load and can also be used to study the behavior of briquettes. The reducibility is determined by applying a static load (**50 kPa**) to a layer of test materials (**1200 g**) of a certain size (10-12.5 mm) when heated to **1050 °C** in an atmosphere of CO (40%), H2 (2%) and N2 (58%). During the test, the loss of mass of the material layer and the pressure drop of the gas mixture are measured. Gas consumption is maintained at 83 liters per minute. Indicators of recoverability under load are determined by the relations:
- $LTD_{+6.3} = \frac{m_1}{m_0} * 100$
- $LTD_{-3.15} = \frac{m_0-(m_1+m_2)}{m_0} * 100$
- $LTD_{-0.5} = \frac{m_0-(m_1+m_2+m_3)}{m_0} * 100$
- Where m_o , the mass of the material after the test, including the mass of dust in the dust collector, g;
- m_1, the mass of particles of the sample with dimensions greater than 6.30 mm, g;
- m_2, the mass of particles of the sample with dimensions of more than 3.15 mm, g;
- m_3 is the mass of particles in a sample with dimensions greater than 0.5 mm, g;
- $LTD_{+6.3}$ - disintegration strength parameter;
- $LTD\text{-}_{3.15}$ - disintegration index;
- $LTD_{-0.5}$ - index of disintegration abrasion.

Test Procedures. Reducibility and Hot Strength

- The Burghardt test (ISO/DOC 3772), based on measuring the gas permeability and shrinkage of a layer of material placed in a heated reaction chamber, can also be used to test the reducibility of briquettes under load.
- Samples of briquettes are crushed and selected for testing fraction with a particle size of 8-20 mm. The mass of the prepared sample is 1000 g. The sample is tightly placed in a glass, which is placed in the reaction chamber and set the load to 1.5 kg/cm. The samples are subjected to reduction in H2 atmosphere (with a flow rate of 1 m3/h) for **three hours** at a temperature of **900 and 800 ° C**. During the period of heating and recovery, the temperature in the retort, the shrinkage of the layer and the change in the weight of the sample are continuously recorded. The degree of reduction is calculated by the formula:
- $R = \frac{m_0 - m_f}{m_0(0{,}429Fe_{tot} - 0{,}111FeO)}$
- Where m_0 is the mass of the initial sample, g
- m_f is the mass of the recovered sample, g;
- Fe_{tot} - mass fraction of total iron in the original sample,%
- FeO is the mass fraction of ferrous oxide in the initial sample,%.

Test Procedures. Porosity

- The porosity of briquette is one of their most important properties and determines their reducibility. It can be measured by:
- **Direct observation**
  - visual optical (micropores; larger than 10-75 μm)
  - light microscopy (number, specific volume, distribution; 0.5-100 μm)
  - SEM (number, specific volume, distribution; 0.002-0.5 μm)
- **Capillary**
  - defects detection (micropores; + 0.1 μm)
  - Permeability (pore size, distribution, specific surface; 0.01-100 μm)
- **Mercury porosimetry** (pore size, distribution, specific surface; 0.0015-800 μm)
- **Adsorption structural** (pore size, distribution, specific surface; 0.0003-0.05 μm)
- **Gas and Liquid Pycnometry** (total porosity, volume, distribution; 0.0002-0.001 μm)

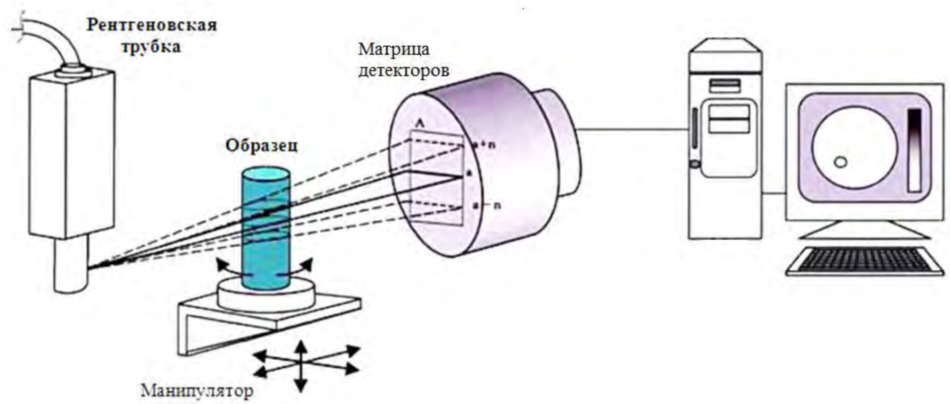
Test Procedures. Porosity

- The microstructure of the specimens and the specifics of their porosity can be investigated with the use of scanning electron microscope (**SEM**) in the range of the pore sizes **0.002-0.5 microns** with a guaranteed resolution of 3.5 nm and **STIMAN** software to quantitatively analyze SEM images obtained in the reflected-electron regime.
- The porosity of briquette is studied on material that was freshly cleaved from the specimens' surface. Morphological studies of the microstructure is performed in the secondary-electron regime and allowed us obtain high-quality half-tone images over a broad range of magnifications.
- The **STIMAN** method makes it possible to obtain correct images with distinct boundaries between the pores and the particles.
- Quantitative analysis of the microstructure is carried out using the software “**STIMAN**” using two methods. 1 - on a series of SEM images obtained in the mode of reflected electrons. This mode allows you to get the correct images with clearer boundaries between the pores and particles. 2 - a comprehensive analysis of a series of SEM images and µCT images of sample sections obtained at various magnifications.

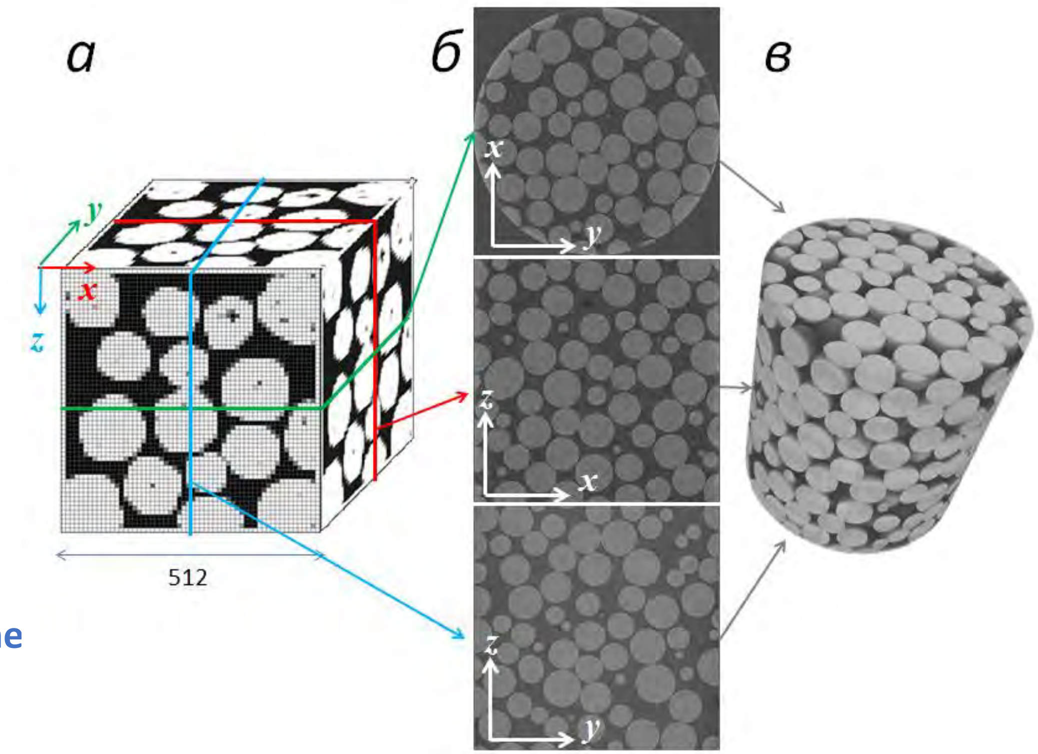
Test Procedures. Porosity

- The distribution of the macropores (with sizes greater than **100 μm**) can be determined by computer-assisted X-ray tomography. The images are captured with a Yamato TDM-1000 x-ray computer microtomography (Japan). The magnification is 32 and the resolution was 11 μm.
- X-ray computed microtomography (**μCT**) allows visualizing the three-dimensional internal structure of an object **without disturbing its integrity**.
- The principle of operation of a computerized tomography is based on the x-ray transmission of the object under study by a thin beam of x-rays. Passing through the object, X-rays are absorbed by various structural elements in varying degrees. Then X-rays are recorded by a detector system, resulting in a shadow projection, resembling X-ray image. By rotating the sample around the axis, a series of shadow projections is typed, the totality of which is the reconstruction of the internal structure of the object.
- As a result of the reconstruction, a cubic data volume is obtained, divided, as a rule, into 512 voxels in each direction. The way of presenting data can be different: orthogonal halftone sections, which can be carried out anywhere in this volume, it is possible to obtain a volumetric representation. The resolution or size of a pixel (voxel) is determined by the sample diameter, given by the number of pixels (voxels) of the image (as a rule, 512 (x512x512)).

Test Procedures. Porosity



The principle of operation and the main components of the computer X-ray tomography TDM 1000H-II



a) initial reconstructed data volume, b) orthogonal halftone sections, c) three-dimensional image

Test Procedures. Porosity

The degree of open porosity determined by the STIMAN method is very consistent with the open porosity measured by liquid saturation in a vacuum in accordance with the standard DIN 51056 (GOST 26450.1–85).

<table>
<tr><th rowspan="2">Sample</th><th rowspan="2">Micro-morphological parameters</th><th colspan="6">Pores category</th><th rowspan="2">n, %</th><th rowspan="2">K_a, %;</th></tr>
<tr><th>D_1 <0.1 µm</th><th>D_2 0.1-1.0 µm</th><th>D_3 1.0-10 µm</th><th>D_4 10-100 µm</th><th>D_5 >100 µm</th><th>D_{max} µm</th></tr>
<tr><td rowspan="3">Vibropressed briquette</td><td>N, %</td><td>1.9</td><td>15,9</td><td>35,8</td><td>46,5</td><td>-</td><td rowspan="3">91.4</td><td rowspan="3">13.37</td><td rowspan="3">19.07</td></tr>
<tr><td>K_f</td><td colspan="5">0.25-0.33; 0.42-0.50</td></tr>
<tr><td>K_f</td><td colspan="5">0.33-0.42; 0.50-0.58</td></tr>
</table>

$n_{из}$– total porosity calculated by SEM image.

K_f – pore shape factor It is calculated as the ratio of the minor and major axes of the ellipse inscribed at the time. For isometric pores, K_f = 0.66–1.00, for anisometric pores, K_f = 0.1–0.66, for slit-like pores, $_{Kf}$<0.1.

K_a – anisotropy coefficient, or the degree of orientation of solid structural elements. Evaluated using the software “STIMAN”. For the samples studied, the presence of a medium-oriented microstructure is characteristic.

THANK YOU FOR ATTENTION!

Extrusion vs Sintering. Competition or Synergy?

Dr. Aitber Bizhanov

Briquetting vs Sintering

- The smelting of iron and steel, in addition to the obvious 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 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 with the requirements of metallurgical processing.

Briquetting vs Sintering. Comparison criteria

- Metallurgical Properties
- Maximum Equipment Capacity
- Environmental aspects

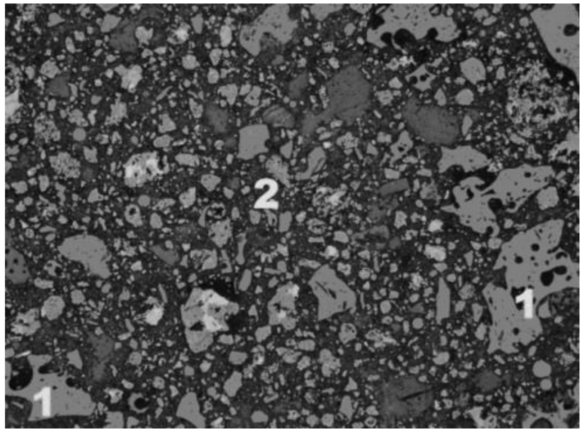
Briquetting vs Sintering. BREX Hot Strength

- Hot strength of the 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

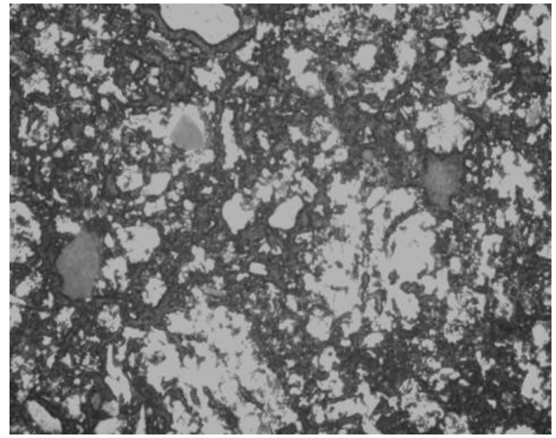
Agglomerated Products	RDI (+6.3), %
Brex No.4* (basicity 0,75)	**96.5**
Brex No.2* (basicity 1,93)	**61.9**
Sinter (basicity 1,2)	**64**
Sinter (basicity 1,4)	**60**
Sinter (basicity 1,6)	**77**

BREX components	Mass Share, %	
	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

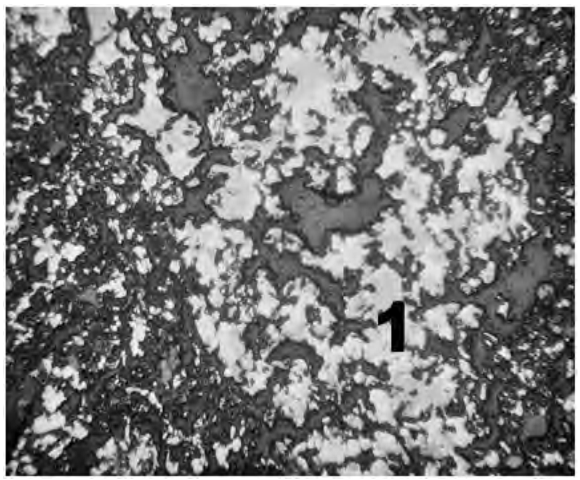
Briquetting vs Sintering. BREX Hot Strength



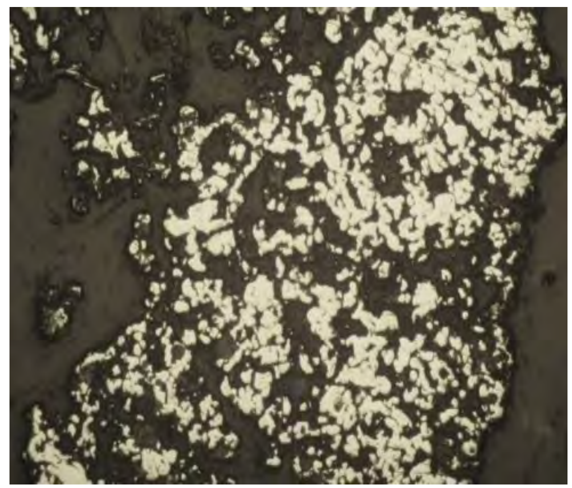
1 – Coke breeze; 2 – iron ore



Core, 900 °C



1 – metal, shell, 900°C,



Shell,   1100 °C

Briquetting vs Sintering. BREX Hot Strength

Agglomerated product	ISO 13930, %			ISO 4696-1, %		
	LTD +6,3	LTD - 3,15	LTD -0,5	RDI 1-1 +6,3	RDI 1-1 - 3,15	RDI 1-1 - 0,5
BREX	89,95	8,68	8,32	94,31	4,67	4,14
BREX				93,72	5,93	5,31
BREX				91,52	7,67	7,24
BREX				95,65	3,64	3,13
BREX				95,24	4,02	3,55
Sinter	65,03	13,93	4,47	76,54	7,57	1,32
Pellets	94,87	3,78	3,49	97,99	0,71	0,15
Pellets	80,7	10,45	7,79	80,49	10,19	5,3
Pellets	82,5	13,94	12,29			

BREX (diameter of 19 mm, the 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 / cub.cm.

Briquetting vs Sintering. BREX Hot Strength

Samples of BREX were heated to 1000 ° C in a neutral atmosphere (nitrogen) for 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 the assessment of the safety of the form.

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

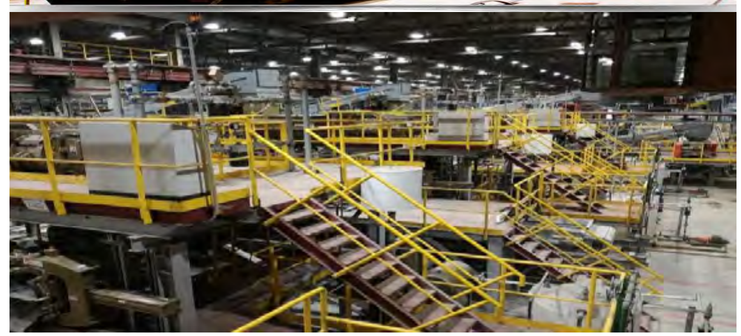
Extrusion vs Sintering. 100% BREX in BF

BF furnace performance	**100% ore**	**80% BREX**	**100% BREX**
Consumption, kg/t:			
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

Extrusion vs Sintering. 100% BREX in BF

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

Briquetting vs Sintering. Maximum Equipment Capacity



- Capacity of sintering belt: **1500–10000** tons per day
- [Capacity of roasting machines: **2500–9000** tons per day]*
- Capacity of extrusion plant: **2000-7000** tons per day; Saudi Red Bricks Plant, 1 million bricks per day.
- NLMK BREX-making Plant: **2000** tons per day.
- * for comparison

Briquetting vs Sintering. Environmental aspects

- The Best Available Technologies (BAT) concept was first time used in the 1992 by OSPAR Convention for the protection of the marine environment of the North-East Atlantic for 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), work performed, services rendered;
- - economic efficiency of its implementation and operation;
- - application of resource-and energy-saving methods;
- - period of its implementation;
- - industrial implementation of this technology on two and more objects having a negative impact on the environment.
- Regarding the processes of 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 vs Sintering. Environmental aspects

Production of sinter as a BAT

- Sinter production, carried out by burning solid fuel in the air flow filtered through a layer of iron ore charge, remains the 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 when coming of the sintering belt; cooling, crushing and screening of the sinter cake after sintering);
- **carbon monoxide (CO) emissi**ons which, due to the combustion characteristics of the distributed solid fuel in the sintering layer (due to incomplete combustion), are technologically justified;
- **emissions of sulfur dioxide (SO_2),** depending on the sulfur content in coke fines, which is used as fuel, as well as the composition of iron ore charge;
- **emissions of nitrogen oxides (NO_x)** from combustion in incendiary 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.

Extrusion vs Sintering. Environmental aspects

Production	Share of production in total emissions of components, %			
	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

Extrusion vs Sintering. Environmental aspects

Production of sinter as a BAT

- A priority source of emissions during sinter production is the processes of combustion. To ensure the goals of minimizing the impact on the environment and reducing the consumption of resources, the following technical solutions which can be attributed to the best available in the sinter production are applied:
- - reduction of fuel consumption due to **rational charge preparation** (optimization of granulometric composition of charge components, the component composition of the charge. the size of coke fines, etc.);
- - increase in the height of the sintered layer (in most cases requires some amount of reconstruction 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 volumes of recirculation are possible, but under the conditions of moisture content, it cannot exceed 35%; in any case, the processing of sinter gases requires an obligatory additional supply of air (oxygen); organization of the flow of sinter gases is associated with an additional power consumption).
- The above measures, improving the classical 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 obtain a specific emission at the level not higher than **10 kg/t** of sinter).

Extrusion vs Sintering. Environmental aspects

Production of pellets as a BAT

- Pellets production refers to pyrometallurgical technologies, since the strengthening of agglomerated granules (raw pellets) requires high temperature (1250-1350 ^{o}C) 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 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
- Due to stoichiometric combustion of natural gas, there is no chemical under burning, so carbon monoxide is practically not formed.
- Measures to reduce emissions of nitrogen oxides 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%).

Extrusion vs Sintering. Environmental aspects

Stiff extrusion briquetting as a BAT

- Pyrometallurgical technologies of agglomeration are associated with the formation of essential emissions.
- The technology of briquetting by the method of stiff vacuum extrusion is devoid of such disadvantages. The technology does not require heat treatment of raw briquettes, it allows to obtain a durable material.
- The main sources of environmental impact in the production of BREX are the following:
- - warehouse of raw materials (unloading operations of charge materials, storage and feed into the technological process);
- - Department of dosing, mixing, extrusion;
- - brex unloading, stacking and handling of stacks (the attrition of the fine fraction. shipment to consumers);
- - aspiration system of brex making unit.
- The main component of emissions into the atmospheric air in the production of brex is inorganic dust. According to the assessment, the specific emission of inorganic dust in the production of brex does not exceed 0.05 kg/t.

Extrusion vs Sintering. Comparison of Agglomeration Technologies. Environmental aspects

#	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	≤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	15.0-33.0
3	Investments, USD/t***	~5000	~5500	~2000
4	Implementation period, years****	3	3	2

Extrusion vs Sintering. Comparison of Agglomeration Technologies. Environmental aspects.

In 2017 Stiff Extrusion has been included into the List of Perspective 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).

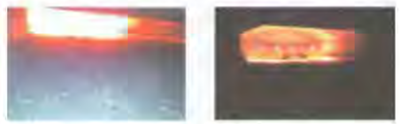


Рисунок 7.3 — Работа горелок ГНП.Р-250-31 в зажигательном горне агломашин

7.1.8.2 Применение селективного каталитического восстановления

Использование антрацита позволяет снизить выбросыNOxпримерно 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.

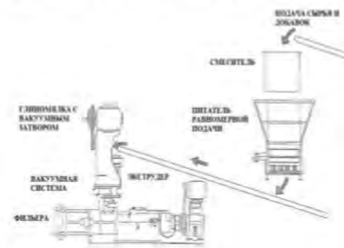


Рисунок 7.4 — Технологическая схема производства брикетов методом жесткой экструзии [165]

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).

А Б

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

Extrusion vs Sintering. Sinter Partial Substitution. 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** program.
- The blast furnace smelting in a furnace with a volume of 4297 m^3, operating under the conditions of NLMK, is 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 caking coal is determined on the basis of the content of cement (6%) and bentonite (1%) in the composition of the brex, taken on the basis of the results of preliminary tests, 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**.

Extrusion vs Sintering. Sinter Partial Substitution. Numerical Simulation

- The basicity of the sinter is determined based on the accepted concept of replacing the sinter with BREX and their 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 phases predominate, providing an increase in its strength compared to the sinter with basicity in the range of **1.5–1.7** characteristic of the sinter, produced in NLMK.
- The coal content in BREX was determined by the method developed based on the results of studying the structural composition of brex after heating in a reducing atmosphere to 1400 ^{o} C, when, after reaching almost complete metallization, unreacted coke breeze particles remained in the BREX structure due to its excessive content in the mixture for briquetting.

Extrusion vs Sintering. Sinter Partial Substitution. 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, the calculated compositions of sinters with 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
Caking 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 (170)	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

Extrusion vs Sintering. Sinter Partial Substitution. Numerical Simulation

BF operation parameters	Basic variant	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, nm³/t	125	125	35
Pulverized coal consumption, kg/t	-	-	160
Blast rate, m³/min	7483	7568	7340
Blast temperature, °C	1240	1240	1240
O_2 content in blast, %	30.5	30.5	30.5
Blast humidity, g/m³	10	10	20
Top gas yield, m³/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/m²·day	92.48	93.66	94.3
Reduction efficiency,%	94.2	94.2	94.2

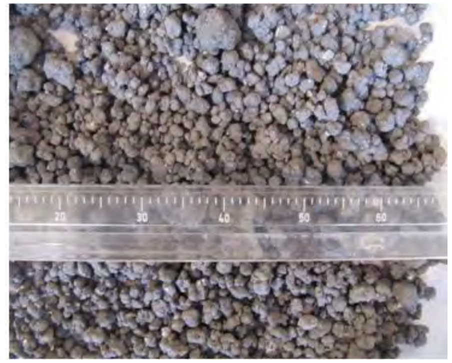
- The simulation was carried out for [Si] = 0.4 %; [C] = 4.8 %; $T_{pig\ iron}$=1500 ° C;
- The results showed that due to the carbon contained in the BREX, the coke consumption for hot metal production is reduced compared to the base case by **10%**.
- When pulverized coal is injected with a flow rate of 160 kg/t of hot metal, coke consumption of **284 kg/t** of hot metal is achieved.
- When blowing natural gas with a consumption of 125 m³/t of hot metal, coke consumption of **354 kg /t** of hot metal is achieved.

Extrusion vs Sintering. Embryos for Sintering

- A negative impact on pelletizing has a fraction of 0.2-1.6 mm (intermediate), which is not involved in the work. In a granular mixture, the grains of this fraction are distributed in the gap between the lumps, reducing the porosity of the layer and the equivalent diameter of the channels.
- Studied sintering mixture consists of fractions: -0.4 mm (70.4%), 0.4-1.0 mm (11.7%), 1-5 mm (8.3%), 5 - 10 mm (6.8%), +10 mm (2.8%), i.e. the ratio between its crumpled, crumpling and intermediate parts is approximately **70:15:15** and is characterized by a relatively small number of pelletizing centers. As a result of the inefficient process of pelletizing, the granulated mixture contains up to **34%** of fractions **0.5-1.0 mm**, reducing the gas permeability of the layer, and up to **14%** of aero active fractions less than **0.5 mm**, which leads to a significant reduction performance of sinter process.
- The problem can be solved by introducing large fractions of any materials or waste suitable for agglomeration into the mixture. In practice, the solution is to use medium fractions (from 4-6 mm to 9.5 mm) of crushed converter slag or raw pellets. This direction also includes the use in the mixture of small fractions of sinter (less than 5 mm).

Extrusion vs Sintering. Embryos for Sintering

- Utilization of extruded embryos made it possible to:
- increase the productivity of the sintering plant by 4–5% compared to sintering of mixture with granules or crushed briquettes;
- increase the strength of granules by 8-32%;
- improve crumpling ability of the charge by 10.0-29.4% and increase productivity of sintering machine by 14.8-25.6%.



Pellets

Extruded briquettes

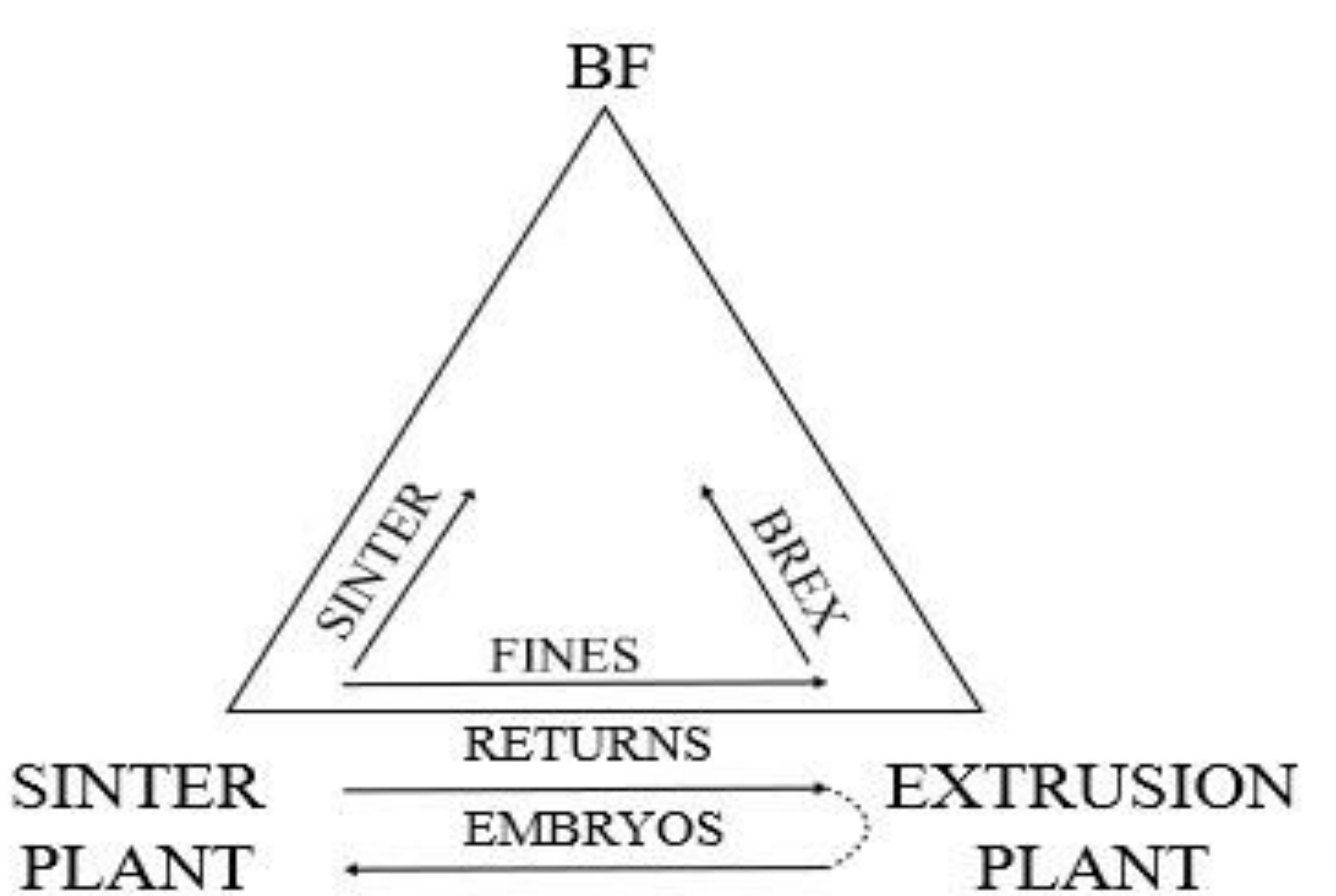
Crushed briquettes

Initial State

Extrusion vs Sintering. Synergy

- When replacing 50% of the sinter production with the production of briquettes:
- - reduced consumption of iron ore concentrate;
- - no flew or aspiration dust is used;
- - eliminated sinter returns, by improving the quality of sinter;
- - limestone consumption increases;
- - increases the consumption of dolomite;
- - solid fuel consumption increases;
- - the consumption of skip sinter is reduced;
- - the pellet consumption increases;
- - reduced consumption of dry skip coke takes place;
- - increases the basicity of the sinter (**3.65**);
- - reduced the mass fraction of iron in the sinter;
- 50% reduction in emissions (CO_2 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**.

Extrusion vs Sintering. Synergy



THANK YOU FOR ATTENTION!

Briquetting. Problems and Prospects

Dr. Aitber Bizhanov

Briquetting? Is it Required? Alternatives.

- Fluidized Bed
- DC Furnaces
- Reduction Smelting
- Encapsulation
- Mold casting

Briquetting? Is it Required? Alternatives.

Fluidized Bed

- In such units, in contrast to shaft furnaces, the charge particles randomly move in a certain volume and, with correctly chosen values of the gas flow rate, do not leave the working chamber. And if in the shaft furnace the charge particles are in direct contact with each other, which determines the specificity of heat and mass transfer processes in a dense layer, then in a fluidized bed conditions such processes occur individually for each particle.
- Restrictions on the grain size distribution of iron ores. In the well-known FINMET process, the proportion of ore particles with a size of less than 0.15 mm should not exceed 20%.
- The degree of metallization achieved on plants commissioned in 1999 and 2000 in Australia and Venezuela based on this process reached 92% with an average carbon content of 1.3%. Natural gas consumption was 13-16% higher than in shaft furnaces. In 2005, the plant in Venezuela ceased to exist, and the plant in Australia has not yet reached its design capacity.

Briquetting? Is it Required? Alternatives.

Fluidized Bed. CIRCORED

- This process has also used agglomeration. For effective metallization of fine materials (gas cleaning dust), their preliminary agglomeration was necessary, for which the company Outokumpu developed and patented a process to produce micro granules.
- The only industrial installation operating under the CIRCORED process was commissioned in **May 1999** in Trinidad. The actual annual production of the metallized product was 360 thousand tons, with the project capacity being 500 thousand tons. The plant was shut down in **2005**.

Briquetting? Is it Required? Alternatives.

DC Furnaces

- **Aktobe Ferroalloy Plant** (Republic of Kazakhstan). The construction of the workshop was started in **2010**.
- The new production consists of four **DC furnaces** of new generation with a total capacity of **440 kty** of high-carbon ferrochrome. The total cost of the project is about **843 million dollars**.
- During the operation of the furnaces, the following indicators were achieved - the consumption of fine chromium ore is **3850 kg/ton** of chromium, the consumption of reducing agent (coal) **is 950 kg/ton** of chromium, which practically corresponds to the performance of the process on alternating current.
- The specific energy consumption was higher than that of AC furnaces - **7552** kWh/ton of chromium versus **6640** kWh/ton of chromium. This is due to the open arc burning on the surface of the bath and, accordingly, to large heat losses by radiation on the walls and roof of the furnace.
- Unfortunately, so far, the furnaces have not reached their design capacity, which indicates the absence of convincing arguments in favor of working on un-agglomerated raw materials.

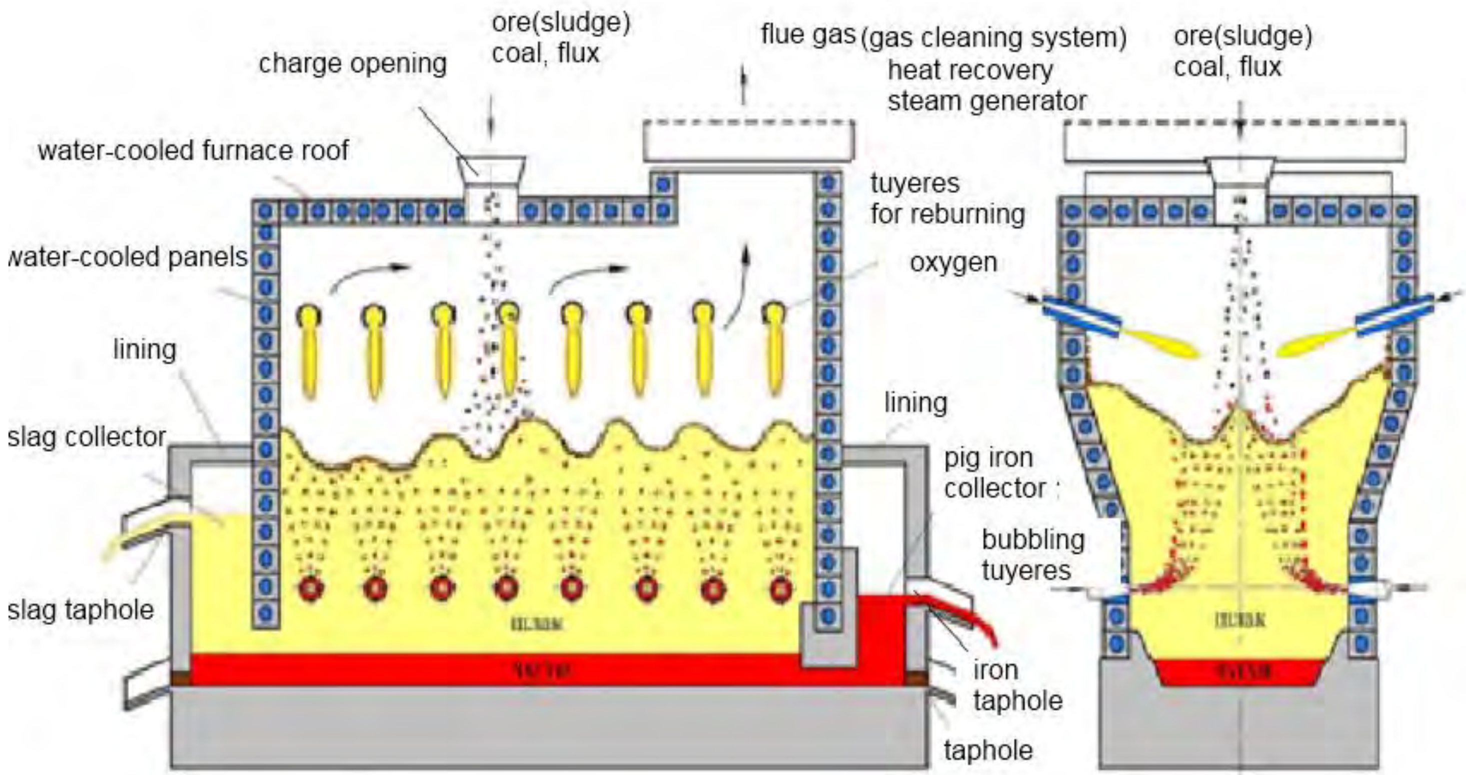
Briquetting? Is it Required? Alternatives.

Reduction Smelting. ROMELT

- An attempt to avoid agglomeration as part of the reduction smelting process was undertaken in connection with the development of the well-known **ROMELT** process, developed in 1979 by employees of the Moscow Institute of Steel and Alloys (Romenets V.A. and others) and implemented in 1985 as large-scale pilot plant at the Novolipetsk Steel Company (NLMK). This technology, unfortunately, did not receive wide distribution as well.
- **ADVANTAGES**: Production of pig iron in one stage from unprepared iron ore materials, without the use of coking coal and natural gas. The possibility of selective, integrated processing of waste metallurgical processing. The possibility of burning low-grade coal grades to produce conditioned generator gas and power generation.
- **DISADVANTAGES**: High specific energy consumption, low quality of produced iron, loss of valuable non-ferrous metals with slag. One of the reasons for the failure of the project was the formation of a significant amount of dust.

Briquetting? Is it Required? Alternatives.

ROMELT

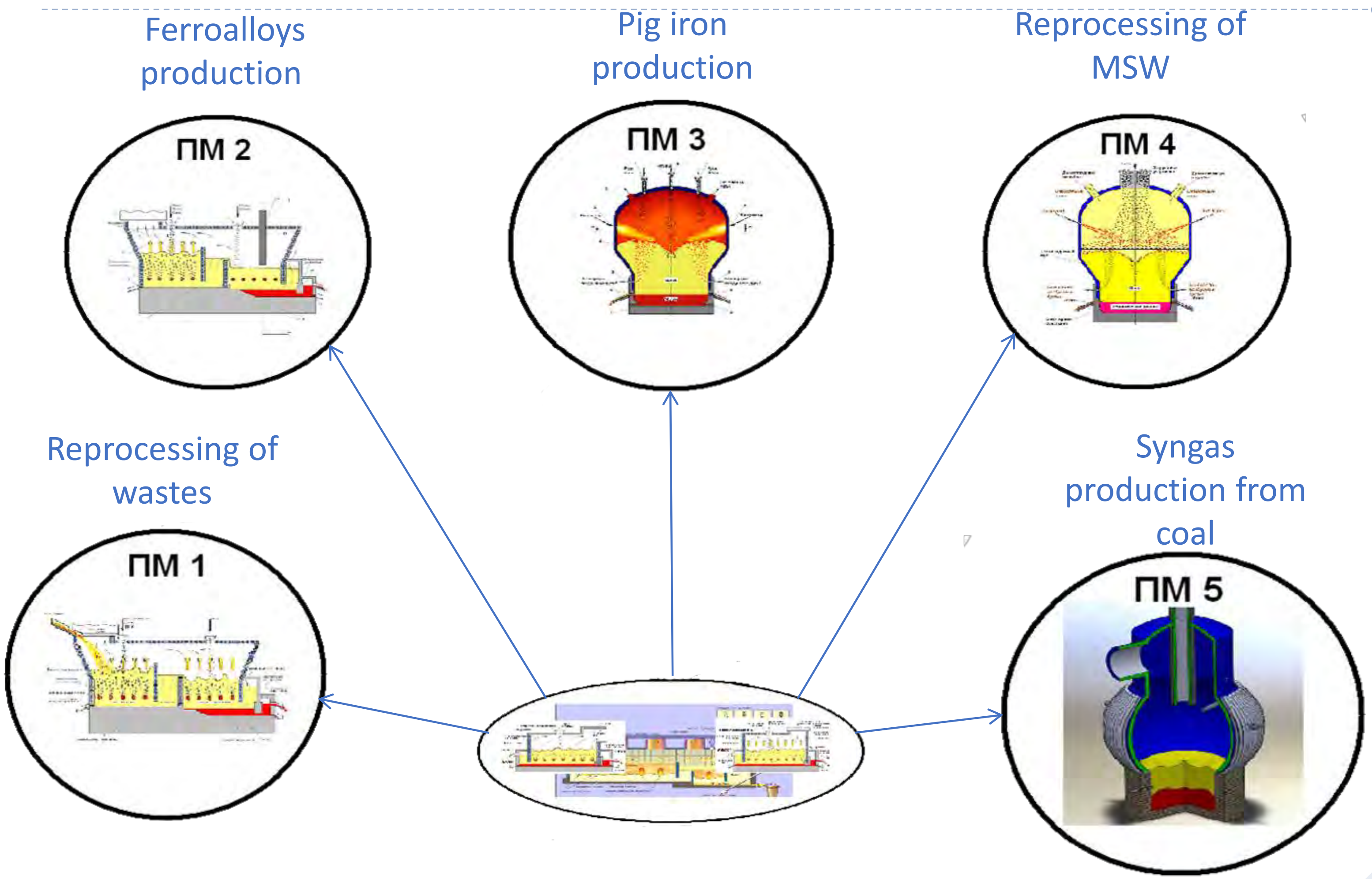


Briquetting? Is it Required? Alternatives.

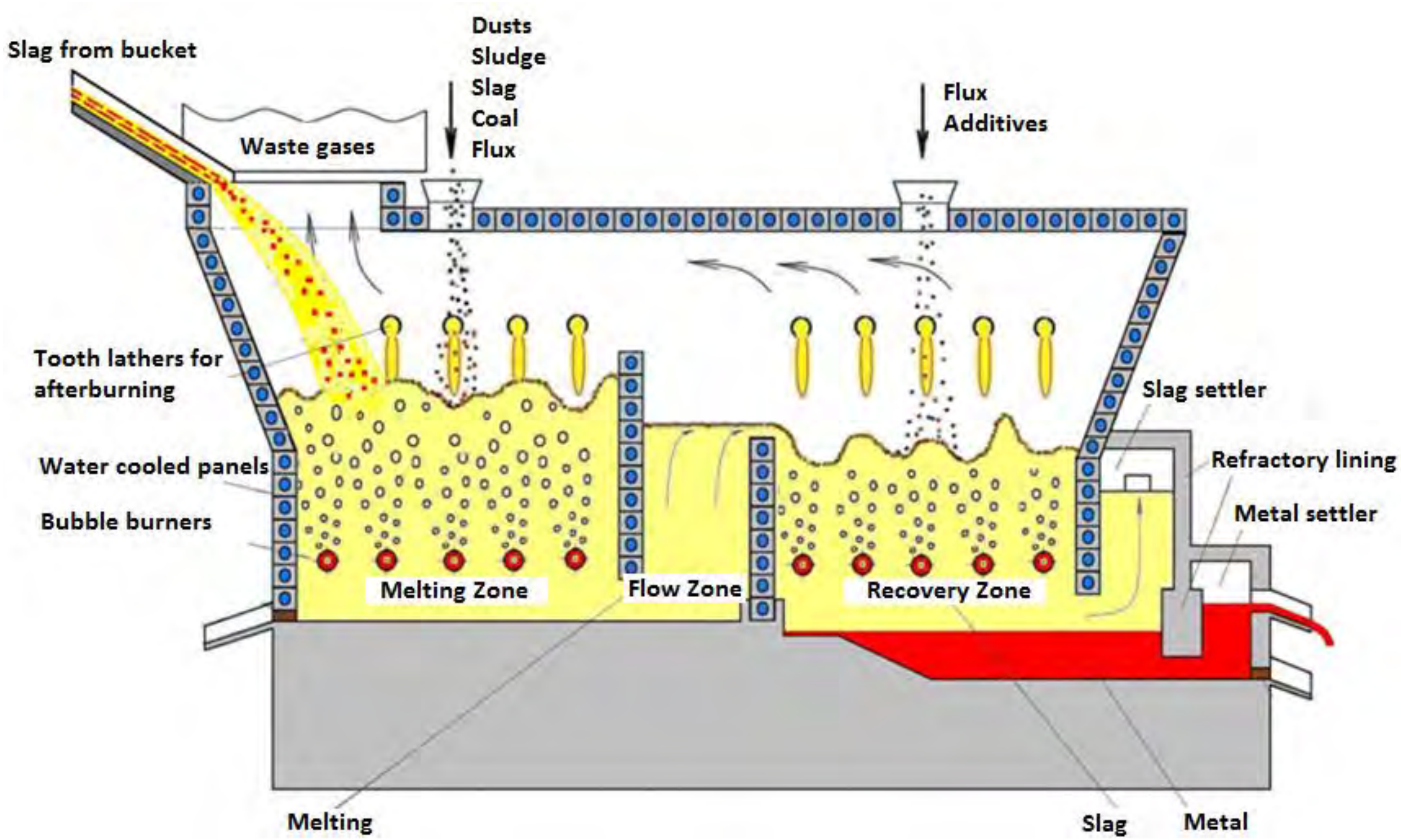
Reduction Smelting

- BARBOTAGE (BUBBLING) Technology: In barbotage technologies main processes are carried out in a molten pool where materials bubbled with oxygen containing gas.
- Barbotage technologies are applied: in the chemical industry, ferrous and nonferrous metallurgy and energy industry.
- High intensity, flexibility, high specific capacity, high selectivity of separation of useful components to industrial products, final products are in a single unit, energy efficiency, environmental friendliness, opportunities for recycling industrial wastes, low specific investment and operating costs.

Briquetting? Is it Required? Alternatives.



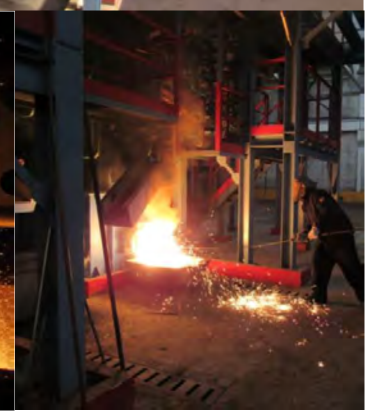
Briquetting? Is it Required? Alternatives.



Briquetting? Is it Required? Alternatives.

BUBBLING TECHNOLOGY. FULL-SCALE TESTING. 2019.

Developer – Dr. Gennady Podgorodetsky
NUST MISIS



Briquetting? Is it Required? Alternatives.

Encapsulation

It was suggested to pack concentrates in ... tin cans. And even laboratory experiments seemed to confirm the fundamental possibility of introducing un-agglomerated material into the charge of the ore-smelting furnace, but a simple calculation showed that for a similar recycling of the resulting dispersed material would require construction, next to the ferroalloy plant, a separate cannery…

Briquetting? Is it Required? Alternatives.

Mold casting

Pouring prepared water mixture of briquetted material with cement (up to 20%) into molds for subsequent curing.

- Briquette was placed in temperature-resistant silicone molds (10.5 $\times 6 \times 3 cm^3$) and stored at room temperature (20 °C) for **96 h** to ensure an appropriate mechanical strength
- Low hot strength of briquette. Destruction at 700-800 degrees Celsius.

Briquetting. Problems and Prospects.

- CHARGE PREPARATION
- PRODUCTION OF BRIQUETTES
- PROCESSING OF GREEN BRIQUETTES

Briquetting. Problems and Prospects. Charge Preparation.

- CHARGE PREPARATION
  - CHOICE OF MATERIALS
    - Chemical composition
    - Physical properties
    - Mineralogy
    - Choice of Binders
    - Briquettes composition
  - MATERIALS PROCESSING
    - Drying
    - Pulverization
      - Grinding
      - Vortex bed apparatus
    - Souring (Homogenization)
    - Selective withdrawal of elements
      - Vortex bed apparatus
      - Dezincing
      - De-Oiling

Briquetting. Problems and Prospects. Charge Preparation.

CHOICE OF BINDERS

- Binderless
- Inorganic
- Organic
- Polymeric (BASF, AMBERSHAW)

Briquetting. Problems and Prospects. Charge Preparation.

BRIQUETTE COMPOSITION

- The selection of the composition of the briquette should be based on the need to process the entire set of dispersed natural and anthropogenic materials.

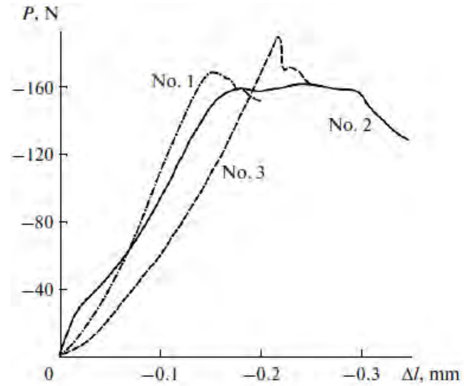
- It is necessary to consider the specific features of the briquetted materials and to achieve compliance of the chemical composition of the briquette obtained with the requirements of the metallurgical processing (content of the main element, cold and hot strength , basicity, etc.).

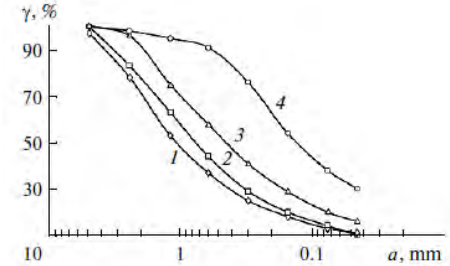
- In some cases it is advisable to choose several different compositions of briquettes.

Briquetting. Problems and Prospects. Charge Preparation. Pulverization.

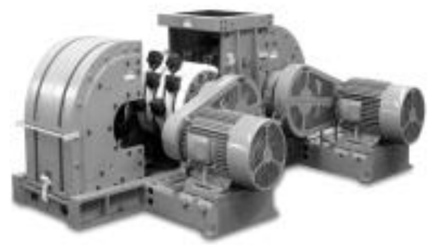
Extruded briquettes made of coke breeze(94%; 5% PC; 1% Bentonite.

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



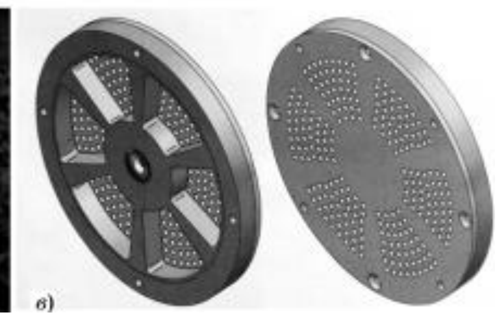


Granulometric composition of coke breeze in the following states: (1) initial and (2–4) after additional grinding in a hammer mill, in a roll crusher, and double extrusion in an extruder, respectively.



a)

б)



в)

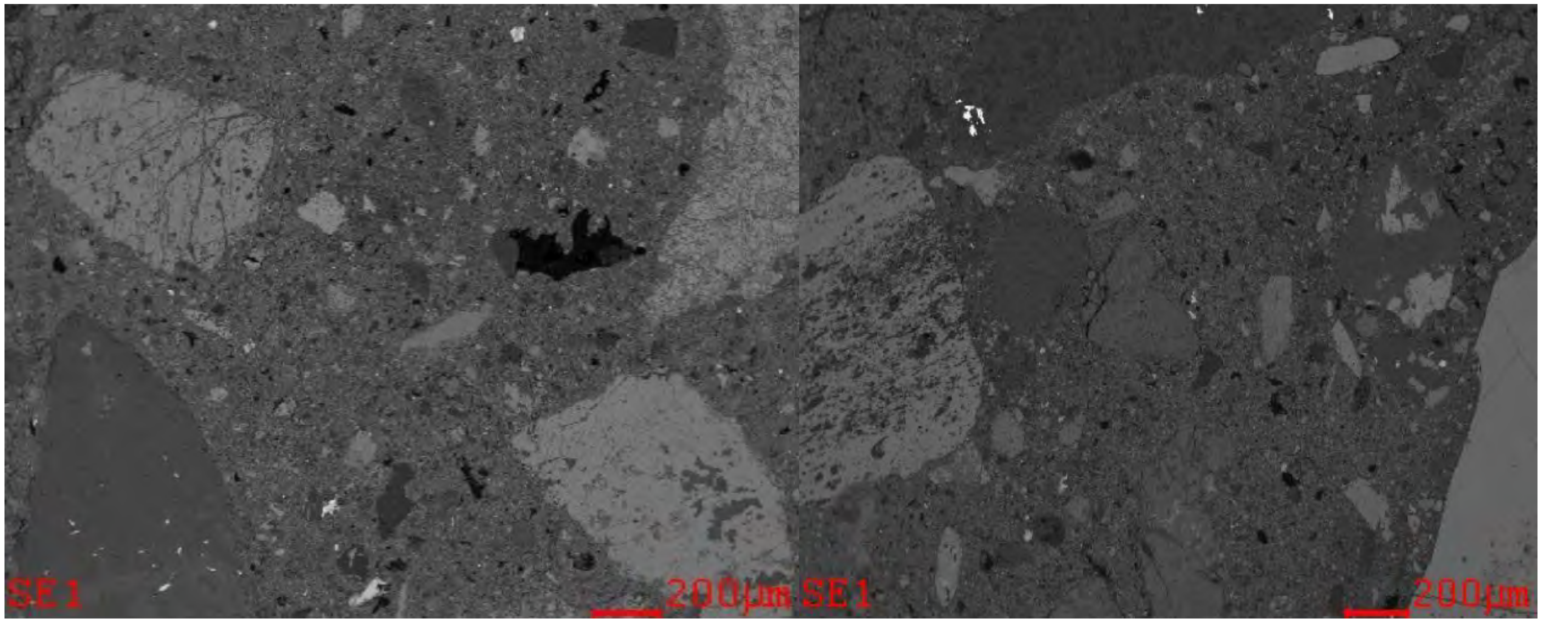
Briquetting. Problems and Prospects. Charge Preparation. Souring.

- Souring (Homogenization) consists of souring of the mixture with the addition of a plasticizer and subsequent storing of such a mixture for some time before further processing.
- The sheared mix was subjected to the souring over the course of 4 hours.
- The increase in compressive strength a week after manufacturing:
- 14.2% for brex No.1;
- 7.62% for brex No.2;
- **54.5%** for brex No. 3**.**

Composition of brex	No.1	No.2	**No.3**
Manganese ore concentrate	80	66	**56**
Bag house dust	14	28	**38**
Portland cement	5	5	**5**
Bentonite	1	1	**1**

Strength/ brex No	**No.1**	**No.1 – soured**	**No.2**	**No.2 – soured.**	**No.3**	**No.3 – soured**
Day 1 (MPa)	**2.97**	**2.76**	**2.69**	**5.76**	**4.10**	**6.17**
Day 3 (MPa)	**4.86**	**4.86**	**6.07**	**7.83**	**6.10**	**10.20**
Day7 (MPa)	**6.67**	**7.62**	**13.13**	**14.34**	**10.17**	**15.72**

Briquetting. Problems and Prospects. Charge Preparation. Souring.



Structure of the brex No.2 structure. Left - without souring; right - with souring during 4 hours after shearing.

Briquetting. Problems and Prospects. Charge Preparation. Selective withdrawal of elements.

РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ

НА ИЗОБРЕТЕНИЕ

№ 2617086

Способ селективного извлечения оксида железа и оксида цинка из шламов и пылей газоочисток металлургических агрегатов

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Заявка № **2016108792**

Приоритет изобретения **11 марта 2016 г.**

Дата государственной регистрации в Государственном реестре изобретений Российской Федерации **19 апреля 2017 г.**

Срок действия исключительного права на изобретение истекает **11 марта 2036 г.**

Руководитель Федеральной службы по интеллектуальной собственности

Г.П. Ивлиев

РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ

НА ИЗОБРЕТЕНИЕ

№ 2521165

СПОСОБ ОЧИСТКИ ОТ МАСЛА ЗАМАСЛЕННЫХ ЧУГУННОЙ/СТАЛЬНОЙ СТРУЖКИ И ОКАЛИНЫ ШЛАМОВ ПРОКАТНОГО ПРОИЗВОДСТВА

Патентообладатель(ли): ***Фарнасов Геннадий Алексеевич (RU)***

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Руководитель Федеральной службы по интеллектуальной собственности

Б.П. Симонов

Briquetting. Problems and Prospects. Charge Preparation. Selective withdrawal of elements.

- **BF and BOF Sludge**– *dezincing.*

- *<u>Hydrometallurgy</u> (ammonium chloride, electrolysis - Metals Recycling, EZINEX; leaching in sulfuric acid - Zincex, ZincOx).*

- *<u>Pyrometallurgy</u> (Waelz process, plasma furnaces Tetronics, Plasmet, Zinc Iron Plasma Process (ZIPP); dust briquetting with less than 2% zinc (Imperial Smelting process, OxiCup, PIZO).*

- ***<u>The proposed method allows us to move the leaching process in the kinetic region and significantly speed it up (cycle - minute instead of 42 hours), which is achieved by using an electromagnetic field.</u>***

- *<u>NLMK sludge test results:</u>*

*The zinc content in the blast furnace sludge prior to testing is **0.85%**, after leaching with the use of e/m field - **0.043%**; in the converter sludge before the tests - **2.17%**, after - **0.088%**.*

Briquetting. Problems and Prospects. Charge Preparation. Selective withdrawal of elements.

Mill Scale (before testing)					
Sample, mass, g	Water mass, g	Without Water, g	Oil mass, g	Scale without oil mass, g	Time, minute
97	13 (13%)	84	24	60	-
1st test					
300	22 (7,3%)	278	2	276	1
2nd test					
100	7 (7%)	93	2,8	90,2	3
3rd test					
100	12 (12%)	88	1,2	86,8	3


РОССИЙСКАЯ ФЕДЕРАЦИЯ

ПАТЕНТ

НА ИЗОБРЕТЕНИЕ

№ 2521165

СПОСОБ ОЧИСТКИ ОТ МАСЛА ЗАМАСЛЕННЫХ ЧУГУННОЙ/СТАЛЬНОЙ СТРУЖКИ И ОКАЛИНЫ ШЛАМОВ ПРОКАТНОГО ПРОИЗВОДСТВА

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Briquetting. Problems and Prospects. Production of Briquettes.

- Equipment
- Transportation and Stockpiling
- Testing

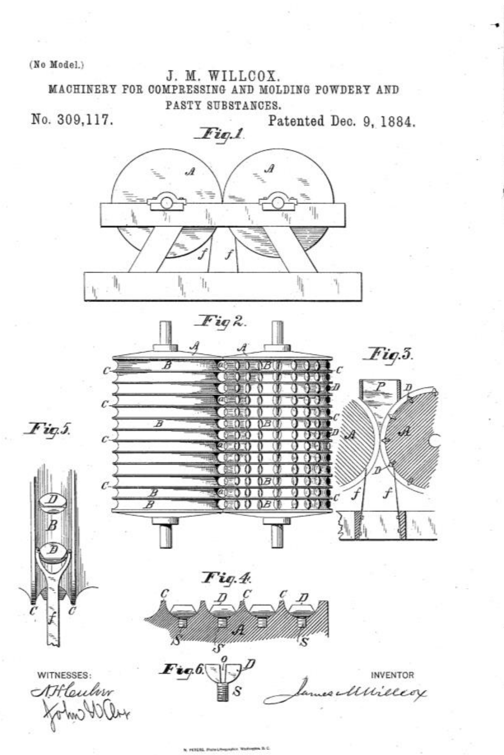
Briquetting. Problems and Prospects. Equipment.

- For the briquetting of dry materials with organic binders, when the achievement of high hot strength of briquettes is not required, **roller-press briquetting** allows to obtain mechanically strong briquettes due to the application of high pressure (**up to 150 MPa**).
- **Vibropressing** allows agglomeration of a mixture containing a substantial part of large fractions (**up to 10 mm and more**) but requires special measures to preserve the strength of raw briquettes (moving on pallets, heat and moisture treatment) and does not allow moisture of the briquetted mixture to exceed **12-15%**.
- **Stiff extrusion** is irreplaceable when agglomerating fine materials and allows to agglomerate:
  - mixtures with a moisture content of up to **20%** at compacting pressures an order of magnitude lower than in a roller press (**3.5 MPa**).
  - EAF dust and gas cleaning dust of ferroalloy production, which practically could not be briquetted with either roller presses or vibropresses.
- The possibility of stiff extrusion agglomeration of wet materials allows either to completely abandon the drying of raw materials, or to significantly reduce the cost of such drying.

Briquetting. Problems and Prospects. Equipment.

- Of all the known modern methods of briquetting only roll is specially designed for briquetting, although it resembles the rolling technology. In the design of roller presses a significant problem is associated with the formation of a significant amount of fines that does not fall into the working volume between the rollers. The properties of briquettes worsens the air pressed inside.
- Vibropressing and extrusion are borrowed from the building materials industry. None of these technologies has yet been modified to fully consider the specifics of briquetting.
- A recent example of stiff extrusion has shown that changing certain geometrical proportions can increase the productivity of a shearing extruder significantly.
- The frequency variations of the vibropresses can also significantly affect the properties of briquettes.

$\rho(A^2\omega^3 l^3/N^2;\ A^2\omega^2/\tau_0;\ A\omega l/\beta\nu)$=f$(Nt/\tau_0\, l^3;\ Nt^2/\nu\, l^3; A\omega^2/g\, ; A\beta)$



Briquetting. Problems and Prospects. Transportation and Stockpiling.

- Usually it is required that the transportation of briquettes is carried out along the existing logistic trajectories of the metallurgical enterprise. In this case, there may be a need for a significant amount of loading-unloading operations and repeated dropping of briquettes from a considerable height.
- In such a situation there is a contradiction in the requirements for strength and value of the briquette, as a component of the charge, since increasing the content of the binder reduces the curing of the main component in the briquette (iron, manganese, chromium, etc.). The briquette may have enough strength for its transportation to the furnace but be too strong for the metallurgical process.
- In our opinion, it is necessary to build new “sparing” ways of transporting briquettes to the furnace, which will make it possible to fully use the metallurgical value of the briquette. An alternative may be an additional heat treatment of the briquette, as is done during vibropressing.
- It does not make sense to transport the briquette, knowing that it, having good hot strength, will collapse on the way before being fed into the furnace.

Briquetting. Problems and Prospects. Testing.

- Drop strength
- Tumble testing
- Compressive strength

Briquetting. Problems and Prospects. Testing.

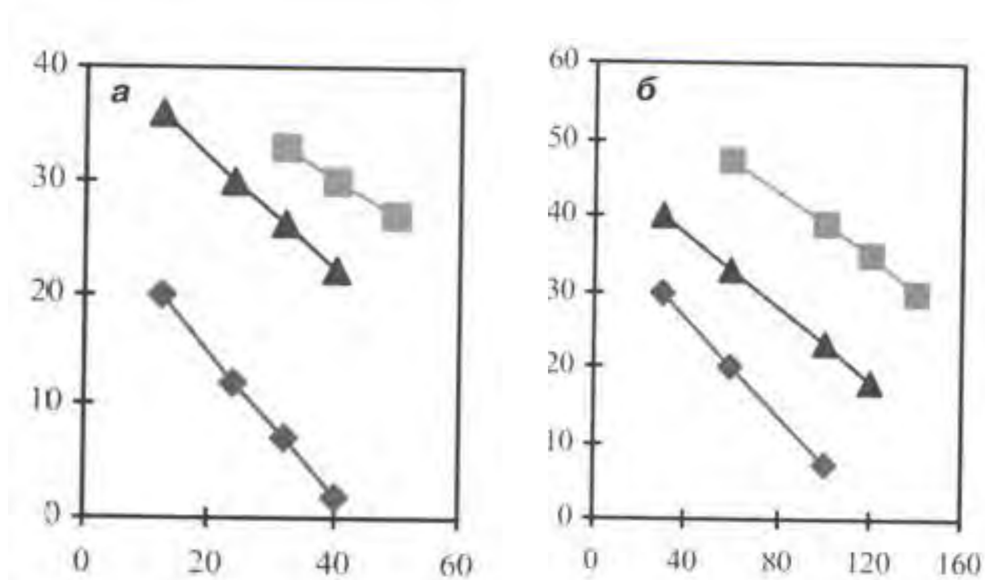
Drop strength

- depends on the type of binder used;
- depends on the volume (or mass) of the briquette;
- destruction is due to a critical number of structure inhomogeneities, which increases with increasing sample size. Even for the same material with the same concentration of structural defects, the probability of destruction with increasing volume increases exponentially.

chromite concentrate and liquid glass

ferrosilicon and oil pitch

copper concentrate and sulphite-alcohol bard



Briquette volume, cub.cm

Briquette mass, g

Briquetting. Problems and Prospects. Testing.

Compressive Strength

- The brick can withstand considerable compressive forces but is easily destroyed after 2-3 falls from 1.5-2 meters.
- For fluxed pellets, compressive strength is 1.5-2 kN per pellet. For non-fluxed ones - 1.8-2.5. Or **180-250 kgF/sq.cm.**
  - in the bunker, the pressure of the vertical layer of pellets (8.3 kg each) with a height of 40 meters (2500 pellets, 40: 0.016) to the lower pellet is equal to **20.7 kgF** only.
  - In the bunker of the same height (40 m), the pressure of the vertical layer of briquettes with a diameter of 30 mm and a mass of 30 g each (1399 briquettes) on the bottom briquette is 39.66 kgF or about **2 kgF/sq.cm**.
- In a high mine blast furnace, the pressure of the overlying layers of loading on coke does not exceed **3-5 kgF/sq.cm**.

Briquetting. Problems and Prospects. Testing.

Tumble testing

- The test result in the drum depends on the simultaneous action of **abrasive** and **crushing** forces. Depending on the design of the drum and the test conditions, the effect of these two factors on the same material is different.
- The testing of different materials in the same drum also differs both in intensity and in the predominance of one or another factor (abrasion and crushing).
- Therefore, despite the same type of transportation conditions for agglomerated raw materials (coke, pellets, agglomerate), the drum methods for their testing differ significantly.
- Testing of metallurgical coke and ore materials is carried out in devices of different overall dimensions (with the same diameter, the drum for testing coke is twice as long) and under different conditions.
- Drum speed, the test duration for pellets is twice as long, and the mass of the analyzed sample is three times less.
- There are more than 10 methods for determining the strength in a drum with different sizes, speed and duration.

Briquetting. Problems and Prospects. Testing.

Tumble testing

- With such a variety of drum methods, various limits of strength are established, although the quality of agglomerated ore raw materials is estimated in all cases according to the **particle size distribution** after the test (in classes less than **0.5 (0.6) mm** and more than **5 (10) mm**.
- Accepted for ore pellets drum test methods are automatically transferred to the briquettes.
- This approach does not consider significant differences in the structure of these agglomerated products (baked pellets and cold briquettes with a binder). Test conditions and their results may differ significantly from the real picture of the destruction of briquettes in the technological cycle.
- The pellets (**5-25mm**) and sinter (5-40mm) are quite heterogeneous in their particle size distribution and are distinguished by high porosity and fracturing. Since pellets and sinter are a granulated and then heat-treated mixture of ore and flux materials, they contain components that are different in their physical-mechanical properties.

Briquetting. Problems and Prospects. Testing.

Tumble testing

- A small volume (mass) of the pellets determines their high resistance to stress during drum testing. Therefore, for them, high values of rejection limits for abrasion (the share of classes less than **0.5 mm** is not more than **4-6%**, the share of classes more than **5 mm** is not less than **90-95%)** and strength are established.
- The sinter is a more easily destructible porous sponge-like material. Tumble testing for sinter after testing usually contains **55-65%** of a class **+5 mm** and **6-8%** of a class **-0.5 mm.**
- Unlike pellets and sinter, briquettes are homogeneous in properties, size and shape agglomerated products with higher density, smooth surface and uniformity of physical and mechanical properties in the whole volume.
- This determines the different nature of the destruction of the briquette in the tumble testing. Briquettes have a greater mass than pellets and sinter, therefore, they will experience a stronger impact-damaging effect. Moreover, in the accepted methods of drum testing, the amount of materials is **15 kg**. The number of loaded briquettes and the volume they generate is significantly less than when testing pellets.

Briquetting. Problems and Prospects. Testing.

Tumble testing

- Each briquette in the tumble testing experiences the same level of destructive loads, which significantly exceeds the degree of impact on pellets or sinter, which have a wider range of sizes and lower weight. Such a combination of conditions leads to more intensive destruction of briquettes and a decrease in the yield of a class of particles with dimensions greater than **5 mm**.
- There is a serious doubt in compliance with the destruction of briquettes in the tumble testing for pellets and sinter real production conditions. The test method must be adapted to the actual conditions of transportation of briquettes.
- It is known that after testing briquettes according to the method for coal briquettes with a binder (**GOST 21289-75**) in samples containing at least **80-85%** of a class of more than **25 mm** (rejection limit), the proportion of whole briquettes can be **65-70%** (mass.). That is, in tests only **30-35%** of the briquettes are destroyed. The content of fines with a particle size of less than **10 mm** usually does not exceed **15%** (on average 7-9%).
- Briquettes in a tumble testing are subjected to more crushing and not abrasive effects. Only destroyed briquette generates abrasion. To reduce the abrasion of briquettes, it is necessary to reduce their crushability, i.e. high overloads should be avoided.

Briquetting. Problems and Prospects. Testing.

- **The destruction of the briquettes due to shock and crushing load**. The effect of abrasive loads is manifested in destroyed briquettes. The mechanical properties of briquettes depend on the type and properties of the binder.
- The determination of the resistance of the briquette to dropping **can be carried out** according to the methods adopted for the **sinter and pellets**. The rejection limits should depend on the mass and size of the briquette.
- The method of determining the resistance to **compression** is not unified. The fixed values of compressive strength values depend on the intensity of the applied loads, therefore different results are obtained for the same material. The existing rejection limits for briquettes and pellets **are too high** and do not reflect the real load.
- Methods for determining the strength in a rotating drum, developed for sinter and pellets, **do not allow an adequate and objective assessment** of the strength properties of **briquettes**. The rejection limits (strength and abrasion) in quantitative terms for briquettes should be adjusted and not automatically transferred from the norms for **pellets**.
- Metallurgists should more reasonably approach the formation of requirements for the mechanical strength of briquettes and establish separate rejection rates for them.

Briquetting. Problems and Prospects. Testing.

Tumble testing (ISO 3271)

		Machine and Process	Lab Extruder - Single Pass				HD-10 - Single Pass		HD-10 Shear/Sour		HD-10 Shear/Sour		HD-10 Shear/Sour	
		Comments	No shear/No Sour				No shear/No Sour							
		SAMPLE #	1	2	3	4	1	2	1	2	1	2	1	2
Test Sample	m_0	grams	15012	15001	14999	15000	15000	15001	15001	14999	14998	15000	15001	14999
Plus 6.30mm	m_1	grams	12917	12948	12943	12909	11202	11327	12906	12637	12549	12388	13096	13103
Plus 500 micron	m_2	grams	239	215	229	221	798	743	309	464	522	620	299	296
Minus 500 micron	m_3	grams	1690	1658	1685	1735	2752	2761	1669	1733	1784	1879	1503	1495
m_0-m_1-m_2-m_3	d	grams	166	180	142	135	248	170	117	165	143	113	103	105
d/m_0	D	%	1,1	1,2	0,9	0,9	1,7	1,1	0,8	1,1	1,0	0,8	0,7	0,7
(m_1/m_0)	TI	%	86,0	86,3	86,3	86,1	74,7	75,5	86,0	84,3	83,7	82,6	87,3	87,4
$(m_0$-m_1-$m_2)/m_0$	AI	%	12,4	12,3	12,2	12,5	20,0	19,5	11,9	12,7	12,8	13,3	10,7	10,7
		TI (avg)	86,2				75,1		85,1		83,1		87,3	
		AI (avg)	12,3				19,8		12,3		13,1		10,7	

Briquetting. Problems and Prospects. Testing.

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Briquetting. Problems and Prospects. Testing.

Spiral Couette-Poiseuille Flow in Simplified Model of Extruder

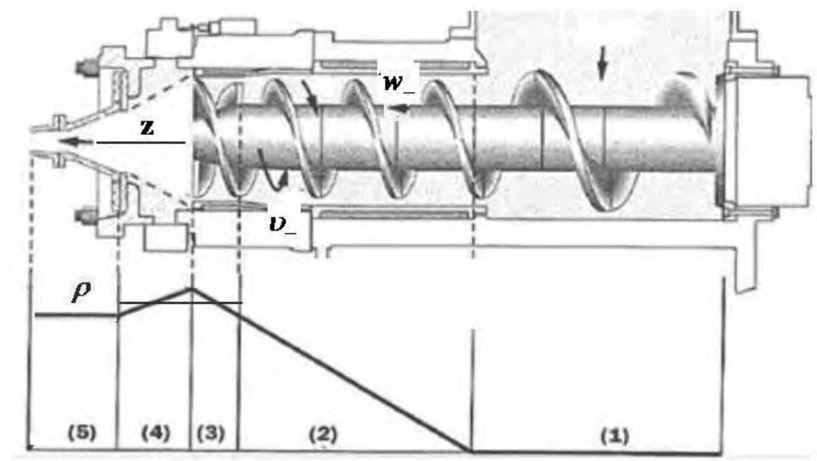
$$w = \frac{\varepsilon^{\gamma_+} w_+ - w_-}{\varepsilon^{\gamma_+} - \varepsilon^{\gamma_-}} \left(\frac{r}{a}\right)^{\gamma_-} + \frac{\varepsilon^{\gamma_-} w_+ - w_-}{\varepsilon^{\gamma_-} - \varepsilon^{\gamma_+}} \left(\frac{r}{a}\right)^{\gamma_+}$$

$$+ \frac{-p_z a^2}{\mu(4-\alpha)} \left(\frac{\varepsilon^{\gamma_+} - \varepsilon^2}{\varepsilon^{\gamma_+} - \varepsilon^{\gamma_-}} \left(\frac{r}{a}\right)^{\gamma_-} + \frac{\varepsilon^{\gamma_-} - \varepsilon^2}{\varepsilon^{\gamma_-} - \varepsilon^{\gamma_+}} \left(\frac{r}{a}\right)^{\gamma_+} - \left(\frac{r}{a}\right)^2 \right)$$

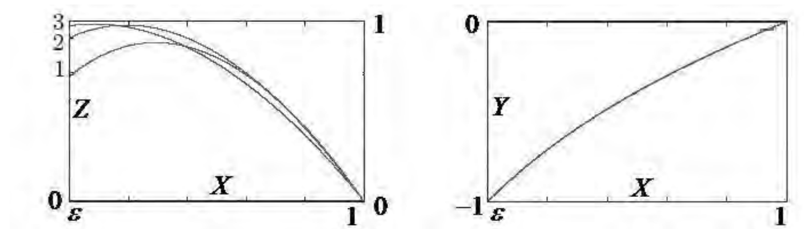
$$\gamma_\mp = \frac{\alpha}{2} \mp \sqrt{\left(\frac{\alpha}{4} - 1\right)\alpha} \qquad \left(\frac{\alpha}{4} - 1\right)\alpha > 0$$

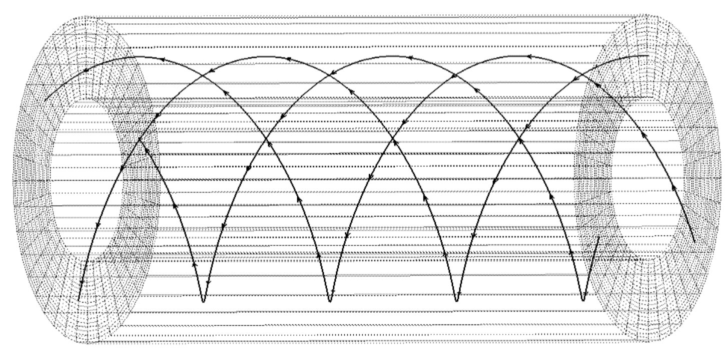
$$\upsilon = \frac{\varepsilon^{\beta_+} \upsilon_+ - \upsilon_-}{\varepsilon^{\beta_+} - \varepsilon^{\beta_-}} \left(\frac{r}{a}\right)^{\beta_-} + \frac{\varepsilon^{\beta_-} \upsilon_+ - \upsilon_-}{\varepsilon^{\beta_-} - \varepsilon^{\beta_+}} \left(\frac{r}{a}\right)^{\beta_+}$$

$$\beta_\mp = \frac{\alpha}{4} \mp \left(\frac{\alpha}{2} + 1\right) = -\frac{\alpha}{4} - 1, \frac{3\alpha}{4} + 1$$

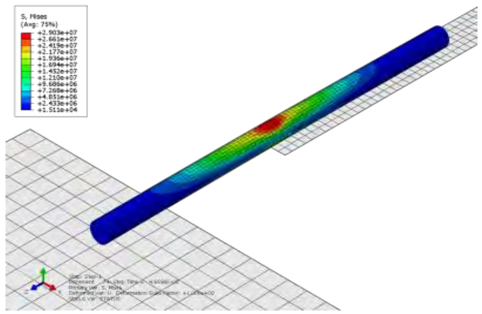


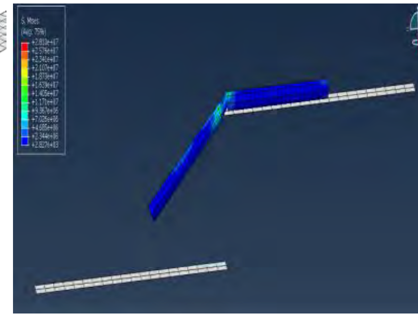
1 conveying, 2 densifying, 3 – metering, 4 pressure distributing, 5- die





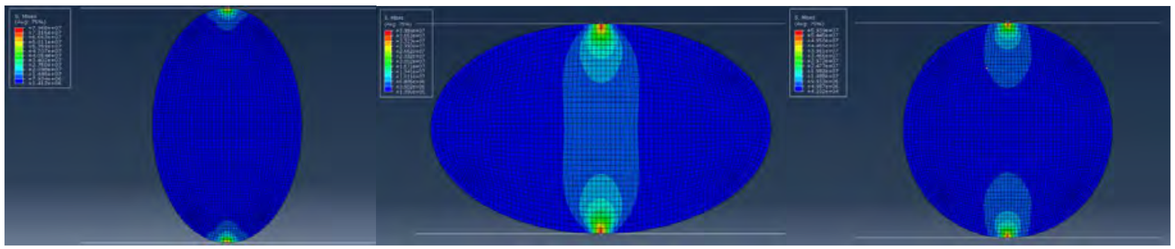
Briquetting. Problems and Prospects. Testing.





Length

Shape



39.8 MPa 79.6 MPa 59.3 MPa

Briquetting. Problems and Prospects. Processing of green Briquettes.

- Heat-Moisture Treatment (vibropressing);
- Drying (soft-extrusion);
- Carbonization
  - + Increasing the Hot Strength; Utilization of carbon dioxide;
  - - increasing Coke rate.
- Crushing

Briquetting. Problems and Prospects. Alternative Applications.

- Lightweight Aggregates
- Red mud
- Bauxite
- Gypsum
- Fly ash
- Bentonite

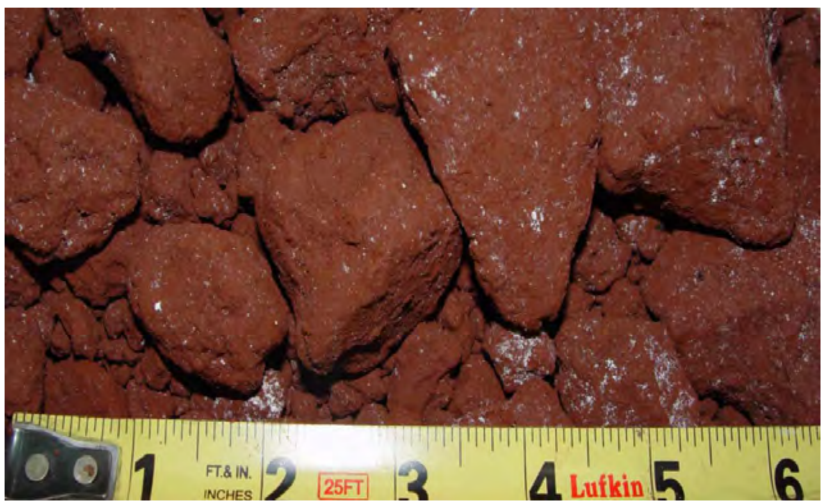
Briquetting. Problems and Prospects. Alternative Applications

Texas Industries, Inc. (TXI, USA) operated several lightweight aggregate (LWA) production plants. They used SVE technology to agglomerate ore fines for further reduction in their rotary kilns. The Company operated two extruders at two LWA plants, one in Texas and one in Colorado. As of July 2, 2014, TXI became a wholly owned subsidiary of Martin Marietta Materials, Inc.

Briquetting. Problems and Prospects. Alternative Applications.

Red mud

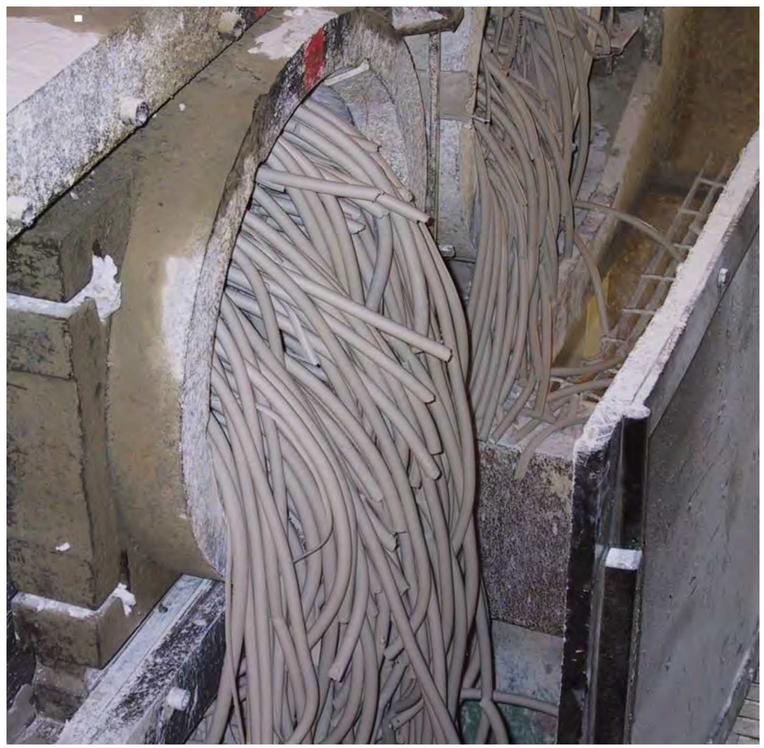
- Another application of this technology may be associated with the briquetting of red mud. The material consisted of moist, soft, sticky lumps ranging in size from fines to pieces as large as 50mm.
- A 4% addition of Portland cement was required to make the mix extrudable. With no water added, brex were well-formed but very soft with virtually no green strength.
- After 7-day cure time, brex were crushed axially in order to determine axial compressive strength. The results of testing showed that this raw material, with the addition of Portland cement binder, is an excellent candidate for agglomeration by SVE.



Briquetting. Problems and Prospects. Alternative Applications

Bauxite

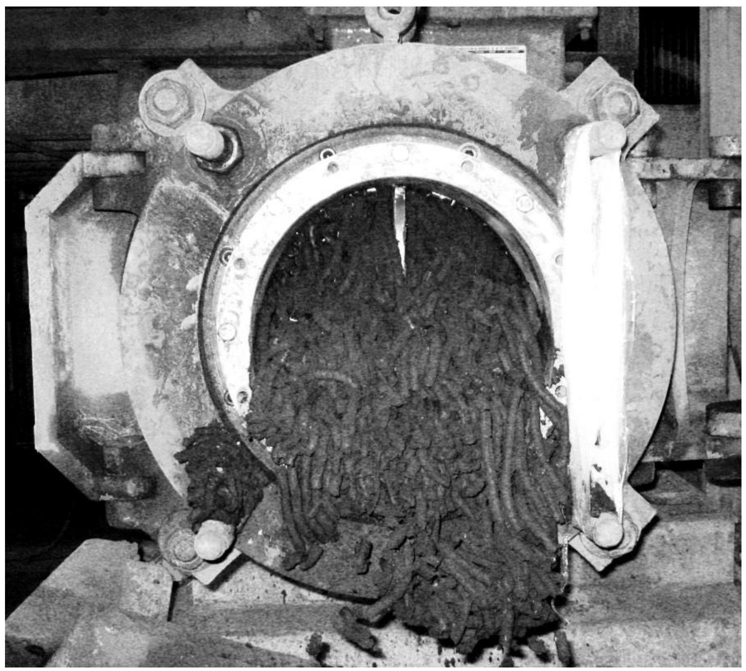
CE Minerals (Andersonville, Georgia, USA and Xiuwen, China): This Company agglomerates high grade bauxite through five of SVE extruders. The extruded bauxite noodles or pellets are dried and fired in order to make high grade alumina feed stocks which are used in making refractory products.



Briquetting. Problems and Prospects. Alternative Applications.

Gypsum

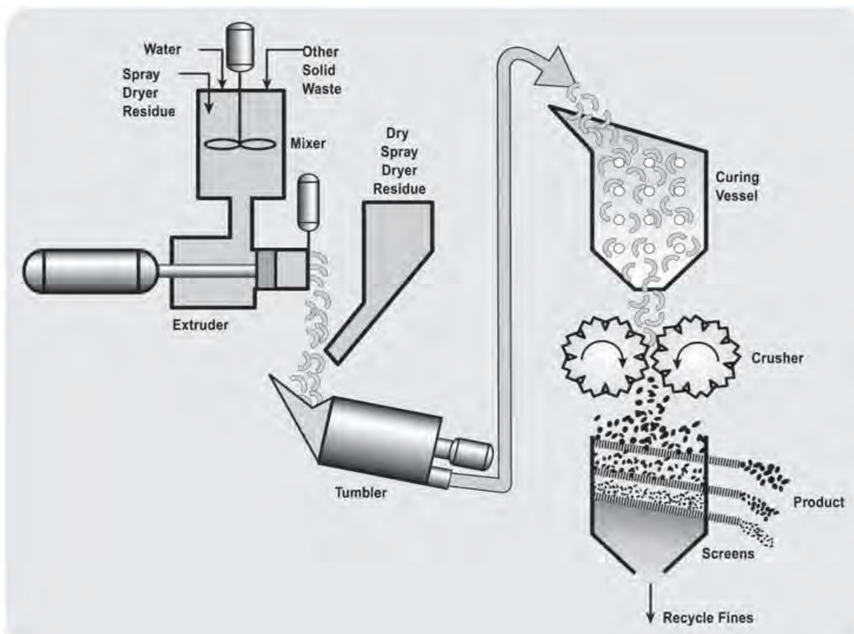
- Carolina Gypsum uses an extruder to agglomerate synthetic gypsum with a lignin binder to make fertilizer filler. Yearly production of this plant is about 20000 tons per year.



Briquetting. Problems and Prospects. Alternative Applications

Fly ash

Universal Aggregates (PA, USA) agglomerates dry scrubber fly ash to make light weight aggregate out of this pozzolanic material. The pellets are cured like concrete in a special curing vessel. Spray dryer ash, water, and other recycle material are fed to a pug mixer where the materials are blended together. This mixing produces a uniformly blended loose, moist, granular material that feeds directly to an extruder. The extruder has an auger that subjects the material to further mixing and then forces the material through a die (metal plate with one or more drilled or specially shaped holes). Wet, "green" brex from the extruder are soft and must be transferred to a curing vessel for hardening .



Briquetting. Problems and Prospects. Alternative Applications

Bentonite

The producer of Bentonite Clay American Colloid (Mineral Technologies, MTX) uses J.C.Steele&Sons extruders to agglomerate and beneficiate dryer dust and low-grade Bentonite clay into brex of high-quality Bentonite using additives and the shearing action of the extruder. This company operates extruders at locations in Wyoming, South Dakota, China, and Thailand. The same equipment is being used also by WyoBen (Wyoming Bentonite).


Briquetting. Problems and Prospects.

- Optimization of the equipment;
- Improving the wear resistance of materials;
- Search for better and cheaper binding materials;
- Optimization of the thermal processing of the green briquettes;
- Delivery of metallurgically valuable briquettes without destruction due to optimization of logistics
- Carbonization as a way of carbon dioxide utilization;
- Application of strong magnetic fields;
- Application of the ultrasound;
- Modification of materials properties (nanomaterials).

निमंत्रण और आपका ध्यान के लिए धन्यवाद।