Modern State-of-Art of Briquetting in Ferrous Metallurgy

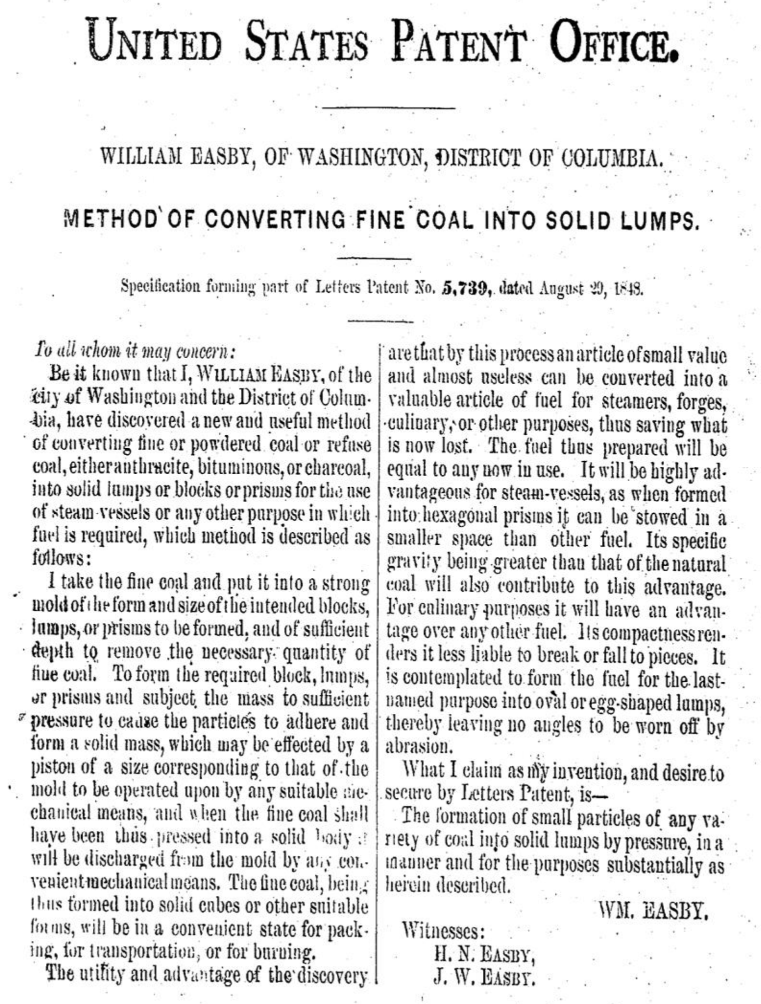
Dr. Aitber Bizhanov

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.
- 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

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—

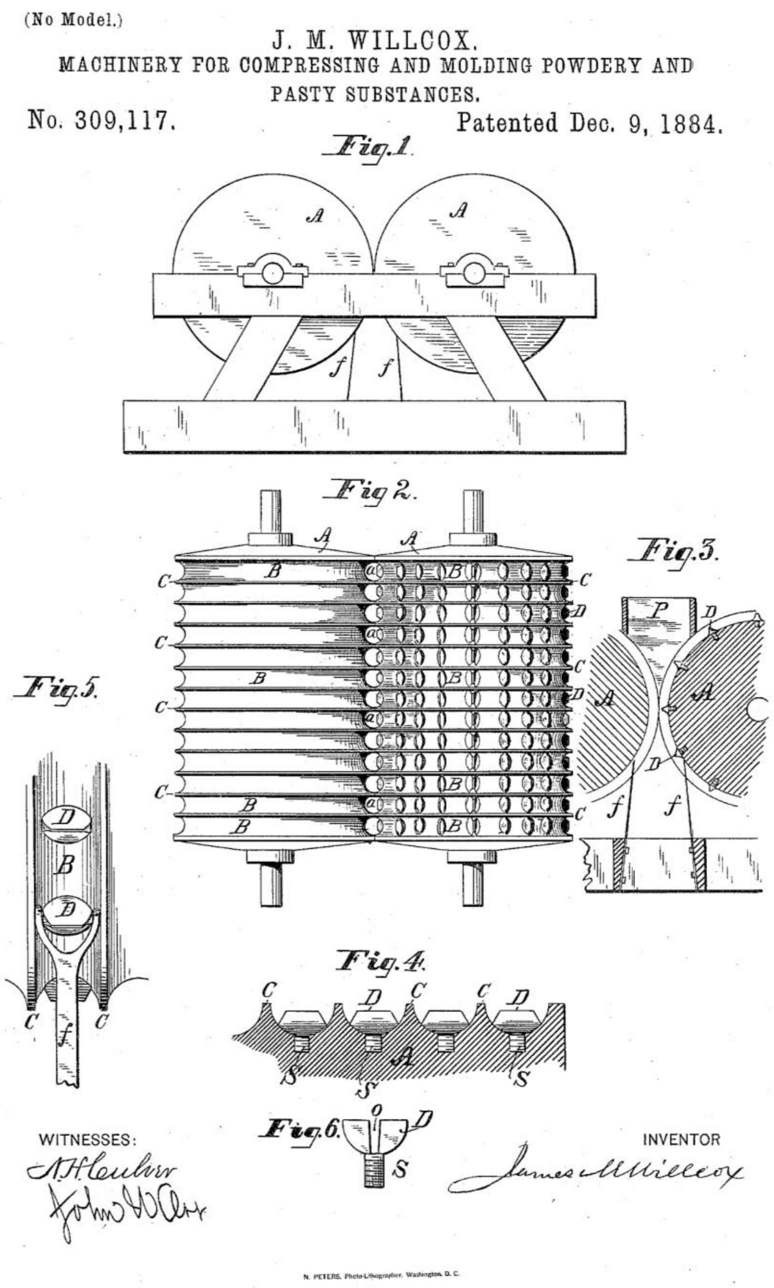
The formation of small particles of any variety of coal into solid lumps by pressure, in a manner and for the purposes substantially as herein described.

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)

જમશેદજી તાતા

3 March 1839 – 19 May 1904

Jamsetji Nusserwanji Tata- Indian pioneer industrialist, who founded the Tata Group, India's biggest conglomerate company.

Tata is regarded as the legendary "Father of Indian Industry". He was so influential in the world of industry that Jawaharlal Nehru referred to Tata as a One-Man Planning Commission.

"When you have to give the lead in action, in ideas – a lead which does not fit in with the very climate of opinion – that is true courage, physical or mental or spiritual, call it what you like, and it is this type of courage and vision that Jamsetji Tata showed. It is right that we should honor his memory and remember him as one of the big founders of modern India." —Jawaharlal Nehru

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

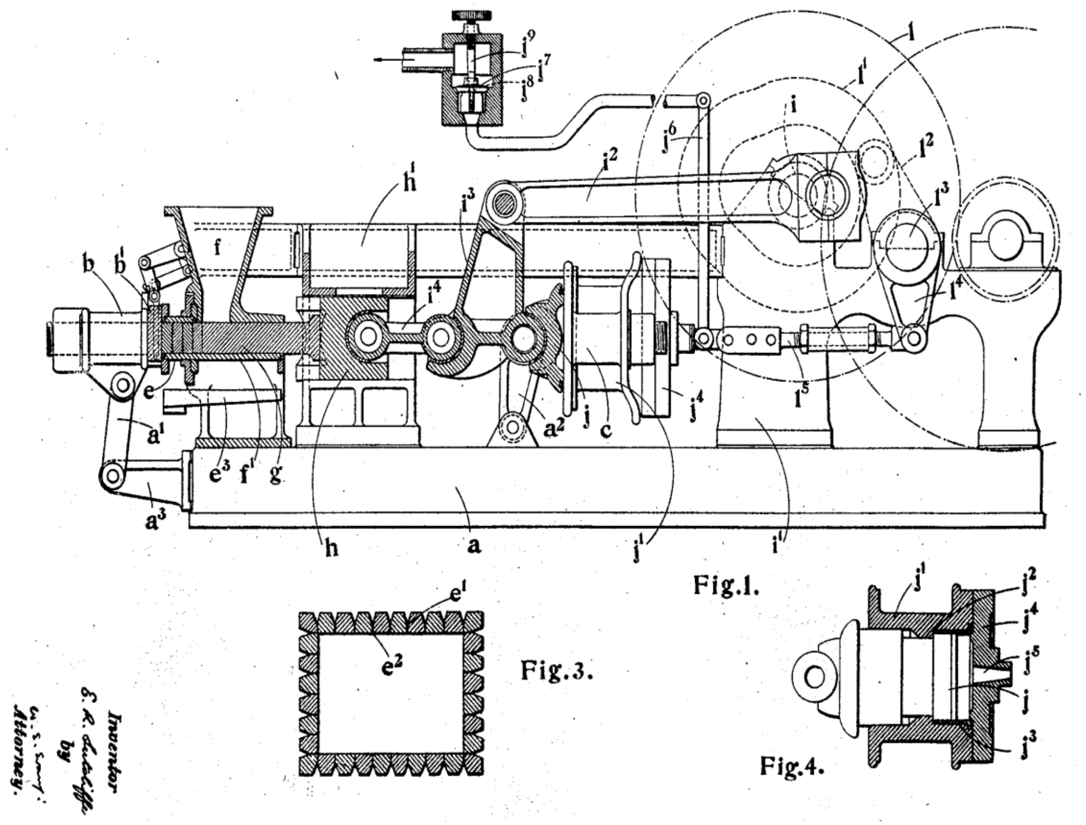
- His energy and inventive talent in metallurgy began to emerge with the beginning of his work in 1880 as an engineer at the Pitkäranta Copper-Tin Plant on Lake Ladoga in Finland near the Russian border.

- 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)

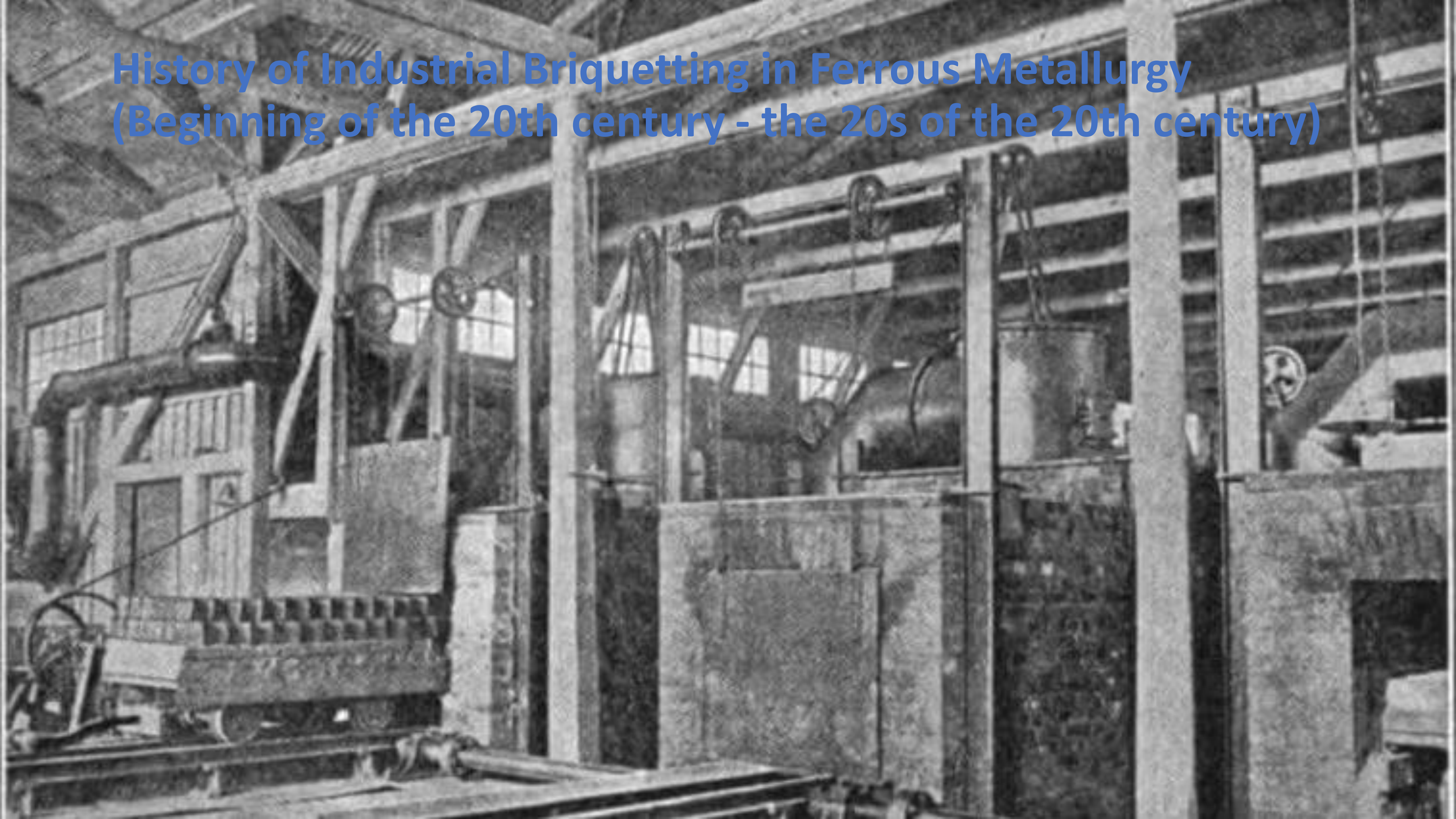
- The fine concentrate was pressed into briquettes **without the use of a binder material**, the moisture content in the concentrate was adjusted to obtain briquettes with strength enough to remove them from the press and load them on special carts for delivery to **Gröndahl kiln**.

- 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)

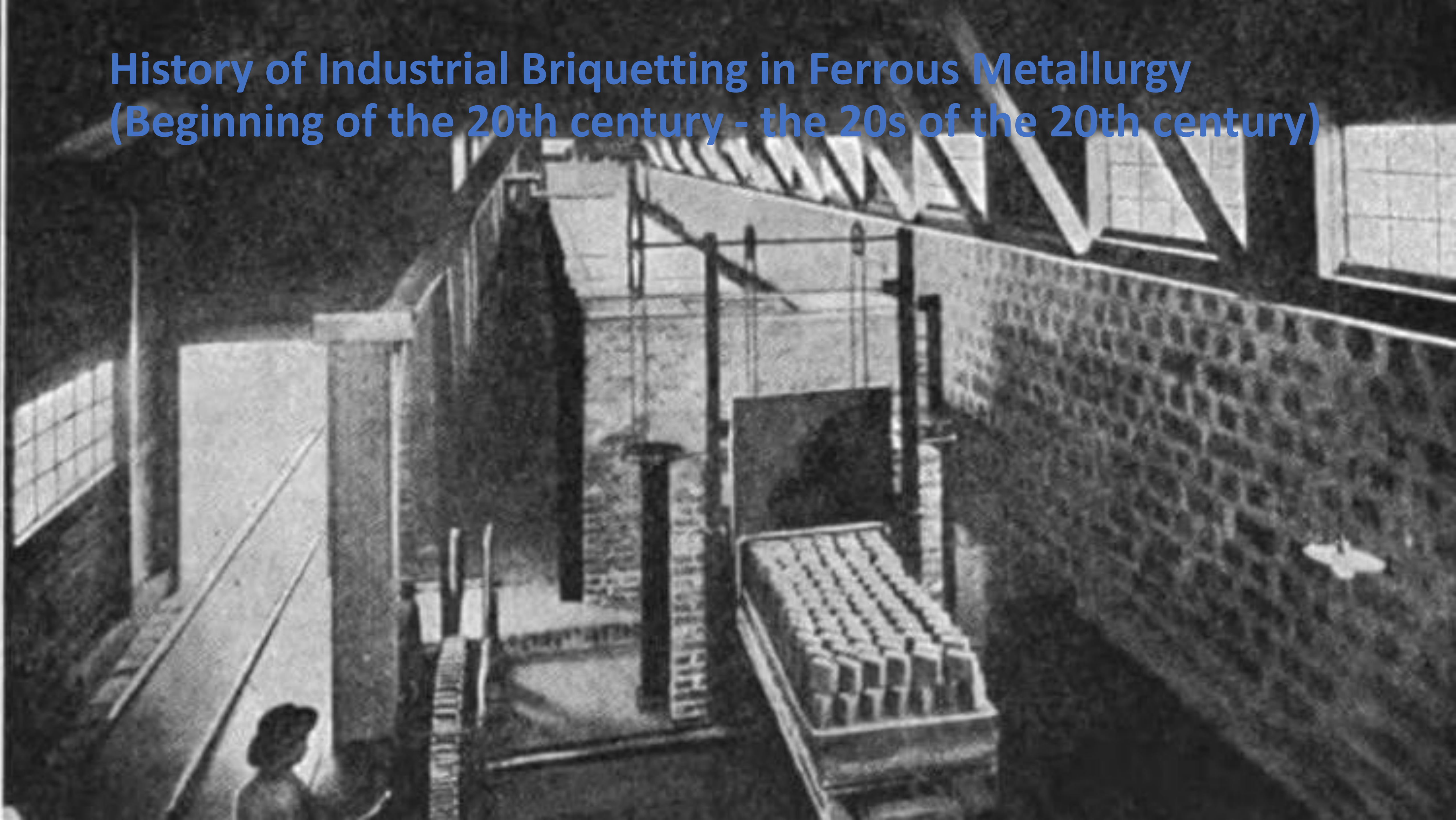


History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

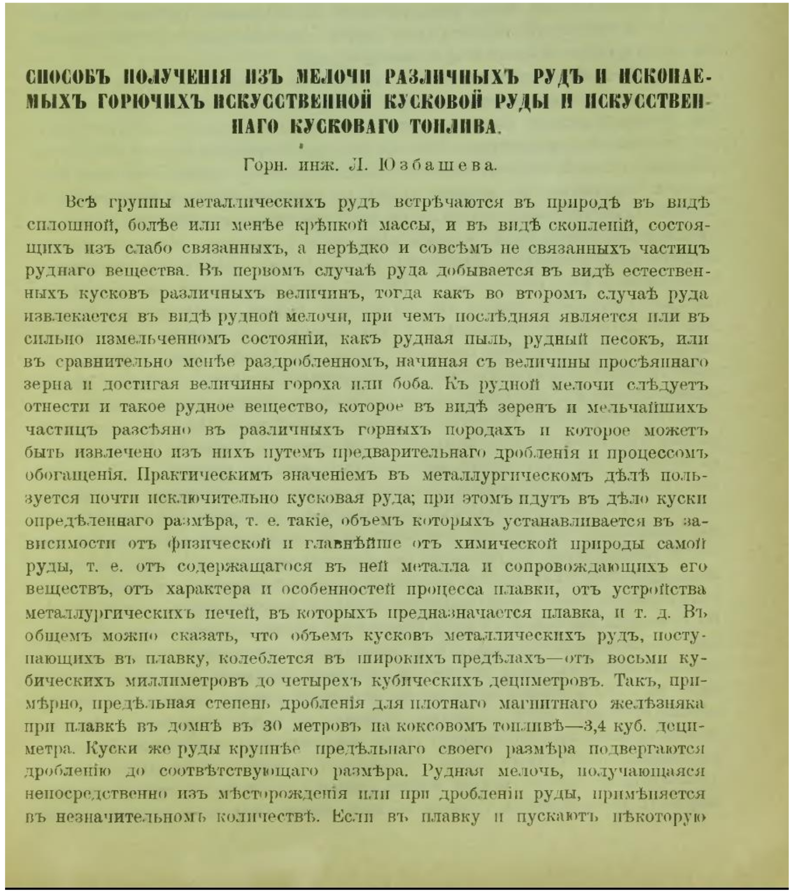
History of Industrial Briquetting in Ferrous Metallurgy (Beginning of the 20th century - the 20s of the 20th century)

- 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 Na2O(SiO2)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 $nSiO_2 \cdot mH_2O$, 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

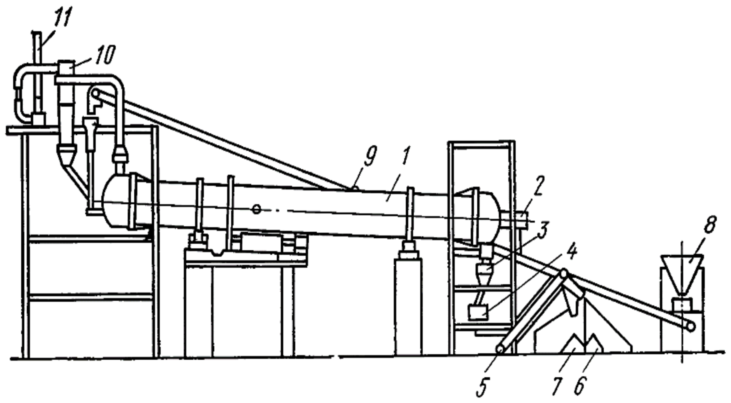
- The essence of the carbonization process as applied to briquetting is that calcium hydroxide (Ca (OH)2), the basic mineral of slaked lime, loses crystalline moisture when heated to **530-580 ° C**, as a result of which the binding properties are lost, and the briquettes lose strength. Carbonization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

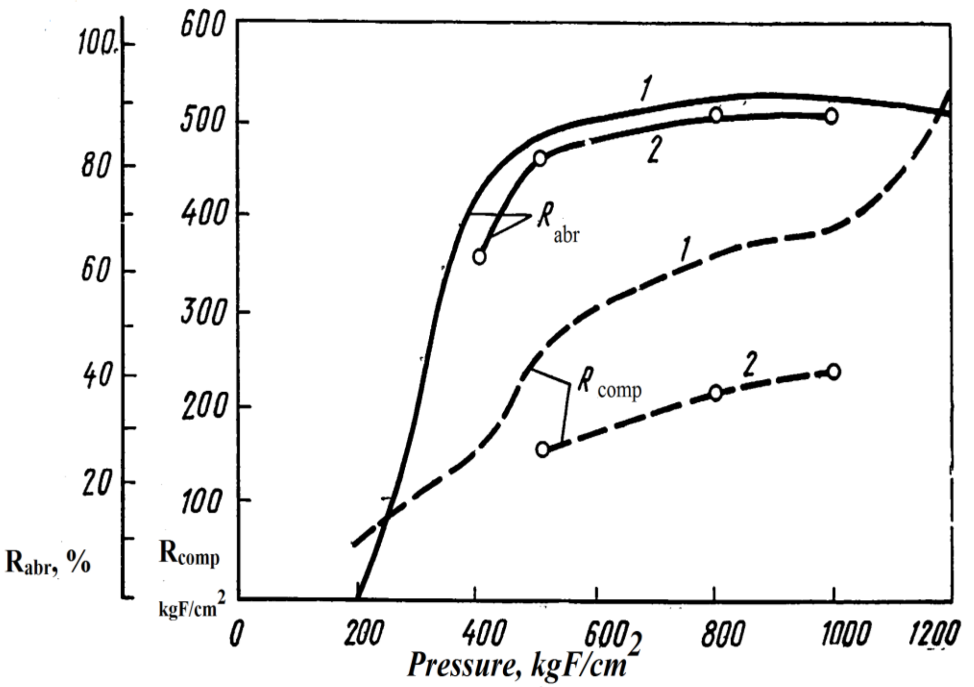
History of Industrial Briquetting. 60-70s of the 20th century. Hot briquetting



(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

- 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.

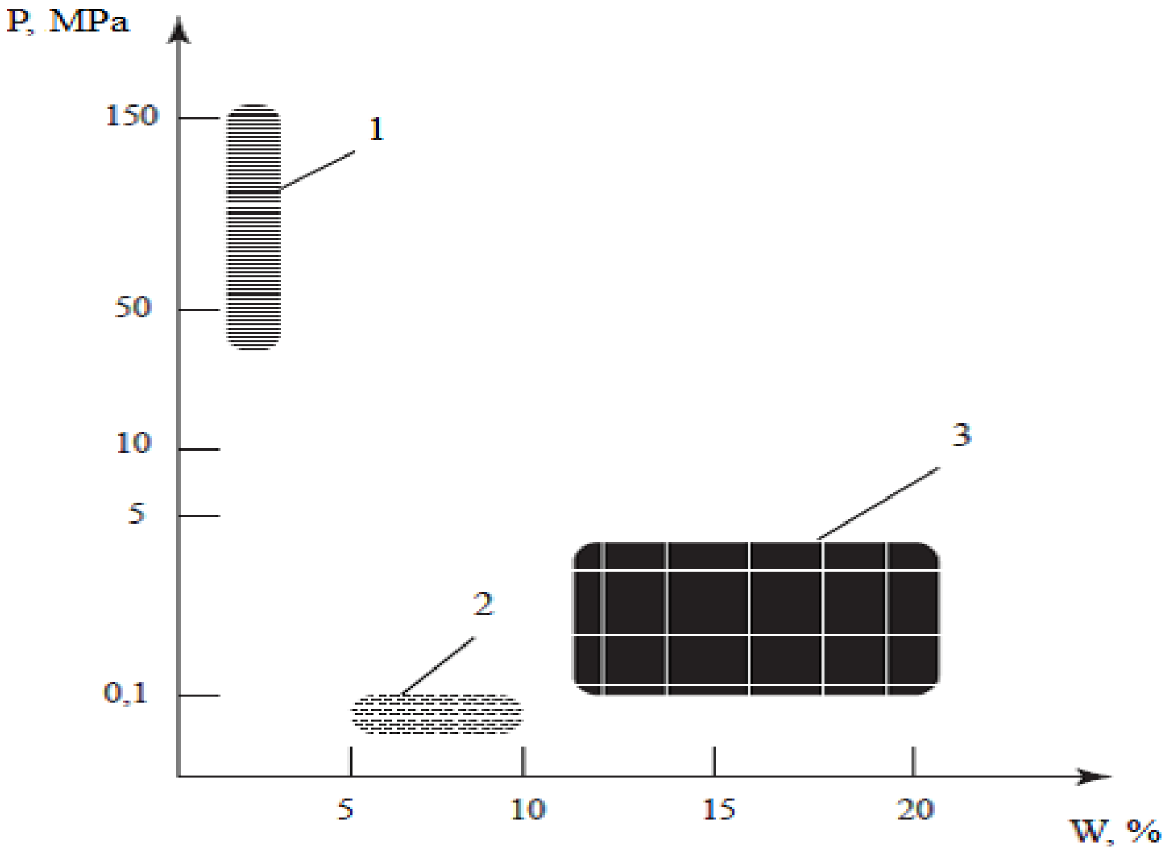
History of Industrial Briquetting. Nowadays

- 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 ^{o}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



1. Roller-press
2. Vibropressing
3. Stiff Extrusion

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!