A BRIEF HISTORY OF STEEL ALLOYING AND FERROALLOY PRODUCTION

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Section 1. Naturally Alloyed Steel

People knew how to use alloying elements for improvement of steel and iron pieces long before they discovered their existence. Even before the Iron Age people used cosmic iron with 8.5% of nickel content. A more or less comprehensive use of alloying elements' properties dates from the Middle Ages in the East being famous for its high quality steel. A chemical analysis performed in the 20th century with steel used for manufacturing Japanese weapons of the 11th - 13th centuries showed presence of molybdenum in its composition. Today it is well-known that molybdenum steel features good hardness, strength and tenacity. Iron sands of placer deposits used by Japanese craftsmen to produce ball iron contained alloying elements. Working with these elements Japanese craftsmen noted that if ore was taken from a particular place then the steel made of such ore would feature special properties. Processing the ball iron through complex chemical and heat treatment people of Japan in Middle Ages produced naturally alloyed and strong steel through hammer-hardening and thermomechanical treatment.

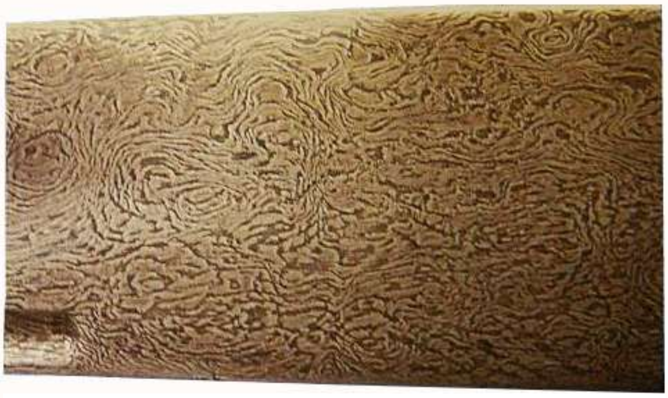
In addition to molybdenum other elements were also used: a higher content of phosphorus and copper can be found in many samples from ancient Damascus. The chronicles tell that close to Damascus there was a mountain that contained natural (telluric) iron with inclusions of carbon (0.9-1 % weight content) and manganese tungstate (8-9 % weight content), plus low content of sulfur and phosphorus. In fact, it was a natural rapid HSS steel. Local craftsmen used this metal from the deposit to make swords and sabres, and later they smelted crucible tungstate damask steel. As polish specialist J. Piaskowski reports ("Damascus steel"), this mountain has been completely mined out by the end of the 18th century.

However, it shall be noted that production of alloyed steel from iron in a catalan hearth is an extremely labour intensive and time-taking process. Before the invention of blast furnace the product of iron ore deoxidization in various catalan hearths was iron ball, a spongeous mass of freshly reduced iron saturated with slag and unburned coal inclusions. In order to remove slag inclusions, increase density and provide a shape to iron for consecutive conversion the iron ball was forged several times to produce a semifinished iron material. However, assuming that the material initially was in hard (pasty) state it was very difficult to achieve its homogeneity. Since mixing was not used, the alloying elements (including carbon) were distributed in the metal volume irregularly.

For example, Japanese steelworkers solved this problem by placing the produced ball iron into boggy soils saturated with acids. During 8-10 years the unalloyed iron would be eaten by acids turning into a porous mass of alloyed metal that could be used for production of high quality weapons. Of course, such technology could not be used in series. Blades produced this way were the weapons of the elite belonging to famous warriors and governors, the features of these weapons became legendary. And only when steel manufacturers started using crucibles with external heat providing liquid alloy, the alloying elements could finally show all their effect.

Section 2. Crucible steel. Technological prerequisites for production of ferroalloys

Steel production in fire-resistant pots, i.e. crucibles, has been known since the ancient world times. It was even mentioned by Aristotle in the 4th century B.C. Crucible steel production was most spread in the countries of Ancient East: Persia, India and Syria where the steel was used for production of arm blanche, knives and hand tools. It involved direct production of steel from ore without the iron ball production phase due to higher temperature. In some parts of Asia crucible iron (steel) production has existed up to the end of the 19th century, while in handicraft metallurgic industry it is still in use. The rise of the highest quality crucible steel – the so called wootz or damask – happened in the 5th – 13th centuries. It is very probable that some craftsmen used additives (keeping their secrets securely) with alloying elements added to steel, however, there are no direct evidences of it.



An example of the variety of damask steel patterns

In Europe crucible steel production raised up to industrial level in Great Britain, in Sheffield – the famous town of metallurgists and blacksmiths. European crucible steel process was invented by watchmaker Benjamin Huntsman (1704-1776). Designing various mechanisms Huntsman experienced lots of difficulties with poor quality of German cemented steel that he used. In particular, he could not find proper metal for making springs and pendulums. It led him to seeking a way for steelmaking that would be superior as compared to cemented steel that was made by carbonizing an iron piece made by forging the iron ball.

Even before Huntsman started his experiments he realized that the main disadvantage of the cemented steel was its heterogeneity in hardness (i.e. in carbon content) and contamination with slag and other inclusions. Assuming this, Huntsman came to a decision to smelt the cemented steel in a crucible with a hope to obtain a homogenous metal with no impurities. The experiments took a number of years until he finally succeeded. In 1740 in Attercliffe (suburbs of Sheffield) Huntsman built the very first steelwork plant in the world that produced details and tools made of crucible steel. This year is known as the date of crucible process invention

Monument to crucible steel producers. Meadowhall trade center, Sheffield

Crucibles, accessories and furnace for metal melting

Huntsman's process assumed smelting of cemented steel under green glass flux in a fire resistant crucible installed inside a furnace with natural draft and heated with coke. In course of the process development the inventor proved that adding various materials into the crucible, e.g. graphite or pig iron resulted in making steels of different hardness suitable for making various products. Adding such materials modified carbon content in steel resulting in different hardness.

Although crucible steel was expensive and the output of the process was small (7 furnaces out of 10 available could produce 150 tons of steel per annum) it has remained the only material for fabrication of important tools and elements of mechanisms for a long period of time. This steelmaking process has been a primary way of producing high quality steels for about 200 years until it was superseded by electrical smelting process.

Krupp plant. One of a few plants that produced big melts by mixing steel from tens of crucibles

As a result, in the middle of the 18th century there was a principle possibility of using alloying elements for improvement of steel quality. However, alloying elements themselves have not been discovered by then yet.

Section 3. A revolution in natural science. Scientific prerequisites for alloyed steel production

Jöns Jacob Berzelius

The period of 1775 -1825 is often referred to as Revolution in natural science. More than 40 chemical elements were discovered then, including oxygen, manganese, chrome, silicon. Designed methods of pure chemical analysis allowed determination of elements content in alloys with accuracy of thousandth of one percent.

Detailed chemical analysis of iron ores, pig iron, wrought iron and cemented steel was performed by an outstanding Swedish chemist Jöns Jacob Berzelius in the early 19th century. He determined that all iron ore materials and iron alloys contain oxygen and phosphorus (sulfur was examined earlier in details by Georg Brandt). The investigation results were published in articles "Jahresbericht" and "Traité de Chimie" (1832). The articles also contain information on full chemical analyses of iron ores, pig and wrought iron of Swedish plants (for all chemical elements known by that time) as well as results of investigation of vanadium and tantalum iron alloys.

The fundamental research performed in these thirty years allowed formulating theoretical theses about influence of phosphorus, sulfur and oxygen on properties of pig iron and steel. In fact, they have not been changed in principle until now. They were colligated by Karl Johann Bernhard Karsten in his work "Eisenhüttenkunde". This book was first published in 1818, and the metallurgic history considers this book an example of being both a textbook and a practical guideline for ferrous metals production. The text of "Eisenhüttenkunde" contained Karsten's section 'Iron Alloys' that became a compulsory component of all metallurgic textbooks in the 19th century. The section provided full information about the content of alloys, their physical properties, production processes and fields of application. Karsten made deliberate research of phosphorus, silicon, copper, lead, bismuth, antimony, manganese, titanium and aluminum iron alloys.

Karl Johann Bernhard Karsten

The most important results of iron alloys research dating from the late 18th to the middle of the 19th centuries are given below.

Iron and copper

Copper iron alloys were studied by Rinman, David Mushet, Stengel and Karsten. The alloys were made by ‘direct’ smelting of copper and pig iron, wrought iron or steel (in crucibles) in all proportions. The researches came to conclusion that copper has poor impact on steel and wrought iron properties (red-shortness) while it is good with cast iron at up to 5% content (here and after percentage by weight).

Impact of iron on properties of bronze and brass was studied in the same times. In 1779 William Ker received a patent for production process of brass that contained 54% of copper, 40% of zinc and 6% of iron. The alloy was produced in crucibles using charcoal and green glass flux. At first, copper and wrought iron were smelted together, then zinc was added under the slag layer. Similar patents have been issued several times later in different European countries up to the middle of the 19th century. The white (iron) brass was mostly spread in Germany where it was named ‘Aich-Metall’ and used for plating of ship hulls.


David Mushet

Iron and tungsten

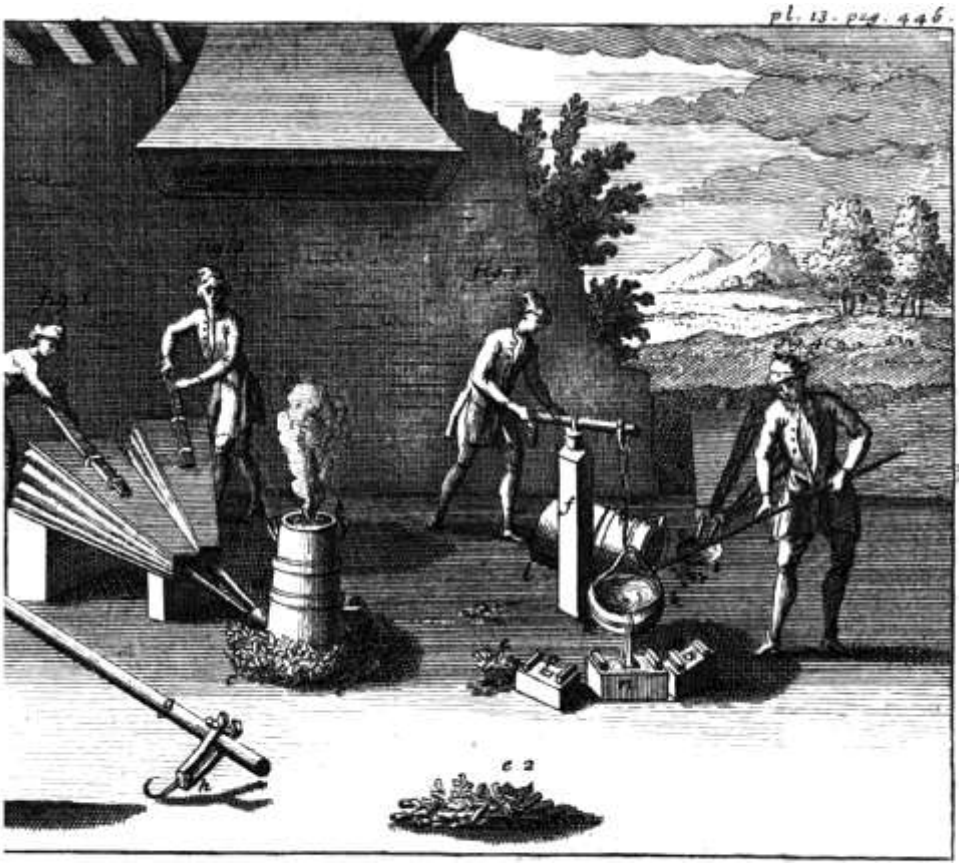
Tungsten excited great interest of researches of the revolutionary epoch in natural science. In metallic state it was first revealed by Elhuyar brothers in Spain in 1783. The Elhuyars made extensive research in studying tungsten alloys that they produced in crucibles with carbon fettling. The crucibles were filled with tungsten oxides and studied metals including pig iron.


Pierre Berthier

Later tungsten alloys were also studied by Berthier. He managed to produce alloys with tungsten content up to 37%. Berthier also studied the triplet system that included iron, manganese and tungsten. Charge mixture that consisted of ores of studied metals was heat treated in a carbon crucible producing an alloy that contained 16% of iron, 6% of manganese and 78% of tungsten.

The efforts of many researches were finalized in 1857 when English engineer Oxland received a patent for production of tungsten iron alloys. The text of the patent contains the following: “Up to 30% of tungsten reduced by carbon from tungsten ore can be mixed with ore in a blast furnace or with pig iron in a cupola. Tungsten iron alloy can be used in metallurgic technique… A good cast steel can be produced by adding 0.5…25% of tungsten. Tungsten iron alloys can be purified and converted into cast steel with ordinary cementing”. Naturally, this is a description of a full production cycle and application of ferroalloy utilized in steel alloying.

In 1859 Oxland’s technology for production and application of ferrotungsten was implemented on industrial level in Austria (implementation is assigned to professor Meier from city Leoben). Five years later tungsten steel was produced by several companies in Austria and Germany (it was used for fabrication of weapons and arm blanche). In 1864 Sievert published a composition of steel that was produced in steelworks in Bochum. The steel contained 1…3% of tungsten and 1% of carbon.



Metallurgic laboratory of the 18th century. Cupola for metal melting (left), metal molding (right)

Iron and titanium

Weller, Karsten and Hochstetter studied the effect of titanium on the properties of steel and pig iron. They recommended producing steel with up to 1% of titanium content making it from pig iron where titanium would appear from naturally alloyed ores. Later in 1859-1861 Robert Mushet received 13 patents for various procedures of production and application of titanium iron alloys including production of ferrotitanium in crucibles and its subsequent utilization for production of alloyed steel.

Alloys of iron with cobalt, molybdenum and chrome

This research was made by Berthier and Smith. They produced alloys by crucible smelting of hematite ore with oxides and ores of the studied metals. Cobalt content in the alloys was up to 55%. They discovered good magnetic properties of cobalt iron alloys. Regarding molybdenum alloys Bethier noted that their production and properties are similar to those of tungsten alloys.

Berthier was also the first to produce and analyze steel with up to 17% of chrome content, he discovered the steel's high resistance to acids. Berthier produced his chromium steel in crucibles using the charge mixture of hematite ore and chromium ore (chromic iron), charcoal and limestone that he 'saturated with silica and alumina minerals'. Smith made his classical model experiments in the laboratory of the Royal School of Mines in London where he smelted chemically pure hematite and chrome dioxide in carbon crucibles. He produced a huge variety of alloys where chrome content varied within 4…77%, while iron content, respectively, was 96…23%.

Research works of M. Faraday and J. Stoddart

Iron alloys research with deliberate method statements were performed by outstanding physicist Michael Faraday and his colleague James Stoddart. The results of their work were published in scientific periodical "The Quarterly Journal of science" in 1820. Faraday and Stoddart analyzed impacts of nickel, gold, silver, platinum, rhodium, palladium, iridium and aluminum on properties of steel, wrought and pig iron. The alloys were produced by smelting packages prepared from twisted wires of pure metals. Content of alloying elements was raised up to 10%. Production of greater amounts of alloyed steel and iron (manufacture of arm blanche and small bells) involved using hardeners prepared in crucibles with containing about 5% of alloying metals.

They produced steel with up to 10% of nickel content and noted its strong resistance to corrosion accompanied by 'strong magnetism'. Production of aluminum iron involved placing bauxite (alumina), iron, sodium and potassium chlorides into crucibles. The crystallized product was then treated with weak hydrochloric acid. The operations resulted in an alloy with 20…80% of aluminum content that was consecutively used for iron alloying in the processes of iron boiling and smelting damask steel in crucibles.

Michael Faraday

As Faraday reported, the produced steel featured favourable properties especially with platinum content. On the basis of the obtained results Faraday, Berthier and their successors explicated the properties the damask by presence of additives in the steel, Faraday dealing with aluminum, platinum and silver, and Berthier with chrome.

Pavel Anosov

Research works of P. Anosov

During the same period platinum deposits were explored in the Urals. The minister of finance, lead of mining engineering corps Egor Kankrin instructed the mining authorities to replicate the experiments of Faraday in smelting steel with platinum. This job was assigned to the Zlatoust barmaster Pavel Anosov who by that time has had a substantial experience in examining good eastern sword blades and who made his own experiments in producing damask steel. The experimental phase took about one year resulting in production of sufficiently high quality patterned steel. However, the patterns were different from the damask. In June 1829 two sabres and one sword blade made from this steel were delivered to the Mining department from Zlatoust.

The next two years Anosov devoted to experimental study of effect of various alloying additives on steel properties. In addition to platinum steels that he studied with special thoroughness he examined steels with additives of gold, silver, manganese, chrome and titanium. Anosov made deliberate descriptions of steel properties for various contents of these elements. Many of them improved the quality of steel, some gave it a pattern, however the attempts to make damask steel failed.

As a result, during the period of the natural science revolution the efforts of many explorers from different countries resulted in scientific fundamentals and ideas about the effect of alloying elements on quality of steel and wrought and pig irons.

ЖУРНАЛЪ

ОПЫТАМЪ, ПО ПРИГОТОВЛЕНІЮ ЛИТОЙ СТАЛИ И БУЛАТОВЪ, СЪ КРАТКИМИ ЗАМѢЧАНІЯМИ.

№	Смѣшенія.	Вѣсъ	Время плавки.		Замѣчанія.
		фун.	час.	мин.	
	1828 года. *Марта.*				
1	Рафинированной стали	5	1	—	Тигель повредился, а металлъ не расплавился; что приписано жидкости шлака; почему къ стеклу прибавлено кирпичной глины.
	Флюсу: бутылочнаго стекла .	$\frac{1}{2}$	—	—	
2	Рафинированной стали	5	1	10	Сплавилась хорошо, но, по выливкѣ въ форму, не сковалась. По обточкѣ оказалось много пузырей. Приписано доступу воздуха.
	Флюсу: глины $\frac{1}{4}$ стекла $\frac{3}{4}$	$\frac{1}{4}$			
3	Рафинированной стали . . .	5	1	15	Сплавилась, форма смазана саломъ,

Section 4. Start of industrial production of alloyed steel.


Carl Scheele

Manganese became the first industrially used alloying element. Manganese combinations – pyrolusite (MnO_2) being in the first instance – have been known and used from the ancient times. Pure manganese was first retrieved in 1774 by Swedish chemists Carl Scheele and Johan Gahn. Name 'manganesium' was first adopted in 1787 by Nomenclature Committee of France but it only became common in early 19th century. Later, to avoid any confusion with magnasium discovered by Humphry Davy in 1808, this metal was renamed into 'manganium'. In early 19th century in Russia it was called 'manganese' and it was used for production of purple enamel. The name 'manganese' became common by the middle of the 19th century when a number popular metallurgic manuals and textbooks were translated into the Russian language (primarily, the books by Valerius and Percy).

In 1801 the above mentioned David Mushet, a bookkeeper at a factory in Clyde, Scotland, who practiced the art of assay tests discovered that manganese additives improve quality of steel.


Johan Gahn

Mushet was the first to add manganese ore to the crucible charge mixture with the purpose to produce alloyed steel. It is often considered that these additives facilitated purification of steel from oxygen that deteriorated steel quality (metal deoxidation), however this is hardly probable. The point is that crucible steel was produced in very little amounts under a layer of slag and with carbon presence which minimized saturation of the melt with oxygen. In crucible steelmaking process manganese, primarily, bound and extracted sulfur. Even a lot later Henry Bessemer declared that manganese extracted sulfur and not oxygen from the metal produced according to his procedure. Besides, manganese served as an alloying element that increased steel strength (if its content exceeded 1%).

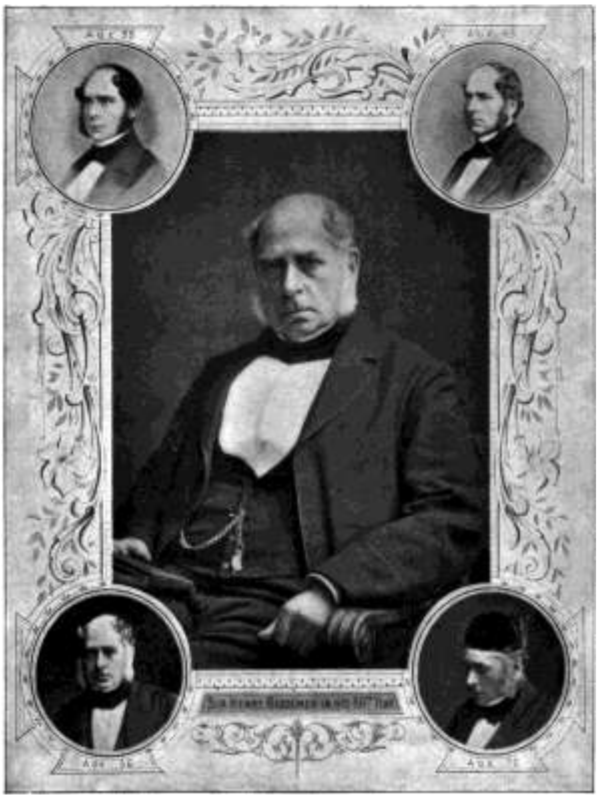
The first patent for using steel in pig iron and steel production was received by Johan Gahn in 1816. Next year, in 1817, David Mushet received a principally significant patent for 'complex' use of alloying elements. The text of the patent declared that the privilege is honoured for "adding and melting of any mixture of known quantities of crushed pig iron, purified iron and manganese dioxide with chrome ore powder with or without crushed tungsten ore or tungsten acid resulting in molten (crucible) steel". Later the other patents were issued. However, the really extensive use of manganese started in 1856 after invention of the Bessemer process that included a mandatory phase of steel deoxidation.

Crucibles for quality steel melting. Early 19th century.

Section 5. Steel deoxidation.

Blowing hot iron with air in the Bessemer process resulted in making steel saturated with oxygen which made it hot brittle. Metallurgists in the middle of the 19th century were perfectly aware that hot brittleness is based on sulfur content; therefore they extracted it with a well-proven remedy, i.e. manganese. Considering that sulfur and oxygen are similar like brothers in terms of their chemical properties manganese was perfect in extracting them both which in the beginning of implementation of the Bessemer process led into a confusion Bessemer himself.

Henry Bessemer was absolutely sure that hot brittleness of his steel was due to presence of sulfur that cannot be extracted in the process as he revealed later. If it was not for this confusion and if the metallurgists had known about oxygen mixed into the pig iron during blowing then it is quite probable that the technology would be rejected for many years ahead. Only in late 1860s appeared an opinion that the problem was primarily the oxygen.



Sir Henry Bessemer

A separate problem was methodology of introducing manganese into metal. Most of the patents for its application were expired by the 1850s. However, in 1856 Robert Mushet, David Mushet’s son, who becam his father’s successor and left an equally significant mark on metallurgic history received 4 patents for application of manganese. Wide spread occurrence of the patents could be extremely dangerous for Bessemer monopoly. The only way of Bessemer’s protection was to prove that this idea was of no news. According to Bessemer himself, he captured the idea of using manganese from an article of Josiah Heath, a famous English metallurgist who worked in India and who declared increase of metal quality by adding manganese.

Robert Mushet

According to Mushet’s patent, manganese was introduced into steel within ‘spiegel’ or ‘specular iron’ that starting from the early 19th century was produced in blast furnaces by adding into the charge mixture the manganese-containing iron carbonates delivered from Rhine Prussia

(Stahlberg). As a result the alloy contained 5…20% (most often 7…12%) of manganese and 3.5…5.5% of carbon.

The spiegel proposed by Mushet for introduction into manganese alloy was also used by Bessemer for metal deoxidation but it featured a significant disadvantage: it contained very little manganese and a lot of carbon. It was not a big problem for production of hard and carbonized steels. But when the target was to make soft and low-carbon metal (for example, for boiler plate production) the specular iron was absolutely impractical. Adding it for required amount of manganese resulted in simultaneous introduction of excessive carbon.

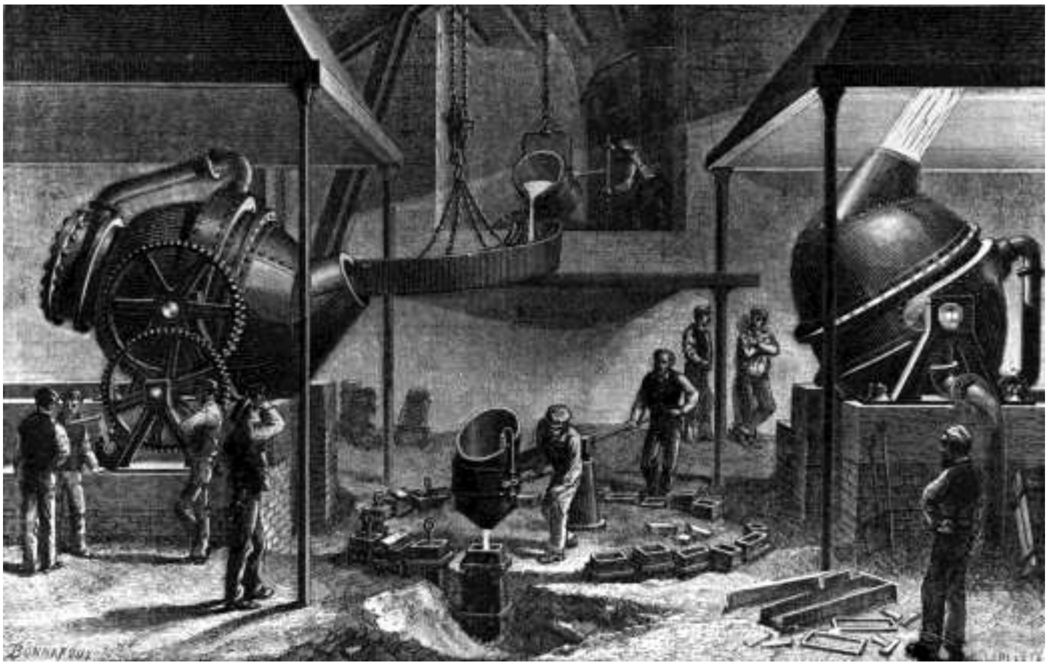
When significance of manganese for the process was discovered Bessemer made a task for himself 'to produce synthetic iron and manganese ore'. His first experiments failed: Bessemer used a copper-smelting furnace in his laboratory in the baker street, and the temperature inside was too low. However, his huge experience with copper alloys gave him an idea to reduce manganese oxides in presence of iron simultaneously smelting both metals together. Under such conditions the process worked at a significantly lower temperature.

Implementation of technology of ferromanganese crucible smelting was initially put into practice in 1863 by manufacturer called Prieger from Bonn. Being led by Bessemer's suggestions Prieger made alloys in crucibles that he filled with a mixture of crushed pig iron, manganese ore, crushed bottle glass and carbon powder. The mixture was exposed to a long-lasting heat in a kiln with coke or in a Siemens furnace until the content melted completely. The process resulted in producing alloys that contained up to 60% (normally about 25%) of manganese and some silicon and carbon. The Bessemer-Prieger process was used at many steelmaking plants, however it was soon rejectedd due to high cost and considerable losses of manganese. A similar process was suggested by Williams where carbonized liquids like oil, resin, tar, etc. were used as reducing agents.

The other processes were being developed at the same time. In 1862 Bessemer learned that a lot of manganese was available at the Tennant's chemical plant in Scotland as a part of production wastes from manufacture of chlorine and bleaching lime. Bessemer visited the plant, declared his idea to the company's chemist Henderson and made and agreement that Henderson would develop the respective process.

In 1863 Henderson received a patent for production of 'ferromangane' with manganese content up to 20…25%. In course of further process development the content of manganese in the alloy reached 35%. Henderson produced ferromangane without crucibles, i.e. directly in Siemens regenerative furnaces with carbon inner lining.

Generally, regardless of any production process, manganese content in an alloy was depended on temperature of a process. The higher was the temperature, the more manganese could be reduced. Besides, introduction of silicon had to be restricted because in contributed to conversion of manganese into slag. In 1868 a plant in Terre Noire, France, produced ferromangane in blast furnaces and reached manganese content of 80%.



Steelmaking in Bessemer converter

Finally, in the late 19th century blast furnace melting became the main process for production of ferromanganese. Small shaft-type furnaces with design similar to blast furnaces were also used. The production technique mastered already by 1875 allowed producing alloy with 62…70% of manganese in blast furnaces with Cowper stoves. In the beginning of the 20th century content of manganese reached 90…94% with 5…6% of carbon content respectively.

Hence, manganese being an easily reducible metal that can be effectively produced in a blast furnace on the one hand, and being an element binding sulfur and oxygen in steel on the other hand, became the first major ferroalloy that was extensively produced for iron and steel industry demands.

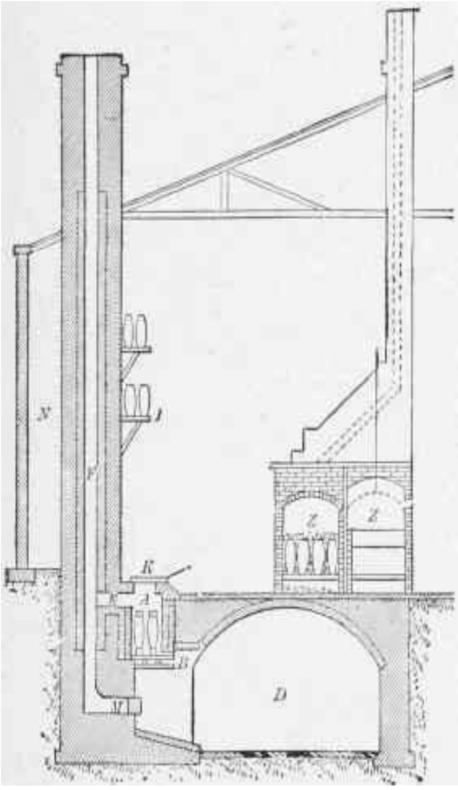
In the end of the 19th century blast furnaces were also used for production of ferrosilicon and ferrosiliomanganese (silicon iron-manganese or ferro-mangane-silicium according to terminology contemporary of that time) with silicon content up to 10% and manganese up to 30% (although there were cases when alloys were produced with less than 1% content of these elements. There were also other processes of ferrosilicon production, for example by reduction of silicon from its combinations by metal sodium in a crucible (metallothermy), however these processes consumed much resources and they were not used in industrial applications.

In general, in the first phase of ferroalloy industry (1825-1870) the basic process for production of alloying additives was crucible melting, though this process was only suitable for medium and small production outputs.

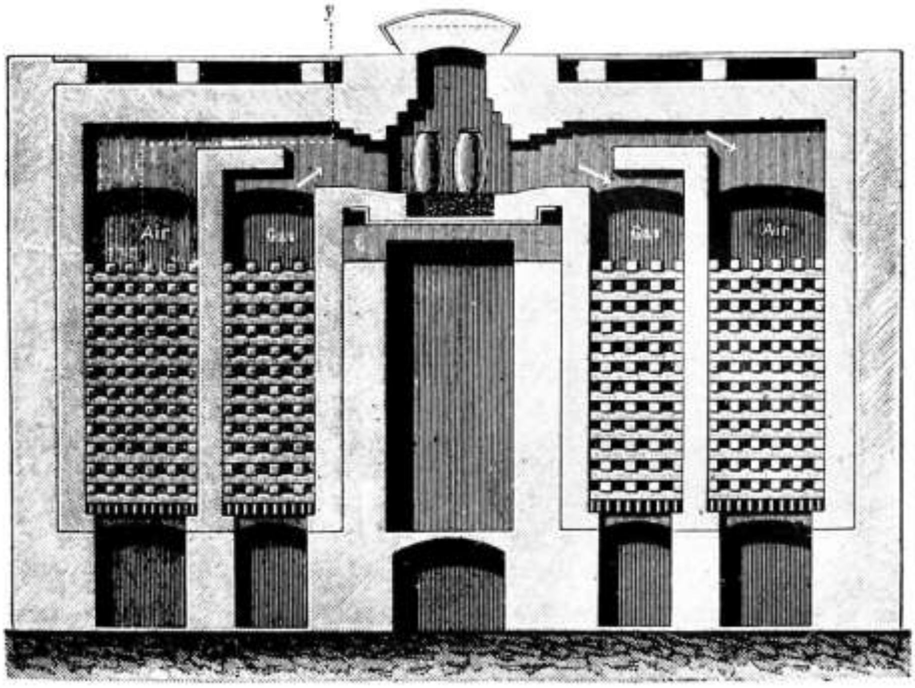
Section 6. Ferroalloys production in crucibles.

Alloys that contained hardly reducible elements like chrome, titanium, tungsten and nickel were initially produced only in crucibles. According to ‘Encyclopedia of Industrial Knowledge’ (1901) “melting of ferrochrome from ore is very simple”. It required manual labour with a spade to produce a mixture of ore, 12…15% of charcoal, 6…7% of crushed resin, about 5% of crushed glass and 10…12% of quartz sand. The mixture was placed in graphite or clay crucibles leaving some space for a thin layer of broken glass and rougher pieces of charcoal. After that the crucible was closed with a cup that was fixed to the brink with clay. The cap had a small opening for fume release.

Then the crucibles were placed into regenerative furnace, normally a Siemens furnace (a prototype of open hearth furnace), or into a special furnace for ferroalloys production, for example into Borchers furnace. Such process resulted in production of ferrochrome as ingots with the shape similar to the shape of utilized crucibles. The same process was used for production of ferrotungsten.

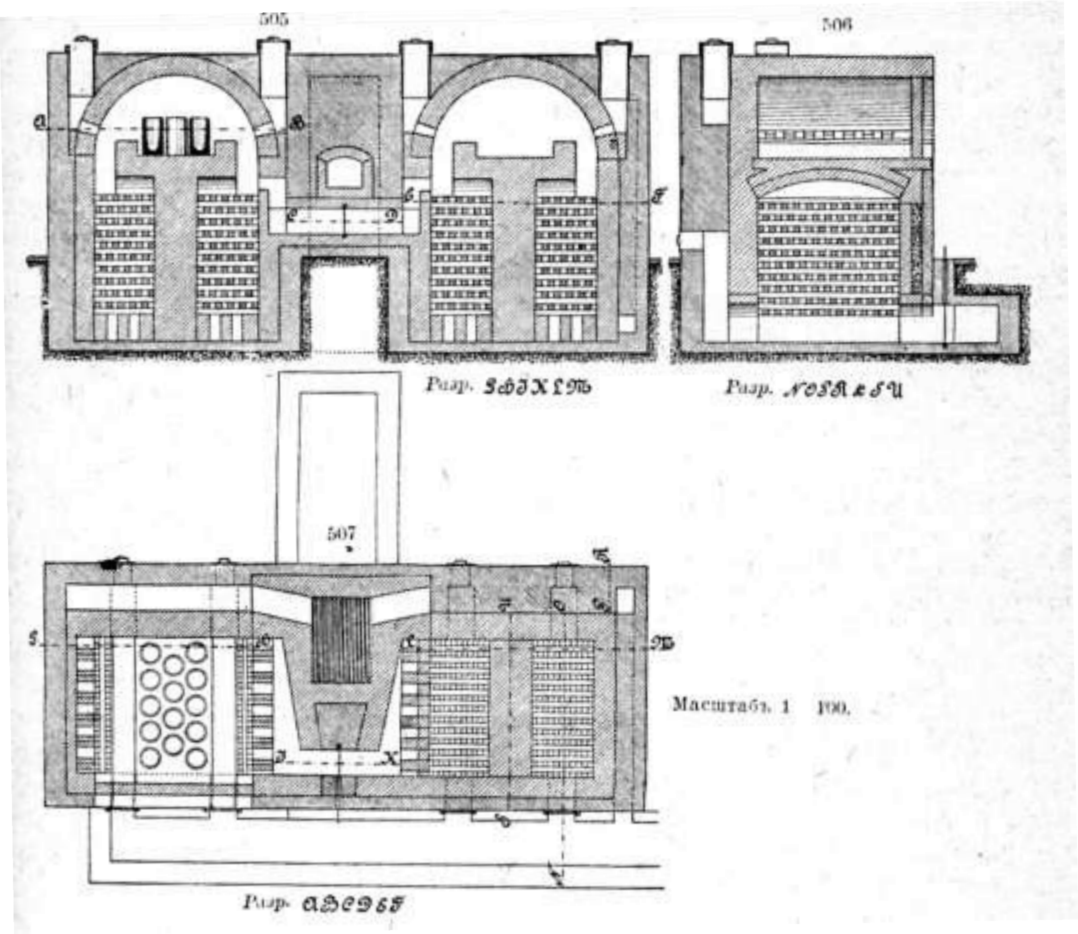


Early furnace for crucible heating



Siemens furnace with regeneration heat exchangers

Large production of ferrochrome and chrome steel was based in Germany, by Biermann in 1873 in Hannover, and by Brustlein in 1875. In 1886 Hadfield published his thorough research of properties and production processes of ferrochrome-carbon alloys.



Borchers regeneration furnace for melting ferrochrome in crucibles

There were also more complicated processes for production of metals the ores of which contained a lot of impurities or which content in the ores was very low. In such case the first step was getting an intermediate product with quite a big content of produced metal, and then such semi-product was purified in crucibles. For example, this scheme was used in nickel production: depending on ore type a particular sub-process was selected to produce crude nickel that was subsequently melted in crucibles.

Production of both ferroalloys and pure metals also utilized other metals. For example, pure metal chrome was obtained in 1854 by electrolytic process with water solutions of chromium chloride; the same method was used to produce high purity nickel. However, such production was mainly on laboratory or small industry levels. The economic effect was achieved only with ferroalloy production in crucibles.

Main problems of production in crucibles were high cost and low output of the process. Hence, manganese and silicon alloys primarily used for steel deoxidation were produced mainly in blast furnaces already in the 1880s.

In the beginning of the 20th century the method of production in crucibles was used to obtain low- and non-carbon ferroalloys, primarily low-carbon ferromanganese. Silicothermic method of producing low-carbon ferromanganese was patented in 1893 by William Green and William Henry Well. However, due to high cost of low-carbon ferromanganese the demand was extremely low and the silicothermic method of production had been out of industrial applications for a long time. It was re-demanded only after the First World War.

In the first half of the 20th century low-carbon ferromanganese and other non-carbon ferroalloys were produced with aluminothermic and silicothermic methods.

Aluminothermic method was mainly used for production of metal manganese. A pre-heated magnesite crucible was loaded with thoroughly mixed powders of manganese oxides and metal aluminum. The process was initiated with a special ignition mixture in a separated part of the crucible. As temperature arose the manganese oxides began reacting with aluminum. Due to heat of this exothermic reaction the adjacent spaces of the crucible were also extensively heated, and manganese reduced therein as well. The heat effect from aluminum burning was so huge that the whole content of the crucible could be warmed up to high temperature in a very short time without any heat contribution from the outside which resulted in almost absolute deoxidation of manganese oxides. Textbook 'Theory and practice of melting ferroalloys in electric furnaces' (1934) suggests that " the method does not require any remarkable expenses: the equipment consists only of the crucible itself that does not require electric, gas or other type of heating".

Industrial production of low-carbon ferromanganese utilized classic silicothermic methods of Jean and Beckert. The Jean's method of low-carbon manganese production included two steps: production of silicon manganese with low-carbon content followed by purification of silicon manganese from silicon with manganese ore. Beckert's method involved ferrosilicon for reduction of manganese oxides. The complicated Jean's method where silicon was initially reduced to produce silicomanganese with about 30% of silicon and then oxidized and transferred into slag was aimed to achieve the minimum carbon content in the alloy.

Section 7. Ferroalloys production in cupolas

In late 19th and early 20th century a widespread technology for producing high-melting metals, primarily ferrochrome and ferrotungsten was melting in a cupola, a small shaft type furnace very close to blast furnace in design. This technology had existed up to the middle of the 20th century and had been widely used in case of electric power shortages. In particular, melting of ferrochrome and ferrotungsten in cupolas was used in the USSR and it featured some specific techniques.

Cupolas. 19th century. Hüttenwerk Peitz museum, Germany

Melting of ferrochrome and ferrotungsten in cupolas included ‘freezing’, i.e. the produced alloy due to its high-melting point would not run free from the furnace but stay inside the furnace as an ingot or ‘freeze’. Cupolas had hinged bottoms to allow convenient extraction of ingots.

Melting of ferrochrome was done on briquettes that were made of coke, chromite, soda and resin. Air blast was pre-heated up to 400…500°C. Melting was in progress until the ‘freeze’ would cover the air lances located in three rows along the cupola’s height (the figure shows a cupola with one row of lances).

One melting produced about 3 tons of ferrochrome. The duration of the session including the cool-down time and cupola lining preparation comprised 7 days. Coke consumption reached 5…6 tons per 1 ton of ferrochrome.

Melting of ferrotungsten also included ‘freezing’ that resulted in alloy with tungsten content of 78…84%. Carbon content normally comprised 0.1…0.7%, manganese and silicon reached the same values, tin and sulfur – less that 0.1% per each element.

The reaction of reducing tungsten with carbon from the minerals (tungstenite, scheelite) was very fast because the end products of the reaction left the system very drastically: produced CO was extracted with fumes while the particles of ferrotungsten with their specific weight incomparably higher than that of slag (16.0 and 3.0 respectively) easily settled down onto the hearth and formed up a ‘freeze’. The upper layer of the freeze on the cupolas hearth worked like a ‘metal bog’ where tungsten and iron could be dissolved. In the normal process the overheated and mobile particles of slag mixed in the ‘freeze’ could easily float up, and the alloy became monolithic. This is why completion of melting was followed by hold period to let the ‘freeze’ get rid of inclusions.

A too hot process resulted in reduction of too many undesired impurities, silicon and carbon in particular. This is why melting of ferrotungsten from ores with over 84% of tungsten content was not practiced. The alloy was so high-malting that it was difficult to make it monolithic (without inclusions) or make it silicon-free.

The produced slag with high WO content was reused in the next melting processes.

Section 8. Blast furnace production of ferromanganese, ferrosilicon and ferrochrome

Ferromanganese

The first Russian textbook for ferroalloy industry titled "Theoretical and practical melting of ferroalloys in electric furnaces (Grigorovich and others, 1934) contained the following statements:

"Ferromanganese is the most significant among ferroalloys in steelmaking. It is used as a deoxidant in production of any sorts of steel. Consumption rate of ferromanganese for deoxidation is characterized by a precise value of 0.9% per the total steel weight in ingots. Manganese is also introduced into steel as an alloying agent individually or in combination with other elements.

Manganese is virtually an irreplaceable deoxidant.

In terms of quality special steels with manganese content sometimes are inferior to other alloyed steels that contain chrome, nickel, etc. This is characteristic of some stainless, heat resistant and other steels. However, taking into account low price of manganese and its relatively wide presence in comparison to other elements we have to admit its significance in production of special steel as a special additive providing especially valuable properties.

Ferromanganese is still melted blast furnaces in most countries of the world. This is due to lack of electric power sources close to manganese ore deposits. Only few countries have quite favourable conditions to practice electric melting of ferromanganese".

The above quotation clearly states that melting in a blast furnace remained the prevailing process of ferromanganese production up to the middle of the 20th century. The process itself had been mastered by 1880s (as was stated above). Let us review the process of ferromanganese production in blast furnaces as of the late 19th century.

The first mandatory condition to ensure acceptable manganese content in the alloy was preheating of air blast supplied into the furnace. As reported by prof. Åkerman, one of the founders of the blast furnace science, a blast furnace operated with charcoal and insufficiently hot blast air cannot ensure continuous production of an alloy even with 50% of manganese content. To produce an alloy with up to 80% of manganese it is necessary to use coal coke as fuel, while the blast air temperature shall comprise 700…800°C (which can be gained using Cowper or Whitwell air heaters).

The most convenient raw materials for melting ferromanganese were ferrous-manganese ores with calciferous gangues deposited on the eastern coast of Spain, in Italy and in several other countries. The ores contained 10…15% of iron and 25…30% of manganese. Where the above ores were unavailable production used a mixture of iron ores with natural manganese ores or synthetic manganese compositions. Production of alloys with high content of manganese involved rich manganese ores with a limited presence of iron.

Due to extreme ferroalloy production environment the blast furnaces were often of a very simple design. The furnace lining was fastened with metal rings. It allowed for easy overhauling.

The charge mixture was composed in such way that produced slag was of alkali nature (basic oxides prevailing in the base-acid ratio) while the growth of manganese content increased the presence of basic oxides in the slag. Manganese content in an alloy also influenced the production parameters: fuel consumption increased while the furnace productivity decreased significantly. Meanwhile regardless of the melting parameters and process techniques not more than 75…80% of manganese from the charge mixture was transferred into the alloy while the rest of it was transferred into slag and was partially evaporated with top gases. However, the more manganese was contained in the initial charge mixture, the less metal was transferred into slag. Evaporation of manganese with top gases was as remarkable, as the furnace temperature was higher and the more manganese was contained in the charge mixture.

Content of manganese, silicon and iron in an alloy depended greatly on properties of charge mixture materials and the technological parameters of the process which is clearly illustrated by operation of two European plants.

The plant in Terre-Noir, France, melted ferromanganese in an ordinary blast furnace 16 m high and featuring capacity of 100m^3, at blast temperature 600…750°C using ores rich with manganese delivered from island Sardinia in Spain and from Saône-et-Loire department. The produced alloy was practically a ferrosilicomanganese with the following composition (the samples were exhibited in Paris in 1878:

Element	Content in ferroalloy, % (weight)			
Iron	66,75	71,50	79,00	85,50
Manganese	20,50	19,50	13,00	6,55
Silicon	10,20	7,45	5,45	5,55
Carbon	2,65	2,65	2,30	2,10
Phosphorus	0,185	0,178	0,145	0,140

The blast furnace in Krajna, Slovenia 17.2 m high and operated under excessive pressure with blast temperature about 600°C used a charge mixture composed of local siderites (calcinated) and manganese ores mined close to village Vigounsica. The charge mixture also featured some lime flux and return slags. The process resulted in production of the below alloys:

Element	Content in ferroalloy, % (weight)					
Iron	43,55	45,90	48,14	53,39	63,27	73,26
Manganese	50,05	48,06	45,42	40,28	30,51	20,3
Carbon	5,73	4,61	4,80	4,90	4,96	5,19
Silicon	1,98	0,92	0,91	0,86	0,79	0,85
Aluminum	0,02	0,00	0,00	0,01	0,01	0,00
Calcium	0,01	0,11	0,07	0,06	0,05	0,09
Sulfur	–	0,01	0,02	0,02	0,02	0,03
Phosphorus	0,26	0,32	0,34	0,36	0,38	0,31

Ferrosilicon

Main conditions for production of silicon iron and ferrosilicon were the following: high temperature of blast air and huge fuel consumption; siliceous slags were used with charcoal fuel, and aluminous slags were used with coke fuel; easily reducing low-saturated ores with high-melting gangue minerals, free silica evenly spread in the whole volume of iron dioxide.

The above mentioned textbook “Theoretical and practical melting of ferroalloys in electric furnaces (1934) stated that “ferrosilicon melting with 12% silicon content consumes 2.5…2.75 times more coke than normally. Hence, the fuel consumption in a blast furnace goes up not proportional to the increment of concentration of silicon in the alloy, but by a lot higher factor. When iron-to-silicon ratio becomes about 4:1 (about 20% of silicon in the alloy) the further increase of fuel consumption does not result in increment of silicon content in the alloy. Hence, a more saturated ferrosilicon cannot be produced in a blast furnace and requires and electric furnace”. Normally, blast furnaces were used to melt ferrosilicon with 12…13% of silicon content.

Melting of ferrosilicon in blast furnaces was relatively seldom because the uttermost heat regime led to fast wear of furnace lining. This is why ferrosilicon was normally melted in the end of melting campaigns before final blasting of the furnace for overhauling.

Ferrochrome

First attempts to produce ferrochrome in blast furnaces date back to the middle of the 19th century. Despite of the fact that reduction of chrome oxides in the blast furnace is quite substantial the temperature conditions do not allow obtaining an alloy with high chrome content. Ferrochrome melted in a blast furnace contains up to 30…40% of chrome. An alloy with a higher chrome content becomes so tenacious that it cannot be released from the receiver. Carbon content in ferrochrome has always been high, from 6 to 12%.

Due to the above reasons melting of ferrochrome was practiced only under special circumstances. For example, this technology was used from time to time in the Urals during the Second World War.

Problems of ferroalloys production in blast furnaces

Using blast furnaces for melting silicon and manganese alloys resolved the problem of low productivity being characteristic of ferroalloys melting in crucibles or cupolas. However the prime cost of the alloys remained very high due to peculiar technology and high losses of manganese. Since the temperature in the operating space of the equipment should have been as high as possible the fuel consumption (charcoal or coke) could reach 3 tons per 1 ton of pig iron, and the heat of a receiver could be so intensive that at some plants, e.g. in Nizhniy Tagil, the receiver was made changeable and moving on a special rail trolley. As was mentioned above, due to very high temperature a huge part of manganese was lost with fumes (with 80% of manganese content in an alloy about 20% of the original charged content was lost). Besides, presence of manganese oxide in the slag sometimes exceeded 15%, and the loss of manganese with slag comprised about 12% of total manganese content in the original charge mixture. Thus, total losses of manganese in a blast furnace comprised 27…32% while manganese transferred into alloy comprised about 68…73% of its overall content in the original charge mixture.

Advantages of ferromanganese production in electric furnaces

Reaction of reduction of manganese from ore and the general process of producing ferromanganese in an electric furnace are similar to those made in a blast furnace. The principal difference is that electric melting consumes power only for reduction and the amount of power per 1 ton of ferromanganese comprises about one quarter of fuel burned in the blast furnace assuming the same quality of the product. Hence:

1) amount of ash and impurities introduced from electric process is about one quarter less than in case of fuel in a blast furnace;
2) amount of slag and loss of manganese are a lot less in electric melting;
3) electric furnace allows using a lower quality deoxidants with a higher amount of ash as compared to blast furnace process.

As a result, a blast furnace is inferior to electric furnace in terms of amount of manganese extracted from ore and in terms of quality of the final product. This is why starting from the early 20th century when industrial electric furnaces appeared the major amount of ferromanganese is produced by electric melting although carbon ferromanganese may still be produced in blast furnaces even nowadays.

Section 9. Dreadnoughts and Krupp cannons

Now the question is: what was the reason for all those gimmicks in producing ferroalloys when iron and steel have always been produced without them?! As was mentioned previously, manganese and silicon were in the first instance necessary to deoxidize cast steel (the steel produced in liquid state). Moreover, these elements were used in production of both Bessemer (Thomas) steel and Siemens-Martin dead-melted steel. The necessity in using other ferroalloys was stipulated by two factors: a) demand of extensively developing industry in materials with special properties, and b) the beginning of the armament drive started after the Crimean War, the so-called "confrontation of armor and weapon".

As stated above, by the end of the first quarter of the 19th century the impact of the majority of alloying elements on steel properties had been learned. However, practical use of the knowledge was restricted by the fact that they could be used only for steel production in small crucibles (and the alloying elements must have been produced in advance in the same crucibles) which of course made the steel production process, especially of huge items, very ineffective both from technological and economical point of view.

The situation changed in the second half of the 19th century when production of huge amounts of cast steel could be started thanks to developments of Bessemer (acid lining), Thomas (basic lining), Siemens (regeneration furnace) and Martin (use of regeneration furnace for steel melting).

In 1864 Robert Mushet introduced 5% of tungsten into the steel as an alloying element. The steel historically known as Mushet's air-hardening steel could withstand full red heat not only retaining but also improving its hardness, i.e. it was self-hardening. Cutting elements fabricated from Mushet's air-hardening steel allowed increasing the cutting speed by 1.5 times (from 5 to 7.5 meters per minute). As time went by, the tungsten content in steel and respectively the cutting speeds continuously increased. Stellite was invented in 1907; it was an alloy of tungsten, chrome and cobalt with a small content of iron. The alloy allowed increasing the cutting speed up to 45 meters per minute.


Robert Abbot Hadfield

A milestone in the history of manganese applications became year 1882 when English metallurgist Robert Abbot Hadfield melted steel with high content of this element (in fact, he was the owner of the plant where that steel was produced). Hadfield steel with

11…14% of manganese and about 1% of carbon featured a high resistance to shocks and wear, and it was used for manufacturing safes, grids, railway forks, Blake crushers, ball grinders and other mechanisms with huge load impacts.

However, the widest application of alloys was practiced by military industry. The history of carbon steel armor was over in 1889 when Schneider started using nickel in steel armor production for the first time. The nickel content in the first samples varied from 2 to 5% and finally was settled at 4%.

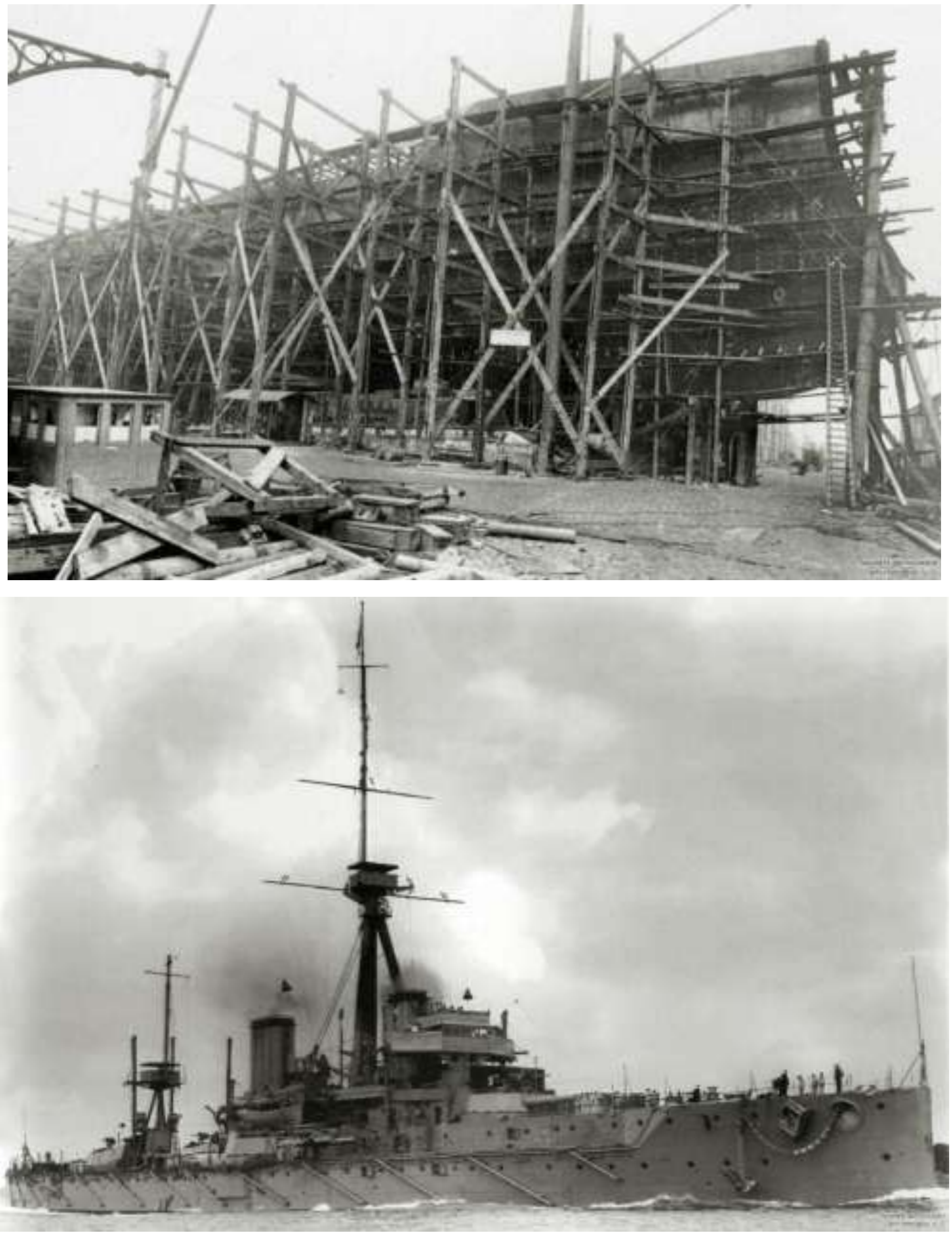
Nickel's feature is in making steel significantly more tenacious. Under applications of the same load impacts nickel steel armors do not crack and do not peel by splinters as compared to normal reaction of pure carbon steel. Besides nickel simplifies heat treatment because nickel steel buckles less during hardening. Thus, application of manganese was followed by nickel, and then by chrome.

Introduction of nickel makes the steel more tenacious and creates its fiber structure under certain treatment. Chrome contributes to steel hardness provided by carbon but gives no increment in brittleness. Also, chrome makes the steel especially sensitive to heat treatment which simplifies final hardening.

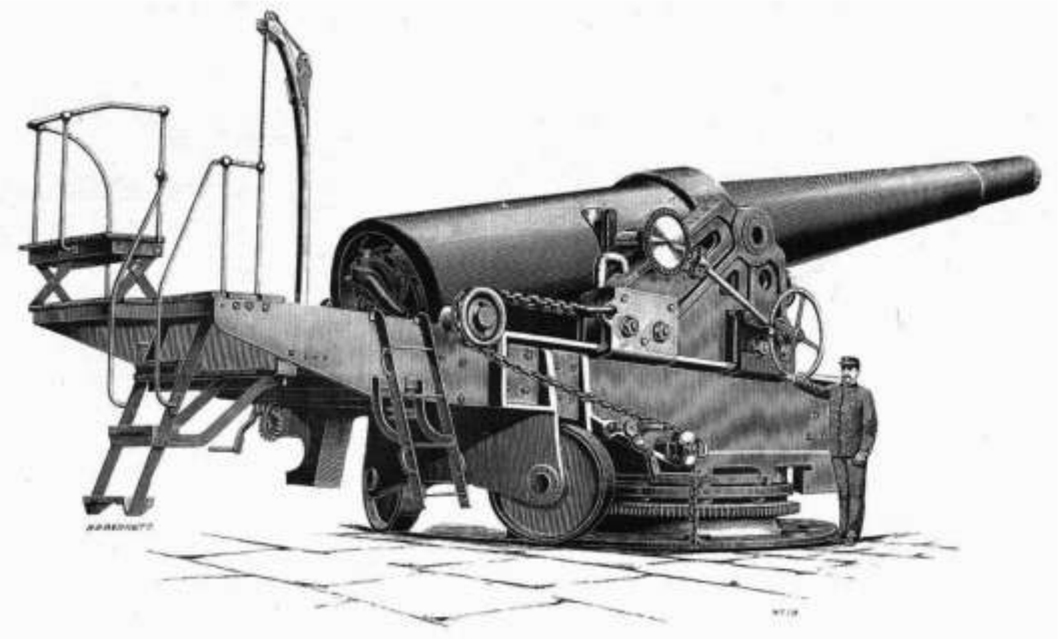
Armour plate forging withsteam hammer. USA, early 20th century

The first patent for chrome steel was issued in 1865. Its wide application started in 1880s (initially for alloying small steel castings). It was revealed that the produced alloy features significant hardness after respective heat treatment. However despite of continuous efforts metallurgists could not make big ingots of chrome and nickel steel and could not treat them until German manufacturer Krupp resolved this problem in 1893.

The defensive technologies were in competition with offensive armament: German engineers noticed that presence of tungsten in steel extensively increases endurance of a barrel. During the First World War light German cannons could make up to 15 thousand shots while Russian and French weapon failed after only 6…8 thousand shots. All these circumstances led to extreme increment of steel production, primarily of alloyed steel for military industry. At the turn of the century the terms ‘dreadnought’ and ‘Krupp cannon’ became common.



British battleship HMS «Dreadnought» on the slipway and in the fight



Krupp coastal gun

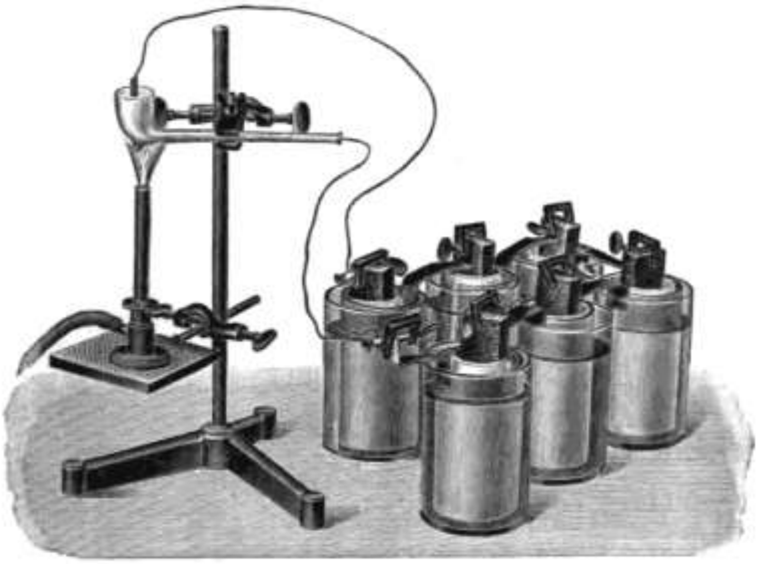
Naturally, this situation influenced the demand in ferroalloys and ores used for their production. For example, in 1890s the world's annual amount of mined tungsten ore was 200…300 tons while already in 1910 the values reached 8 thousand tons, and in 1918 – 35 thousand tons respectively.

Of course, the increase in production by 140 times within about 20 years was not only stipulated by the demand in ferroalloys. Another factor was industrial implementation of electric melting - a principally new process of alloys production that substituted low output crucibles and raised the ferroalloy industry to a higher level.

Section 10. Early history of electric furnaces

The first researches that later allowed designing industrial electric steelmaking furnaces were made as early as in the 18th century. In 1753 the member of St. Petersburg scientific academy Georg Wilhelm Richman declared of a possibility to use electric discharge for melting metals. Later in 1782 a German physicist Georg Lichtenberg reported that he succeeded to melt and connect thin steel wires and plates using an electric discharge.

In late 1799 Alessandro Volta created a galvanic battery. That first voltaic pile consisted of 20 pairs of copper and zinc circles separated with felt circles moistened with salt water. This invention allowed the scientists to proceed with their research and use a continuous source of electric power. In 1801 Louis Thénard found out that a platinum wire can be warmed up with electric current, and in 1802 Vassily Petrov discovered an electric arc and he became the first to demonstrate a possibility of using electric power for industrial processes. He heated and melted several metals using electric arc and reduced some metals from their oxides. Finally in 1812 Humphry Davy designed the first laboratory type electric resistance furnaces with direct and indirect heating. He used them to study the properties of alkaline earth metals and noble metals. In 1839 Robert Hare (Great Britain) made an electric furnace covered with a bell wherein he created vacuum. Hare was the first who segregated metals by their evaporation using a galvanic battery.



Galvanic batteries as electric power source for laboratory experiments

Laboratory type electric arc furnaces appeared in the middle of the 19th century produced by Siemens, Deprez, Pichon and Johnson. Up to the late 19th century arc furnaces remained only laboratory tools although there were about ten types of their design. This was due to absence of strong electric power sources.

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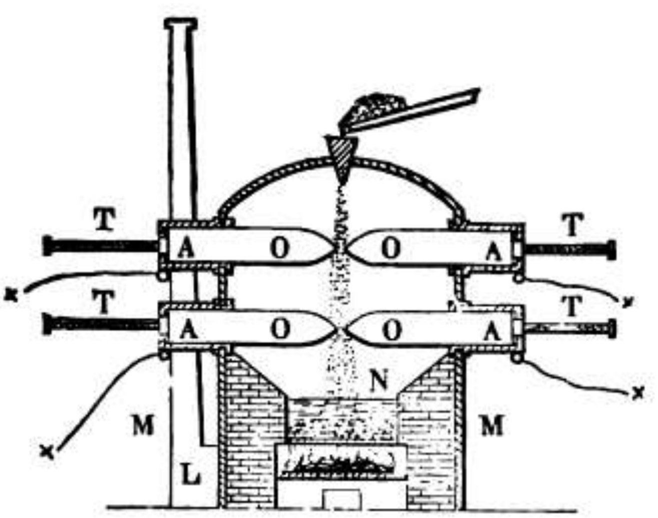
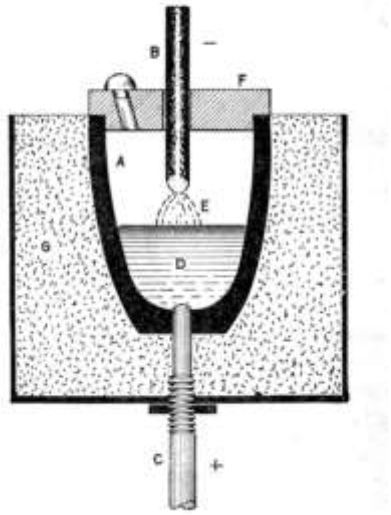


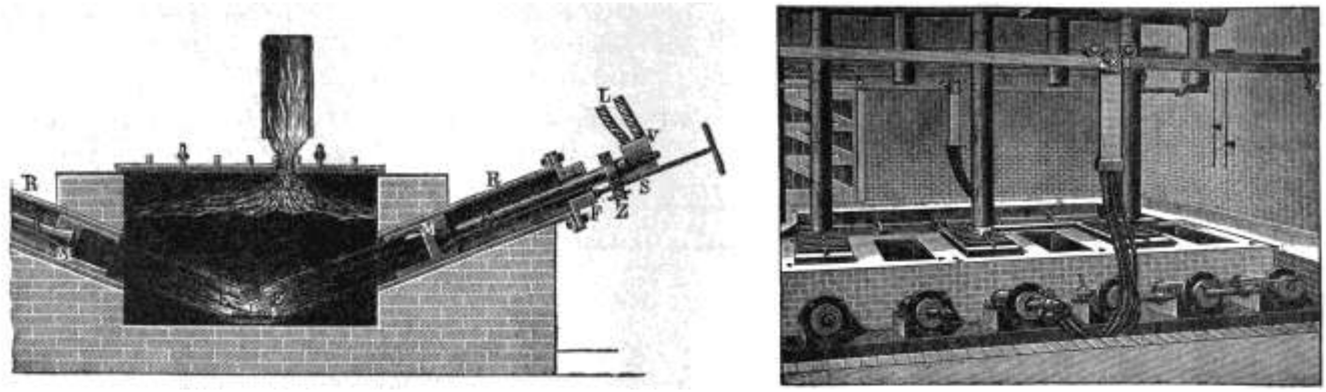
Pichon furnace



Siemens furnace

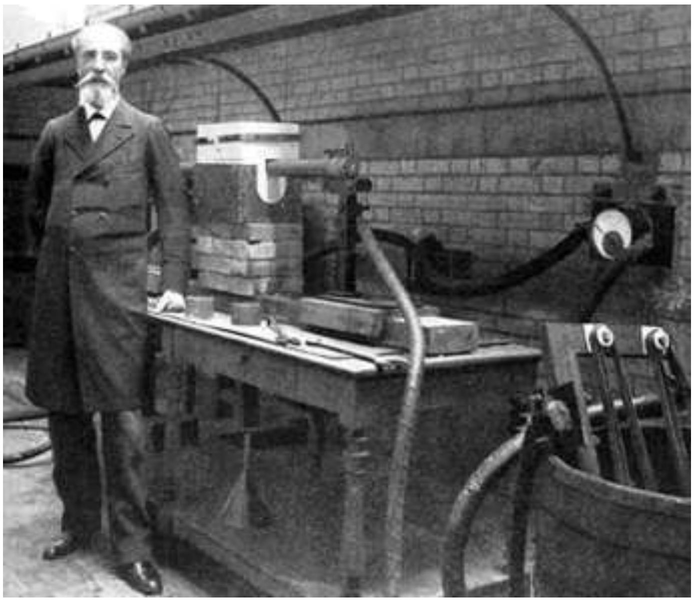
In 1883 Ch. Bradley developed a process of electric melting in skull when the melting space of the furnace was restricted by the charge mixing unit. Ore placed on a coal pad was connected to anode and was smelted in the zone around the electrode. Unmelt ore and the cooled down solidified alloy – the skull – worked as furnace lining. Later, some principles of this invention were used in design of ore thermal furnaces.

In 1884 John Napier became the first who produced a metal ingot that was smelted with electricity. He made it in a crucible with a metal water-cooled bottom connected to the negative pole of the battery while the positive pole was connected to a metal disc placed on the liquid metal surface.



Cowless bros. furnace

Electric furnace of American inventors Cowless brothers was the first in the technical history that was widely used for industrial production of aluminum. The space of the furnace contained two holders with carbon electrodes connected to the poles of an electric generator. The furnace was filed in with coal, aluminum silicate and crushed copper placed layer by layer. Such furnaces with some small improvements in design had been in operation since 1884 until introduction of the electrolytic process of aluminum production.



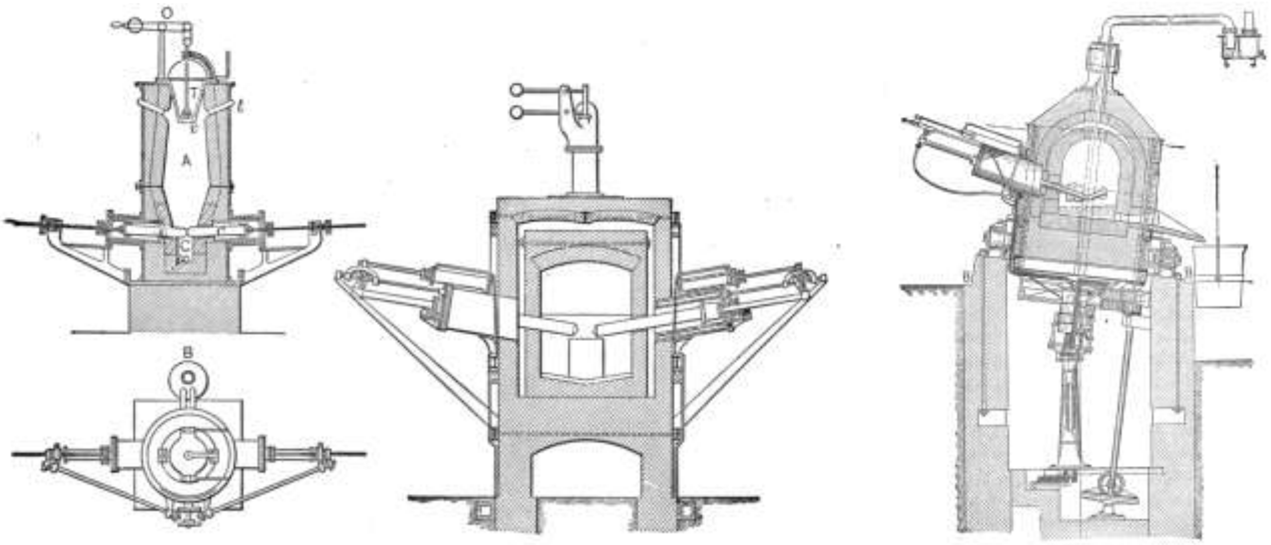
Henri Moissan and his laboratory arc furnace

In 1890s the design of electric furnaces improved rapidly. French chemist H. Moissan designed an electric arc furnace with indirect heating. In such configuration the arc appeared between two electrodes while direct heating method assumed that the arc would work between the electrode and the metal. Moissan suggested that the arc can be controlled with a magnet located outside of the furnace which would allow for a high concentration of energy. Due to this Moissan succeeded in reducing chrome, tungsten, vanadium, titanium, molybdenum and uranium from their oxides. These were the metals that previously had been considered irreducible. Moissan also proved that any metals can not only be melted in an arc but they can also be evaporated.

In 1892 Acheson developed a process for producing carborundum in a direct heating electric furnace. The charge mixture was warmed up to 1800°C which was necessary to produce carborundum. The same year Moissan became the first to produce calcium carbide in a small arc furnace.

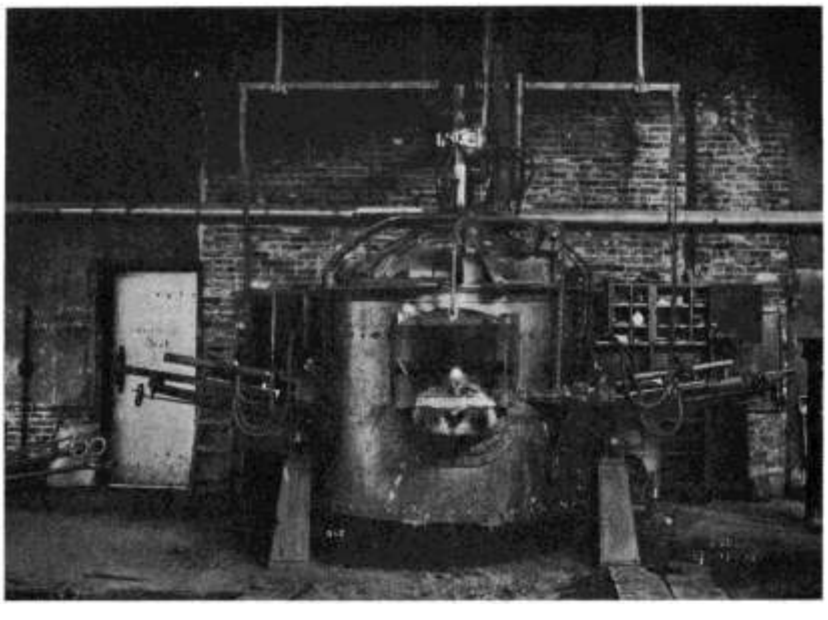
In 1898 the Italian engineer Ernesto Stassano designed and manufactured an industrial indirect heating electric furnace for melting iron and other metals directly from ores. His furnace was installed in the northern Italy where the land was rich with water resources that produced the most affordable electric power from nearby rivers. It was a shaft type furnace; in fact it was a small blast furnace where electrodes were located in the receiver. However this process appeared to be much expensive and Stassano refused the idea of using the shaft, so he redesigned the furnace for malting steel scrap. Furnaces of similar design became very convenient for melting non-ferrous metals.

In 1918 ‘Detroit’ company in the USA built a tilting furnace for meltback of copper and copper alloys. The design of the furnace became so good that it remained almost unchanged till the present days, and lots of attempts to improve it eventually failed.



Stassano electric furnaces (left to right): shaft type, low shaft type, final design

Research works of N. Tesla and M. Dolivo-Dobrovolsky in three-phase electric power enabled construction of three-phase electric furnaces starting from 1891. In 1912 P. Rennerfeldt (Sweden) redesigned and improved the Stassano's design of electric furnace. Rennerfeldt's furnace was operated by three-phase electric power and it contained three electrodes. It was widely used for refining steel and pig iron, for malting copper, nickel, silver and aluminum alloys.



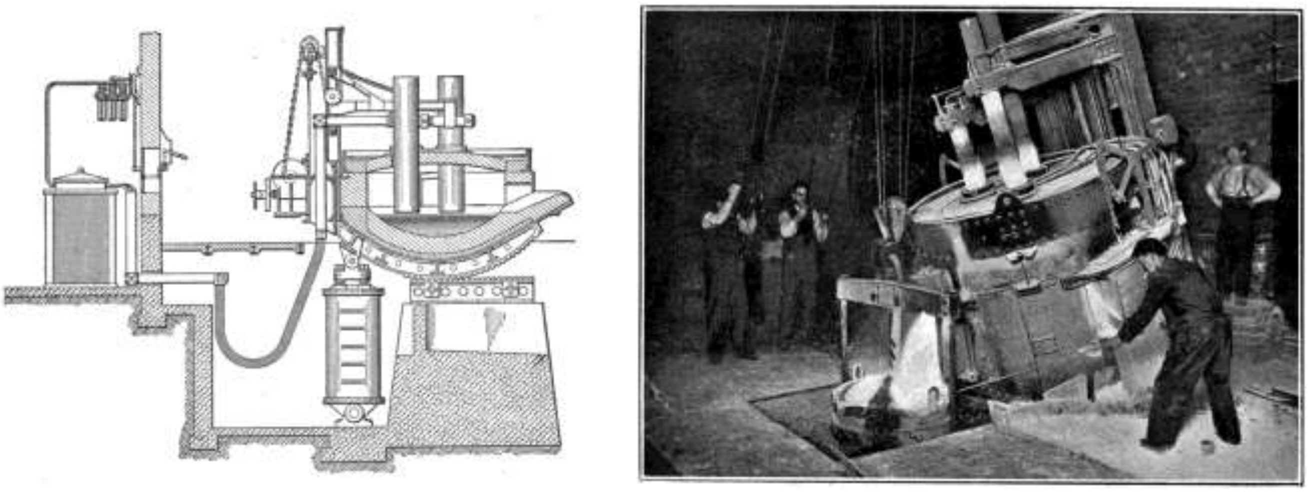
Rennerfeldt electric furnace

A furnace invented in 1899 by French engineer Paul-Louis-Toussaint Heroult became a prototype for modern electric steelmaking furnaces. The furnace contained two vertical electrodes located close to metal bath. The design was remarkable due to its simplicity: two electrodes came from top through a hole in a detachable dome and ran down to the rectangular elongated bath. The electrodes were fixed in their holders but they could be moved up and down along vertical posts resulting in arc current control. The furnace was loaded through edge doors, and the produced metal was extracted through a tap hole by tilting the furnace. The current between the electrodes ran through the bath while the arcs appeared between the electrodes and metal (or slag), thus it was a direct heating furnace.


Paul-Louis-Toussaint

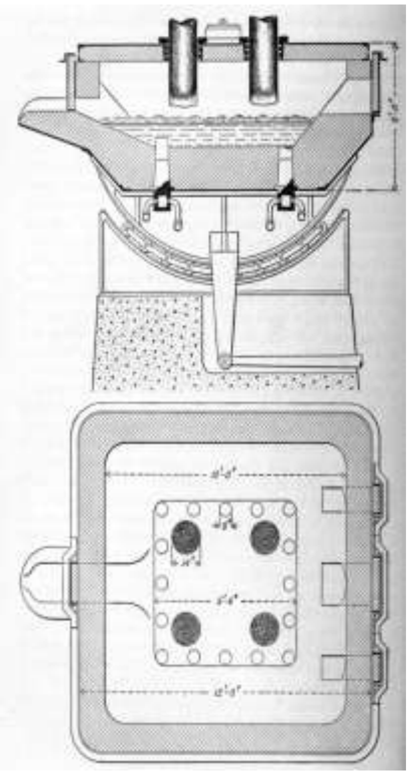
The first Heroult furnace was built in Savoie in the foothill of the Alps because that area was favourable for producing affordable electric power. The first industrial Heroult furnace started working in October 1900 at a French plant and its purpose was making qualitative steel. Main disadvantages of Heroult furnaces were low operating voltage and, respectively, small specific power rating. It resulted in a longer time period for melting metal.

Development of circle diagrams for electric arc furnaces and modeling of their electric specifications allowed for introduction of a new electrical operating mode for electric arc furnaces. Instead of low operating voltage (90…130V) the furnace transformers provided a higher voltage of 180…230V. Retaining the same size of the furnace and electrical conductors it allowed to rapidly increase the unit power, significantly reduce melting time, heat losses and increase the efficiency factor.


Heroult furnace – a prototype of modern designs

As a result of these improvements Heroult furnaces became leading facilities leaving other more complicated furnaces far behind, including their main competitors, Girod furnaces that were peculiar of their hearth electrodes that were considered contributing to additional mixing of the liquid metal bath.

Threaded carbon and later graphitized electrodes that appeared in 1910-1910 made significant effect on further development electric arc steelmaking furnaces.



Girod furnace with hearth electrode

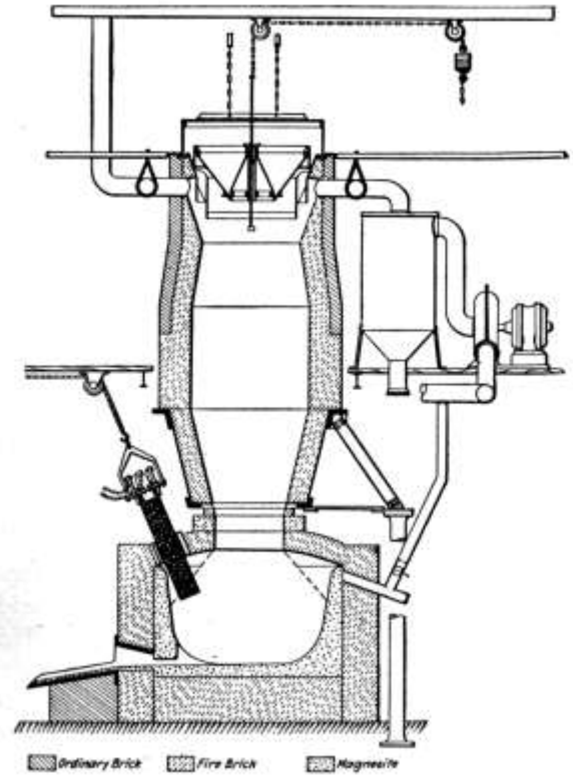
In 1910 the total number of electric furnaces in the world was 114. In 1915 the number increased up to 213, and in early 1920 the steel was made in 1025 electric furnaces while another 362 were in installation and startup phases. In various countries being rich of electric power electric steelmaking and production of ferroalloys grew especially fast. For example, in the USA production of steel in electric furnaces increased within 4 years (1914-1918) from 24 to 800 thousand tons, i.e. by 33 times. The same was characteristic of Germany and Canada.

During the same period electric furnaces were utilized for production of ferroalloys, melting of non-ferrous metals and in chemical industry for production of calcium carbide, phosphorus, etc.

Hydroelectric power station for electric metallurgy production, early 20th century, Norway

Section 11. Ore thermal furnaces

The design of electric arc ore thermal furnaces was originally the same as of ordinary blast furnaces where electrodes were placed into the receiver. Stassano shaft-type furnace has already been mentioned here. A furnace in Domnarvert, Sweden featured a similar type of design. Power capacity of this furnace that was built in 1920 comprised 1850 kW, it had a two-phase circuitry and contained four round electrodes.



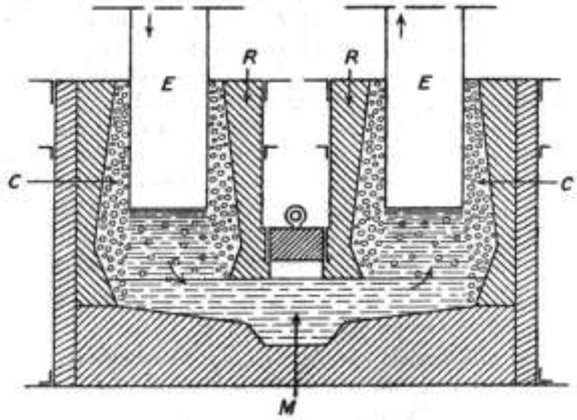
Ore thermal furnace at Domnarvert plant

High shaft of the furnace allowed for acceptable operation only with charcoal which restricted both sphere of application and the power of the facilities. Design of Helfenstein’s low-shaft furnaces allowed eliminating this restriction and provided for building powerful coke furnaces. Alternative designs also existed, for example Keller furnaces.

Shaft-type ore thermal furnaces were first industrially used in production of calcium carbide. The production technology was designed by Moissan and Wilson in 1892. Next year, in 1893 Moissan using an electric arc furnace melted a carbonized ferrochrome that contained 60% of chrome and 6% of carbon.

In 1890 calcium carbide production furnaces were operated by direct current. In course of melting ferrosilicon appeared as a by-product. Iron and silicon oxides that were present is coke ash were reduced resulting in ferrosilicon with low silicon content.

Use of direct current emerged significant problems in operation of ore thermal furnaces. Direct current evolves an electrolytic process resulting in reduction of not only silicon but other elements as well. As a result, ferrosilicon, deoxidized by direct current included significant amount of aluminum and phosphorus. Due to this fact it crumbled into powder and under humid environment it could be dissociated evaporating hydrogen phosphide, a poisonous gas. In early 1890s when ferrosilicon was transported by ships there were lethal cases due to toxic effect of hydrogen phosphide, therefore shipping of ferrosilicon with 50% silicon con-



Keller ore thermal furnace

tent by water transport was prohibited for a certain time period.

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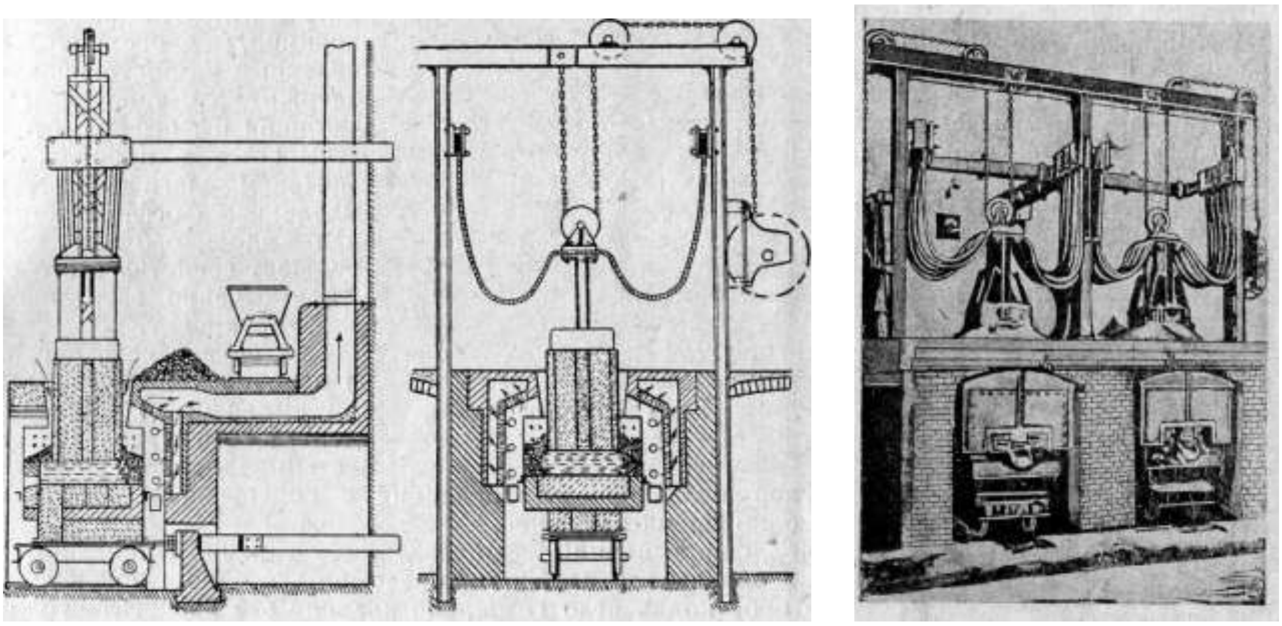
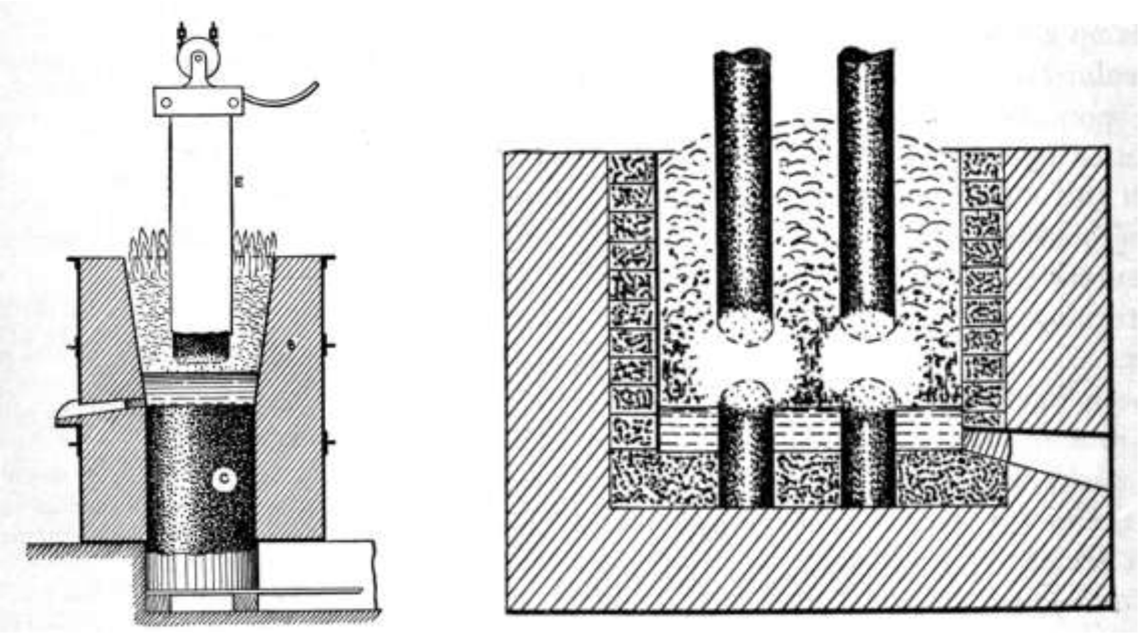


Section and general view of single phase furnace

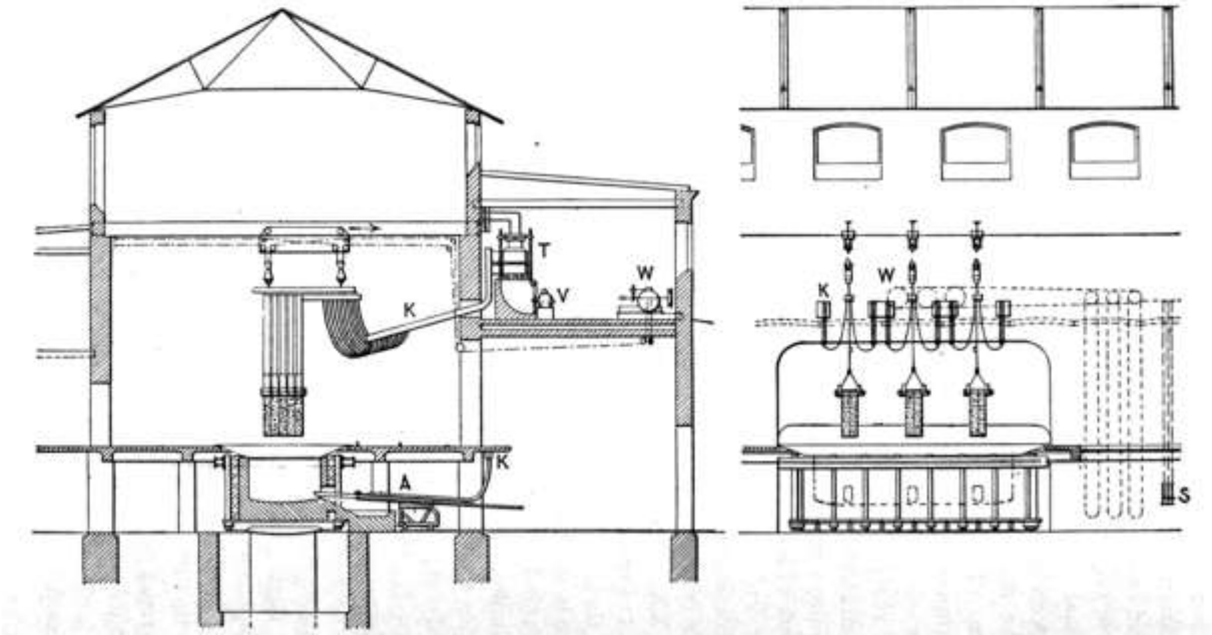
Another technological problem that appeared due to electrolytic effect of direct current was formation of graphite block that slowed down the material ejection from the furnace. To avoid formation of the graphite block the polarity of electrodes in the furnace was changed every two or three weeks. These complications associated with direct current operation were so significant that transfer to a three-phase alternate current became the major breakthrough in the ferroalloy furnace construction.



Ferrosilicon (left) and crystal silicon (right) production ore thermal furnaces

The first three-phase electric arc steelmaking furnace with 3 tons capacity was built in Makeyevka, Ukraine in 1910. In approximately the same period of time two 6 tons furnaces were installed at Thyssen plant. In 1912, at the same plant they installed another 25 tons furnace. In 1912-1915 electric steel production in Germany and the USA exceeded the crucible steel output rates.

The power of ore thermal furnaces was constantly increasing; the furnaces were operated by three-phase power sources and contained six electrodes connected to three single-phase transformers. Ferroalloy and calcium carbide production plants used a huge amount of smaller furnaces with power capacity about several hundreds of kilowatts. Utilization of powerful three-phase electric power stations resulted in using big three-phase furnaces featuring capacities of about several thousand kilowatts. One big three-phase furnace could substitute from 12 to 36 smaller furnaces.



Ferrosilicon production three-phase furnace

Apart from application of three-phase power supply there were other significant achievements on the way of improvement of ore thermal furnaces. One of them became development of bifilar (dual-core) conductors and ramed self-baking electrodes (Søderberg, Fiskaa plant in Norway, 1919). As a result, by 1930 the ore thermal electric arc furnaces for production of ferroalloys were finalized in their “classic” design: a furnace with round shape in cross-section containing three electrodes located in the corners of a triangle. Power capacity of ore thermal furnaces could reach 24 thousand kilowatts.

Section 12. Production of alloyed steel and electric arc ferroalloys in the early 19th century

By 1920 all industrially developed countries produced almost all ferroalloys in electric arc furnaces with exception of ferromanganese. The output rates increased rapidly because the demand in in alloyed steels was continuous. Below are the data illustrating this process in the USA (up to the Great Depression of 1930) and in Sweden that possessed significant amount of electric power resources and exported its ferroalloys. However, the production increment of the same rates was witnessed in other European countries as well.

Production of ferroalloys and alloyed steel in the USA

Year	Ferroalloys production, thousand tons/year	Ferroalloys production, kg/ton of pig iron	Alloyed steel production, thousand tons/year	Alloyed steel presence in overall steelmaking industry,%
1909	294	9	181	0,76
1915	398	13	1021	3,17
1920	623	17	1660	3,94
1929	843	21	4000	7,00

Production of ferroalloys in Sweden, tons:

Ferroalloy	1921	1922	1924	1925	1926
Ferrosilicon	3443	5 657	13 228	18 216	20466
Ferrochrome	725	3 754	5 052	8 921	11 213
Silicospiegel	520	372	2 238	1 348	4 065
Ferromanganese	–	54	41	53	63
Silicoaluminum	294	34	52	313	400
Spiegel	–	–	–	64	326
Ferrotungsten				4	
Total	***4 982***	***9 871***	***20 611***	***28 919***	***36 533***

Ferrosilicon production

Along with ferromanganese, ferrosilicon was the most used ferroalloy for production of all sorts of steel (with the exception of open-hearth steel). Apart from its application as a good deoxidant ferrosilicon was widely used for production of special steels with high silicon content. At initial stage ferrosilicon was normally melted in furnaces built for melting calcium carbide at several plants in France, Austria and Switzerland. In 1903 the company titled “Campagnie Generate d'Electrochimie” originated a syndicate for production of all kinds of ferrosilicon in the territories of Germany, France and Austria. Later production was founded in the USA, Sweden and Norway. In 1920-1930 the leaders in ferrosilicon production were the USA, Canada, Scandinavian countries, France and Italy.

Both lean (12…13% of silicon) and rich (45…90%) ferrosilicon was used in steelmaking industry. Classification adopted in the USSR in 1931 (similar to European standards) ferrosilicon was manufactured in four grades varying in silicon content:

Grade	Content of elements, % weight						
	Silicon	Carbon	Manganese	Phosphorus	Sulfur	Calcium	Aluminum
13 %	12-13	1,3	0,3-1	< 0,20	< 0,03	–	–
45 %	43-50	< 0,15	< 0,4	< 0,06	< 0,04	< 0,3	1,0
75 %	72-80	< 0,15	< 0,4	< 0,05	< 0,05	< 0,6	< 2,5
90 %	87-95	< 0,12	< 0,2	< 0,04	< 0,04	< 0,5	< 1,0

13% ferrosilicon was produced in blast furnaces and was later utilized in open hearth steelmaking as deoxidant. Other grades were produced in electric arc furnaces. Great amount of rich ferrosilicon was consumed by production of other ferroalloys (ferromanganese, chrome, vanadium) with low carbon content by running a silicothermal reaction, for example:

$$2Cr_2O_3 + 3Si = 2Cr_2 + 3SiO_3 + Q.$$

This reaction produces heat as well as other silicothermal reactions which is why silicothermal methods played a significant role in ferroalloy metallurgy.

Ferrochrome production

Industrial production of ferrochrome in electric arc furnaces was started by Paul-Louis-Toussaint Heroult in1899. His process became widely used, and following the First World War all ferrochrome was melted in electric arc furnaces. The process used high-grade chromites and deoxidands: coke, anthracite and charcoal. By that time it was obviously clear that the main problem of the process was the tendency of reduced chrome to be saturated with carbon due to production of carbides. The necessity to use high-grade chromites and big factor of slag forced the specialists to seek for better and more economic methods of refinery.

It must be mentioned that electric melting easily took the leading place in production of ferroalloys, however it did not replace completely the other methods of extracting alloying elements from ores (except for the crucible method). If a long-forgotten method of ferroalloy production suddenly appeared to be more economically effective in particular circumstances, it was used in certain cases.

Thus, having its roots in the ancient times the natural alloying process was used in the late 19th century when Russia started extensive construction of railroads. According to some sources, the rails of Katav-Ivanovsky plant in the Urals featured such high quality that there had never been any claims raised regarding them. It was revealed that Katav-Ivanovsky cast iron was produced from sulfur- and phosphorus-free ores that were rich with iron. These ores were mixed with locally mined low-iron ore that contained chrome and manganese. The produced naturally alloyed pig iron was blasted with air in Bessemer converter resulting in naturally alloyed chrome-manganese rail steel.

Section 13. Production of ferroalloys in Russia in the 19th century

Russian practice of ferroalloys production existed mainly in line with the world tendencies. However there were some significant differences. Even at the best plant of those times, in Nizhny Tagil, melting of rich ferromanganese (50…60%) in blast furnaces directly from ores was impossible. Such ferromanganese was obtained in blast furnaces using pig iron and return slag.

Normal blast furnace melting was also used for production of 40% ferromanganese from the ore of Lebyazhya mountain. Any discrepancy in the melting process resulted in bigger amount of manganese transferred into slag (content of manganese oxide in the slag comprised from 30 to 60 %). Consumption of charcoal comprised 4.25…4.5 tons per one ton of produced alloy.

After 6 or 7 days of operation the receiver became sufficiently ‘burnt’, i.e. its lining became extensively worn and expanded in size. It resulted in decrease of manganese content in produced alloy. In such case the production transferred to melting silicon iron with 3…7% of silicon content that was later converted into steel by Bessemer process. After 1 or 2 days the receiver shrank due to hearth accretion and production of ferromanganese could be reinstated. As was mentioned before, the receiver was made detachable and could be replaced every 6 weeks.

Increase of ferromanganese content was achieved by using dual-stage production scheme. The first option assumed that the mixture of manganese ore and charcoal with iron ore additives would be charged into boxes and placed into carburizing furnace for 10 days for the initial reduction process. Then the obtained sintered material was melted in a blast furnace. However, such production was extremely expensive and it was rejected very soon. Another option suggested using return slag as a source of manganese taking it as a by-product of ordinary melting of ferromanganese. As stated above, such slag contained up to 60% of MnO.

Ferromanganese was de-carbonized (whenever necessary) by mixing it with ferrous-ferric oxide followed by putting into boxes and placing them into carburizing furnace. The process continued 10 days after which carbon content did not exceed 0.3 %.

Since 1878 the plant in Nizhny Tagil started production of ferrosilicomanganese using the same furnace. The production assumed melting of silicon iron as the first phase, and then, when the furnace was sufficiently warmed up, manganese ore and return slag were added. The obtained alloy contained 40…45% of manganese and about 3…7% of silicon. The same furnace was used for production of ferrosilicon that contained 6…9% of silicon and was used for deoxidation of open hearth steel.

Section 14. Electric arc steelmaking in Russia before revolution

In the beginning of the 20th century V. Izhevsky, the professor of Polytechnic Institute in Kiev, suggested a number of designs of laboratory type electric arc furnaces for melting and heat treatment of metals. The first laboratory furnace was constructed in 1901 for melting small amounts of pig iron with iron scrap and ore additives. Ceramic walls of the furnace were heated with electric current running in embedded electrodes. The capacity of the furnace was 16.5 kg. The furnace could produce homogeneous metal, it was rather small in dimensions and could be operated by both direct and alternate current at various voltages. In later years the furnaces designed by Izhevsky (with capacities up to 100 kg) were operated at a number of Ukrainian plants.

The first industrial electric arc furnace for steelmaking was installed in Russia in 1910 at Obukhovsky steel factory. The furnace contained two electrodes and featured capacity of 500 kW. It was designed for refinery of steel using duplex process (open hearth – electric arc). If operated with hot metal charge the capacity of the electric furnace was 3.5 tons while cold charge reduced the capacity down to 2.5 tons.

Right before the start of the First World War Russia was far behind the European countries and the USA in terms of electric metallurgy. In 1913 Russian plants numbered only 4 electric furnaces that melted 3500 tons of steel per year while the total production output was 4.2 million tons.

In 1915 Motovilikhinsky plant in Perm started operation of the first single-phase steelmaking furnace that was designed by S. Steinberg and A. Gramolin. Later, same type of furnaces with capacities of 0.75-1 ton were installed at Zlatoust, Nadezhdinsky and other plants in the Urals. In 1915 the total number of Russian electric furnaces (only one of them featuring 8 tons capacity) was nine, and in 1917 there were 12 of them with overall capacity 26 tons.

Construction of the first special electric steelmaking plant near Bogorodsk (Noginsk) in Moscow Region was started in 1917. The plant for quality steelmaking included four direct heating type electric arc furnaces and later was called ‘Electrostahl’. One of the construction leads was N. Belyayev who later became the head of chair ‘Thermal treatment of special steels’ at Moscow Mining Academy. The construction of the plant was also conducted by K. Grigorovich whose activities will be described below in particular.

In November 1917 the first electric furnace with capacity of 1.5 tons was put into operation and thus ‘Electrostahl’ plant that was constructed under the reign of interim government became the first huge enterprise of the Soviet regime.

The same situation was characteristic of ferroalloys production. Until 1930s there was only one small plant.

Section 15. Ferroalloy production in Russia before revolution. “Porogi’ plant

Ferroalloys production in Russia was first arranged several years before the start of the First World War. In 1910 the first ore thermal furnaces started operating at plant ‘Porogi’ where the first Russian ferrosilicon and carbonized ferrochrome were melted, and at Allaverdy plant in Armenia where production of calcium carbide was organized in electric furnace with power capacity of 250-300 kW.

In 1904-1905 Russian mining engineer Alexander Schuppe (former manager of Satkinsky cast iron plant) made a research near the river Bolshaya Satk. He possessed information of chrome ore and quartzite deposits in southern Urals. He had to make explorations of the river near such deposits to build a hydroelectric power station. The location for an electric metallurgy plant Schuppe found in 35 mile from Satkinsky plant, in 18 miles from railway station Berdyaush and in 5 miles above the fork of rivers Bolshaya Satka and Ay. In that narrowest place of the valley Bolshaya Satka ran between two ranges, Uary and Chulkovsky. It was assumed that Chulkovsky range would be mined for quartzite - the initial raw material for ferrosilicon production. The area was also rich of forests to produce charcoal.

On the 29th of September 1905 Alexander Schuppe made an application to the minister of finance of Russia to transfer to him 50 arpents of governmental lands at the left bank of Bolshaya Satka for construction of electric metallurgy plant. The application was approved followed by contract with treasury dated the 3rd of June 1906 for a rental period of 99 years. The rental fee was 1 ruble per 1 arpent, while the price of using river power comprised 500 rubles annually.

Engineering of waterworks and plant facilities started in 1906. The engineering was conducted by professor Boris Bakhmetyev, a Russian hydraulics engineer who later became an ambassador of the interim government in the USA, and then became a professor of Columbia University. On the 13th of October 1907 A. Schuppe requested a permit to extend the area of the rented land for 10 arpents more and to build the second dam at Bolshaya Satka. On the 9th of November 1907 the permit was issued.

In May 1908 appeared a company called ‘Ural Electric Metallurgy Partnership’ organized by count A. Mordvinov, countess E. Mordvinova, baron F. Ropp and I. Shuppe’. The capital of the partnership was used for construction of the plant complex. Below are the extracts from the memoirs of Schuppe himself:

“In the beginning of 1890s I came to an idea of making an electric metallurgy plant in the Urals for melting special ferrochrome and ferrosilicon with high silicon content. The alloys had never been produced in Russia before but they were extremely important for making special grades of steel, primarily for production of armour and also for fabrication of automobiles, airplanes etc. Having this target I

obtained a right from the Ministry of Trade and Industry to build a stone dam at the Satka river in Zlatoust region, and for construction of metallurgic plant. Necessary funds were given by count A. Mordvinov, and in 1910 we started construction of the highest stone dam in Russia and construction of the plant and its equipment.

Since there were no Russian specialists in the electric metallurgy at that time we invited engineer Rochand from one of the plants in the South of France. He designed the electrical part of the plant, put it into operation and stayed to work at it till the end of his days. Construction of the dam, the workshop and all other parts of the plant and equipment was managed by me.

During this whole period of time I was one of the directors in the Board of the company, and in the last 1.5 years I was the only manager there due to distant location of the plant from St. Petersburg where the Board was situated"

Construction engaged foremen from the nearby enterprises (Satkinsky, Yuruzansky, Katav-Ivanovsky, Asha-Balashovsky). Solid construction of the dam and production premises was ensured by 40 qualified bricklayers delivered from Pskov. Construction of the dam and the workshops was performed using local stones. Near to the plant there was construction of houses for workers and clerks. Overall duration of construction comprised less than two years.

'Porogi' dam and plant construction, 1909

The plant was represented by a uniform complex of premises and erections logically located on the left bank of the river. The facility consisted of the dam build from stone with height 21 m and crest width 125 m. The base width was 12.5 m and the dam crest was 4.2 m. Production premises included a main generator hall, a bedding plant with Blake jaw crusher, an electric melting workshop and a shop for preparation of charge mixture and electrodes. Besides, the facility included a chemical laboratory built of stone, a wooden warehouse, a weighing shop, a horse barn, a fire fighting shed, a blacksmith and an office that was located in the village several hundred kilometers from the plant.

The plant was equipped with mechanisms, machines and devices manufactured in Western Europe – in the United Kingdom, Germany and France. The generator hall of the power station contained a “Francis” turbine. It was connected to a “Briegel, Hansen and Co.” 560 kW electric generator that was manufactured in 1909 in Gotha, Germany to supply power to the electric furnaces. Another 50 kW generator was used for lighting of the plant and the nearby workers camp. The generator hall also contained a 5 ton overhead travel crane produced in Birmingham in the United Kingdom..

The melting shop contained four ore thermal, single electrode electric furnaces of Heroult design. All the furnaces were single-electrode using single-phase power, and their hearths were interconnected by electric busses into pairs. A set of two furnaces could work at a time. Power supply to the vertically mounted electrodes was made through a system of flexible cables and buses directly from the generator.

The furnaces worked with solid block-type carbon electrodes 400x400 mm in cross-section. The electrodes were of stack type and were made of electrode bars, 200x200 mm each that were produced in electrode preparation shop. The carbon electrodes were moving in the furnace bath against the hearth by a rope lifting mechanism.

Electrical specifications of the furnaces:

• operating voltage on electrodes of two furnaces	60-80 В;
• current in electrode	6-7 кА;
• voltage across the furnace (electrode-to-hearth)	30-40 В;
• frequency	25 Гц.

The shell of the furnaces was made of riveted steel plates. The size of the shell in plane view comprised 1800x1800 mm. The space between the operating lining and the shell was filled with quartz grit.

Operating space of the bath in plane was 1300×1300 mm on top, 1000×1000 mm at the bottom, 1550 mm deep and the overall volume was 2,05 m^3. The front walls of the furnaces included tapping holes to release alloys and slag. Melting of carbonized grades of ferrochrome and ferromanganese utilized magnesite lining while melting of ferrosilicon required silica lining. The hearths of the furnaces for melting all ferroalloys were assembled of carbon modules and stiffed with carbon and coke mass. The charge mixture was introduced from the top: manually in the beginning, and then from a trolley. The charge mixture preparation shop contained a crusher for granulation of the charge mixture.

'Porogi' dam and workshops

By the 1st of July 1910 'Porogi' plant that was named after the rock ledges that were flooded with waters of the plant's pool was fully compiled, and the plant's equipment was fully commissioned. On the 12th of July 1910 experimental operation of the furnaces was started, and the first ferrosilicon was produced. However, the official opening date of the plant is the 19th of August 1910. This date is considered as a start date of electric metallurgy of ferroalloys in Russia.

Experimental melting of ferrochrome with weight 954 kg was performed on the 24th of August 1910. Chrome content in the alloy comprised 63.5%. During the first six month of the operation the 'Porogi' plant melted 533 tons of ferrosilicon and 206 tons ferrochrome.

Ferrosilicon melting process used quartzite (95…97% SiO_2) from Chulkovaya mountain. Charcoal was selected as deoxidant and it was burnt nearby the plant. Materials for the charge mixture were delivered by horse transport. Prior to melting the materials were crushed and sifted from small particles. Optimum size of granules of quartzite was 15…65 mm while the granules of charcoal had to be 10…100 mm. The charge mixture was supplied in to the furnaces continuously.

Every 3 - 4 hours ferrosilicon was released into mould boxes that were filled with fine sand. Silicon content in lean ferrosilicon was about 22…29%, while in rich ferrosilicon it was 41…60%. It was noticed that rich ferrosilicon had a tendency to crumble. Average output of the electric furnaces was 1.3…1.9 tons per day when melting 50% ferrosilicon and 3…4 tons per day when melting 25% alloy.

Melting of carbonized ferrochrome utilized ores of Miass, Nuralinsky and Mokroyamsky deposits of the Urals. Prior to charging into the furnace the chrome ores and fluxes were crushed down to granules of 5-30 mm, fine coke to 5…15 mm, and charcoal to 5…50 mm. Melting of ferrochrome was performed with a closed furnace top. The alloy and the slag were released every 2 or 3 hours. Quartzite, limestone, fluorspar, barite and halite were used as fluxes. Ferrochrome content was the following: 60…65% of chrome, 5.5…60% of carbon, 3.0…7.5% of silicon.

The product was crushed into pieces with a sledge hammer, packed into barrels and moved away by horse transport to railway station Berdyaush. After installation of one more generator the production output of ferrosilicon was increased. In winter times the yard also melted silicon carbide.

After October revolution in 1917 the yard continued operation for some time under management of the A. Schuppe. Then the property of ‘Ural Electric Metallurgy Partnership’ was nationalized and declared as property of Soviet Russia upon Decree of the Council of People’s Commissars “On nationalizing of major enterprizes…” dated the 28th of June 1918. The plants’s production was stopped. After that, in 1918, A. Schuppe moved to Zlatoust, and then left for Odessa.

In 1919 appeared the Board of Satka plants that included Satkinsky cast iron works, ‘Magnesite’ plant and ‘Porogi’ plant. In 1920 the plant was removed from the Board and made a separate entity.

Only by 1926 the first ferroalloy plant was rehabilitated and put into operation again. Originally it was a part of South Ural Mining Trust, and then it was transferred to ‘Vostokstahl’ association. In 1928 the plant became assigned to Satkinsky metallurgic plant (Glavuralmet) and continued production of ferroalloys till 1959 when it was redirected for production of fused refractories.

In 1920-30s the plant originally melted carbonized ferrochrome, then 30…40% ferrosilicon, and later 45…75% ferrosilicon with production rate of 640 thousand kilograms annually. Installation of one more 750 kW turbine in the 1930s enabled operation of another two new electric furnaces. The turbine was installed jointly with a Russian and Austrian stock company ‘Rotao’. The hydraulic turbine was manufactured under license at Moscow factory named after Kalinin. The electric generator was manufactured in Leningrad factory ‘Electrosila’, and the oil speed generator (produced in 1929) was supplied by an Austrian company located in Leobersdorf in the suburbs of Vienna. Installation of the new turbine doubled the output of ferroalloys.

Until 1931 'Porogi' plant was the only Russian company that produced ferroalloys with electric arc process. It played a huge role in education and qualification of personnel for other new ferroalloy plants that were put into operation between 1931 and 1934 in Chelyabinsk, Zestafoni and Zaporozhye. In particular, soviet scientists and specialists in production of ferroalloys S. Steinberg, M. Iovnovich, V. Gusarov practiced at 'Porogi' plant.

Besides, 'Porogi' was a real base for experiments. By 1921, i.e. in ten years of operation, the processes for melting ferrosilicon, carbonized ferrochrome and ferromanganese, silicon and calcium carbides and ferrotungsten had already been practiced. On the 20th of January 1921 experimental melting of carbon silicide was performed.

The unique plant was stopped in November 2000; the equipment of the melting shop was dismantled but the Porogi power station still remains in its almost original state. Despite of the plant's 100 years anniversary in 2010 the plant has never undergone any overhauling, the equipment is still working and provides electric power to the nearby village. However the condition of the dam and some devices degrades which requires some rehabilitation activities.

In 1993 'Porogi' became one of the candidates to a list of UNESCO World Industrial Heritage. The decree no. 378 of Chelyabinsk regional parliament dated the 15th of February 1996 assigned the plant a title of historical and cultural monument of the region.

Section 16. Development of ferroalloy production in the USSR during the first five-year plans

The situation with production of ferroalloys in the beginning of the USSR was laconically and yet concisely described by Vladimir Gusarov, a contemporary of ‘Porogi’ plant and one of the pioneers of the Russian ferroalloy industry, a participant of construction and later the director of Chelyabinsky ferroalloy plant (electric metallurgy plant since 1960).

In his book “Magic alloy” (Chelyabinsk, 1981) he wrote:

“We, the veterans of domestic metallurgy will never forget ‘Porogi’. Creation of domestic ferroalloy industry was impossible without passing the thresholds of a scanty production. We did not have other opportunities at that time. Although such plants as ‘Electrostahl’ in Moscow, Zlatoust metallurgic plant, Verkh-Isetsky in Sverdlovsk and Hammer and Sickle in Moscow were small they required however sufficient amounts of ferroalloys. But we did not have our local ferroalloys, so we had to procure them from abroad and the costs were enormous. By 1931 foreign supplies of ferroalloys exceeded 30 thousand tons. It cost over 70 million golden rubles to our country. Thus, construction of our own ferroalloy industry was the question of life and those big challenges that the country set out”.

These words are supported by another creator of domestic high quality metallurgic industry, a corresponding member of the Academy of Science of the USSR – V. Yemelyanov. In his memoirs he reflects back on the conversation that he had had with one of the metallurgists in Germany during his studies of the western experience:

“In 1922 I visited a small German plant and I asked the lead engineer:

Who do you sell you ferrochrome?

He started enumerating:

– About 5% of our total output we supply to the nearby chemical plants. 2% are purchased by Bekker, about 3%...

I interrupted him and asked:

– How much does USSR buy from you?

– He answered: It depends. 75…80% of our products we supply to your plants. And in fact, we work using chrome ore supplied from the Urals”.

Chrome ore was removed not only to Germany but also to Sweden, Italy and the USA. The same situation was with manganese alloys: about 90% of manganese ore mined in Russia was exported while the ferroalloys were imported from the West.

Anticipating the below narrative it must be mentioned that complete resolution of this problem took long lasting 30 years: the first ferroalloy production plants were put into operation in the 1930s. Those were Chelyabinsky and Lipetsky plants (the latter then became a workshop of Novolipetsky works), Zaporozhsky (Ukraine) and Zestafonsky (Georgia); in 1942-1945 appeared Kuznetsky, Aktobinsky (Kazakhstan) and Kluchevskoy ferroalloy plants. In 1950-1960 appeared Serovsky (1956), Stakhanovsky (Ukraine, 1962), Nikopolsky (Ukraine, 1966), and Yermakovsky (Kazakhstan, 1968). As a result, the production output of ferroalloy industry of the USSR exceeded 6 million ton per year which fully satisfied domestic demand and export campaigns.

'Electrostahl' plant. Steelmaking workshop, 1932

The USSR's policy of extensive industrial development required rapid increase of qualitative steelmaking. To give a solution to the target within the first 10-years plan a number of electric arc melting plants and shops were constructed: Zaporozhsky plant for tool steels (later 'Dnieprospetsstahl'), metallurgic plants in Leningrad and Gorky.

At the same time powerful steelmaking shops were constructed in major machinery plants, the pioneers of tractor production. Automobile plants in Moscow and Gorky now contained electric furnaces for production of high quality cast iron using duplex method (cupola – electric arc furnace).

Good supply of ferroalloys to those enterprises was ensured by construction of big ferroalloy plants that used domestic ore (as already been mentioned those were plants in Chelyabinsk, Zestafoni, Lipetsk and Zaporozhye).

Soviet science of electric furnaces was created in parallel. 1924 is considered as its initial date when designers at 'Electrosila' plant in Kharkov created their small engineering group headed by L. Aronov. In 1925 they designed the first soviet electric arc steelmaking furnaces, and in 1926 two of them – single and double electrode types of 0.25 ton capacity were put into operation mainly for mold steel castings.

In late 1926 fabrication of electric furnaces and transformers to them was transferred to electric plant in Moscow where a separate department for electric furnaces was established in 1928. During 1928-1938 this department designed and produced a series of arc furnaces with capacities 0.25…12 tons. Within 10 years they produced over 150 furnaces. Other development were furnaces for pig iron refinery with capacities of 3 and 10 tons, and a series of tilting furnaces for melting copper and its alloys, plus some ferroalloy furnaces. The plant also produced furnace transformers, reactors and contactor type power regulators for the arc furnaces.

The striving to arrange domestic production of ferroalloys in USSR initially appeared as an engineering solution in 1925. A group of metallurgists that worked on the problems of Dnieprostroy under specification tasks of I. Alexandrov issued a project for building an electric metallurgy plant near the Dniepro power station. The production output of the plant had to comprise 80 thousand tons of ferromanganese and 10 thousand tons of ferrosilicon per year.

At the same time the Supreme Council of National Economy of Georgia started the similar project of utilizing the republic's water resources and promoted the idea of making an electric metallurgy plant in Kutaisi with the designed output of 25 thousand tons of ferromanganese per year. Both projects were negotiated and developed until 1928.

An engineering group for design of ferroalloy plant on Dniepr was founded in spring 1929. The group worked on the project individually for about two years, then they engaged a French design company. In autumn 1928 positive resolution was issued for development of ferromanganese production in Georgia. Moreover, the Supreme Council of National Economy of the USSR approved construction of a ferromanganese plant with annual output 30 thousand tons with a potential possibility to expand it to 150 thousand tons.

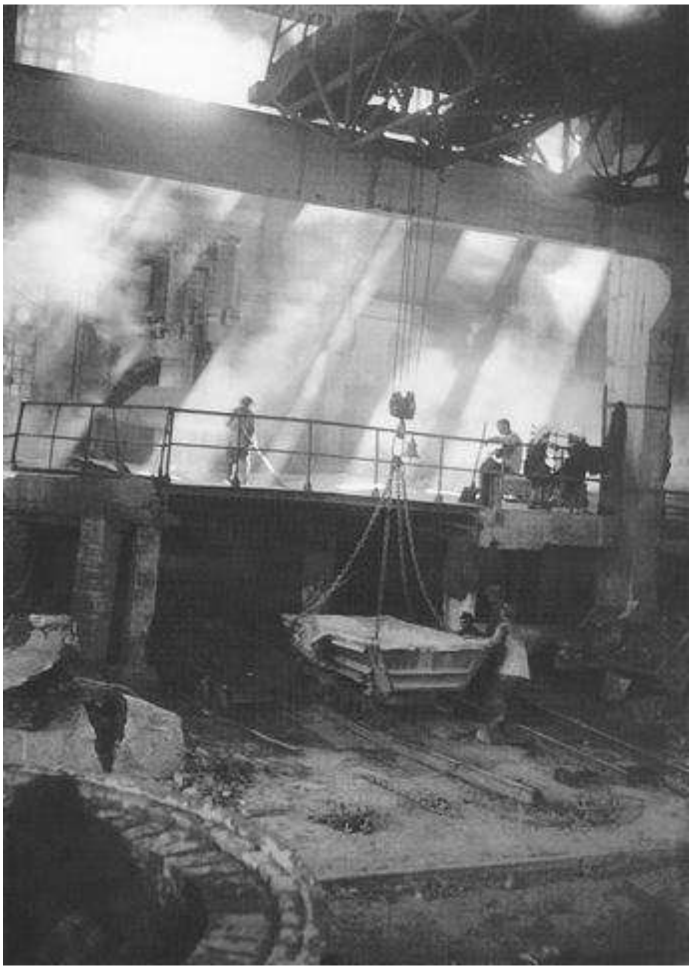
Ferroalloy plant in Chelyabinsk

Construction of the two above mentioned plants resolved the problem of ferroalloy supply for the country's own purposes. However the construction schedules were fearsome. This is why in 1929 the Head of Directorate of metal industry F. Lokatskov raised the issue of construction of the third ferroalloy plant in Chelyabinsk. Within summer of 1929 Uralmet was suggested to select a construction site for the future plant, make soil surveys, prepare design of the plant, make an engineering expertise of it and start the construction at the end of the construction season in 1929.

In April 1929 the Supreme Council of National Economy of the USSR takes a final decision for construction, and the very next autumn the construction site was selected, the design of the plant was prepared and approved by respective expertise authorities. The end of construction season in 1929 was used for building a railway to the construction site plus main excavation works, delivery of construction materials and the start of civil works. The foundation of the first workshop was laid on the 7th of November the same year.

Almost all major construction sites of the first 5-year plans, especially the pioneering projects were implemented under conditions with no experience for their realization. Material and manpower resources (including management resources) were insufficient. The overall situation was a fanciful mixture of poor organization and everyday heroic acts. People engaged for construction of the ferroalloy plant lived in dug outs, they encountered lack of machinery and materials. Winter of 1929-1930 was extremely cold and the soil had to be warmed up by fires. However it was a normal state of things rather than extraordinary cases. Five years later during construction of Chelyabinsky zinc plant people had to make water supply using stems of the trees because of lack of pipes.

Despite of all difficulties the first furnace for ferroalloy melting was put into operation already in early 1931, and on the 25th of July 1931 the first construction phase of Chelyabinsk ferroalloy plant (Workshop 1) was put into operation and handed over to the State committee. This day became an official date of the plant's opening. It would not be an overstatement to say that it was the beginning of the new history of Chelyabinsk that transformed a hick town into a powerful and prosperous industrial center. Thus, Chelyabinsk ferroalloy plant became not only the first ferroalloy plant constructed in the Soviet Union but also the very first metallurgic enterprise constructed in the USSR within the first 5-year plan.



According to official specifications the plant was designed to produce 10 thousand tons of ferrosilicon, 1500 tons of ferrochrome and 500 tons of ferrotungsten per year.

The novelty of the ferroalloys production processes and the lack of qualified workers and technicians who would be familiar with the production assumed that the maximum output of the furnaces would not be reached within the first two years of assimilation period. Considering this fact as well as inevitable growth of demand in ferroalloys that was based on rapid development of Soviet machinery the designers of the plant made a deviation from the original project specification and envisaged sufficient reserves both in terms of equipment and space. The essence of the deviation was to enable execution of the official program in the very first year of operation regardless of the "teething problems" and in the next years when production of ferroalloys in Chelyabinsk plant would start running its normal way the original task would be overfulfilled and the following production rates would be gained: ferrosilicon (75%) 7900 tons, ferrosilicon (50%) 7900 tons, ferrochrome 2000 tons, ferrotungsten 600 tons.

In compliance with this strategy the plant was equipped with seven electric furnaces, three of them featured power capacity of 7800 kVA for melting ferrosilicon, another three were powered from transformers and had power capacity of 1300 kVA for melting ferrochrome, and one furnace with transformer and power capacity 1130 kVA was used for melting ferrotungsten. In 1933 the plant was equipped with one more furnace for ferrochrome refinery.

During the relatively small period the Chelyabinsk plant mastered this industry which was new for the USSR and it reached good technical rates both in terms of productivity of the furnaces and in terms of consumption of electric power and electrodes.

Zestafoni ferromanganese plant

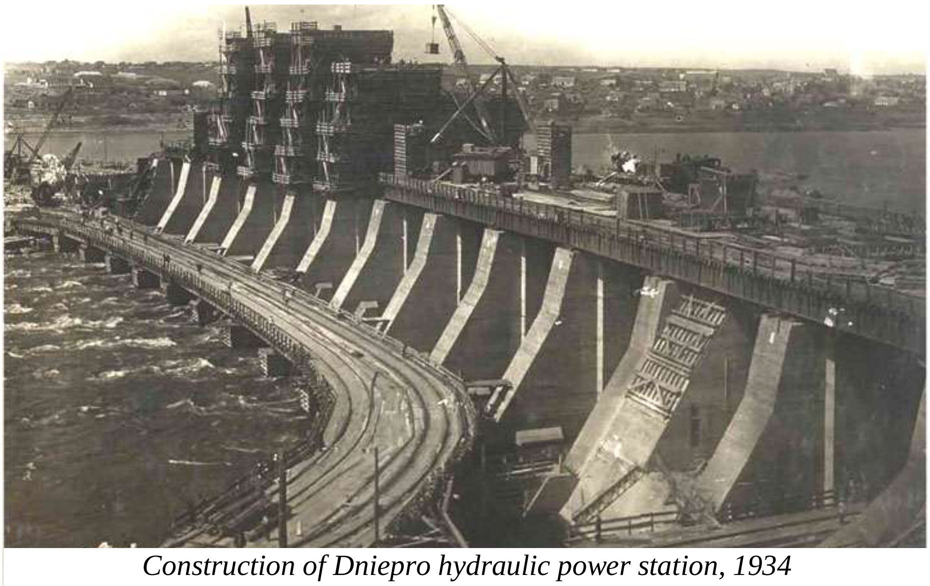
Georgean ferromanganese plant in Zestafoni was designed for annual production of 150 thousand tons of ferromanganese. In the late October 1933 the first phase of the plant's construction was completed and included three ferromanganese furnaces with transformers of 7500 kVA providing the output of 30 thousand tons of ferromanganese per year.

Zestafoni ferromanganese plant had opportunities to train their technicians and workers at Chelyabinsk ferroalloy plant and at the experimental ferromanganese furnace in Tiflis; hence it was assumed that the “teething period” and the time to master the operation skills would be a lot shorter and starting from summer 1934 the furnaces would reach the designed productivity. However the assimilation period was extended due to a number of disadvantages in the design of the furnaces and the required productivity could not be reached even by autumn 1934.

Dniepro ferroalloy plant

The construction of the plant was started in 1931 but it was somehow delayed. This is why on the 10th of October 1933 only two small ferrochrome furnaces were put into operation. The first big Miguet ferroalloy furnace with transformer capacity of 11 thousand kVA was put into operation as late as in the middle of January 1934. Construction of the ferrochrome workshop with five furnaces was completed by August 1934.

Construction of ferrosilicon shop was carried out in parallel, and its first furnace began operating in February


Construction of Dniepro hydraulic power station, 1934

1934. Main equipment of the ‘Dieprosplav’ plant were six single-phase Miguet furnaces with capacity of 11 thousand kVA each, and four three-phase furnaces 1600 kVa each for melting ferrochrome.

.By 1941 two melting shops of the plant contained 11 electric furnaces that produced more than 50% of all domestic ferrosilicon and 45% of domestic refined ferrochrome.

Further expansion of ferroalloy production

As of 1934 the three new plants produced over 60 thousand tons of ferrosilicon, ferromanganese and ferrochrome.

In 1934 a new ferrochrome department was constructed at Chelyabinsk plant with output rate of 10 thousand tons of ferrochrome. At the same period ferromanganese plant in Zestafoni was expanded by installing three more furnaces that featured the same capacities as those of the first phase of the plant’s construction.

All big ferroalloy furnaces for the first plants were procured from abroad (exclusive of some components of Miguet furnaces that were casted in the USSR). However the first big soviet ferroalloy furnaces were those installed at Zestafoni plant, and their start-up was planned for the beginning of 1935.

Due to the fact that small particles of Chiaturi ore implied difficulties in correct operation of big ferroalloy furnaces, trust ‘Spetsstahl’ took a decision to rehabilitate the Zestafoni furnaces for operation with granulated raw materials – the agglomerate. In the middle of 1935 the Zestafoni plant was equipped with Dwight-Lloyd agglomeration band.

In 1934 upon the task of People’s Commissars of Heavy Industry engineering of ferromolybdenum department for Zestafoni plant was started to give annual productivity of 1000…1200 tons of ferromolybdenum per year. A new ferrochrome shop for Dniepro ferroalloy plant was also designed to ensure output of up to 10 thousand tons of ferrochrome and 1500 tons of ferrotungsten. These new shops were planned to start operation in the middle of 1936.

Upon development of technology for processing ores with higher content of titanium and vanadium “titanomagnetite problem” the plans included domestic production of ferrotitanium and ferrovanadium by to be initiated in the USSR by 1936.

Section 17. Ferroalloys production and new production facilities in the Second World War

All in all, construction of the first three ferroalloy plants in the 1930s allowed the USSR to mainly resolve the problem of alloyed steel production. By early 1940s the country could even afford export of the ferroalloys to its allies, primarily to Germany. Troop trains with food and raw materials (ferroalloys in particular) in which German industry experienced a huge demand were sent their right until the beginning of military operations in 1941.

However, ‘militarization’ of the industry and the loss of southern metallurgic base of the USSR in Ukraine rapidly degraded the overall situation. The acutest problem was production of ferromanganese that was used both as deoxidant for production of open hearth steel and in production of steel for armour and tank tracks.

Militarization of industry and creation of Eastern industrial base

On the 16th of August 1941 the Central Committee of the Soviet Party and the Council of People’s Commissars of the USSR approved and effected the military and economy plan for the IV quarter of 1941 and for 1942 for the regions of the Volga, the Urals, Western Siberia, Kazakhstan and Central Asia. Along with rapid increase in production of ammunition and military equipment the new military and economy plan assumed rapid production increase in metallurgic, coal and other heavy industries plus mining for strategic raw materials. The scientific basis for this extremely complicated task, primarily in heavy industry, was arranged by the Committee of the Academy of Science of the USSR by mobilizing the resources of the Urals, Western Siberia and Kazakhstan to meet the needs of military defense.

The most important target of that period was immediate relocation of Zaporozhye’s metallurgic plants to the East. Stalinsk became the new center of ferroalloy industry by joining the plant’s camp Sad-gorod and Kuznetsk town. Latr Stalinsk was renamed to Novokuznetsk. Kuznetsky metallurgic plant was constructed there a short time earlier.

Later, one of the organizers of the evacuation Jacov Dashevsky wrote in his memoirs:

“The equipment of plants ‘Dnieprostahl’, Ferroalloy plant and Aluminum plant was moved to Stalinsk. The evacuation was carried out under military operations and continuous bomb attacks. Two episodes are stuck in my memory. During pulling of the power cable German troops appeared at the opposite side of the gallery. The plant’s workers had to take riffles and join the soldiers of the 16th Guards Army to withstand the enemy’s attacks. And during ferriage over the Dniepr German aviation shipwrecked the barge with especially valuable electrical equipment, but the plant’s employees rescued the equipment at night and delivered it to the left bank where the equipment was relocated into the railway cars. Several ferroalloy specialists were later awarded with the Order Red Star for that heroic act”

The first troop trains started arriving to Stalinsk in 1941. They carried the evacuated equipment, qualified workers and specialists from Zaporozhye. The Kuznetsky ferroalloy plant in Stalinsk started its operations in 1942 particularly on the basis of Zaporozhye's equipment.

Organization of ferrosilicon production

However, melting ferroalloys in Stalinsk started even before the arrival of equipment evacuated from the South. In fact, construction of a ferrosilicon plant on the bank of the Tom river was started in 1939 near Baydayevsky coal deposit (in Starokuznetsk). But it the construction had not been completed by the start of the war.

Due to this fact one of the blast furnaces of Kuznetsky metallurgic plant was converted for production of ferrosilicon. Ferrosilicon was melted in short 5-7 day campaigns in order not to decrease the production of pig iron output. The produced alloy was of small silicon content, and the furnace operation mode degraded the quality of operation itself. This is why in September 1941 according to the decree of the Council of People's Commissars one of the Kuznetsky's 10-ton electric furnaces in the molding shop was transferred for production of ferrosilicon to cover its deficiency. But the small furnace could not fully meet the demand of the plant. Then the decision was taken to transfer the first furnace delivered from evacuated plan 'Dnieprospetsstahl' for production of ferrosilicon.

The difficulty was within the fact that the furnace was not designed for production of ferroalloys. Also, there were no specialists at the plant who would know the process of ferrosilicon melting. This is why when the electric furnace was put into operation it took certain time to achieve necessary results, and it required ferroalloy specialists to arrive from Zaporozhye.

As the process of producing rich ferrosilicon was mastered one of the serious constrains for military steelmaking had been eliminated. However, since Kuznetsky plant had to produce ferrosilicon it was necessary to arrange urgent mining for quartzite.

Delivery of quartzite from Antonovsky deposit located 450 km far from the plant was complicated due to absence of any transport. In 1942 a Chugunash quartzite deposit was explored relatively close to the plant, near railway route Kuznetsk – Tashtagol. By the end of 1942 the employees of mechanical and boiler workshops of the plant fabricated the equipment and constructed the temporary production camp, so the mine was put into operation. It allowed not only providing raw materials for the production camp but also for the Kuznetsky ferroalloy plant built on the basis of evacuated equipment from Zaporozhye. On the 3rd of July 1942 the plant produced its first ferrosilicon.

Ferroalloys production in blast furnaces and raw manganese supplies

However ferrosilicon was not the only problem. Even by the end of 1941 the plants experienced the acute need in ferromanganese that had previously been produced in the regions occupied by military troops. As early as on the 29th of August 1941 the Council of People's Commissars urgently developed and approved a plan of building a new site for manganese ore mining but in 1942 the ore had still not been available.

On the 27th of January 1942 the plant received a telegraph message from the Council of People's Commissars I. Tevosyan. The message suggested immediate start of ferromanganese production in one of the blast furnaces using a small reserve of Chitaury manganese ore available in the plant's store. As it has already been mentioned, ferromanganese production in blast furnaces was quite successful previously, but those were small capacity furnaces. New and powerful furnaces of Kuznetsky plant had never been used for such purposes before. Despite of the complexity of the task the employees of the Blast furnace shop released the first batch of ferromanganese.

Under conditions of deficient ferroalloy facilities and raw materials the transfer of blast furnaces for ferroalloy melting was a coercive but necessary measure. And if the challenge to melt ferromanganese was only difficult, the next target – melting ferrochrome in blast furnaces – was considered irresolvable.

Development of lean chrome ores from Saranovsky deposit in the Urals was started in 1941. It was decided to process this ore at Tagil plant that had had some poor previous experience of melting ferrochrome in a blast furnace before (1890). The joint brainstorm of the specialists from the Urals and evacuated South helped to find the solution and develop a respective technology. On the 30th of August 1941 the first ferrochrome from a blast furnace was produced, and by the middle of September the technology was mastered and the chrome content changed from original 9.2% to 30…50%. Also ferrochrome was melted in some other blast furnaces in the Urals.

The problem of supply of manganese raw materials was under resolution at the same time period. By the end of 1942 the small reserves of Chiatury ore at Kuznetsky plats were almost used out. The closest sourse of manganese ore was a small deposit located 70 km from Guryevsk, near Durnovo village that had been explored in the 1920s. The mine was built in the very short time, and in winter 1942-1943 mining and supply of the ore were commenced.

Like Saranovsky and many other deposits the

Durnovskoye deposit was located many kilometers afar from railroads in practically uninhabited areas. This is why the first ore batches had to be transported by automobiles at no roads at all. In case of poor weather one trip could last several days.

Blast furnace process utilizing Durnovo ore with presence of barium was also an exquisite task. When the metal and slag were released from the furnace the slag tended to boil and spill over the production areas. However there were no other sources of raw materials.

Durnovo deposit was completely mined out by the beginning 0f 1943. However due to efforts of geologists, miners and builders the critical situation with supplies of manganese ore to Kuznetsky and Magnotogorsky plants was resolved because construction of Jezdinsky manganese mine in Kazakhastan and Polunochny mine in the Urals had been completed by that time.

Thus, the problem of a manganese basis in the eastern part of the country was solved. In 1940 the unit values of manganese ore production in the eastern regions comprised 8.4%, and in 1941 it was incremented already to 13.7% and in 1942 after the start-up of Jezdinsky deposit the eastern regions supplied already 84.6% of all manganese ore production in the country.

Organization of ferrochrome production

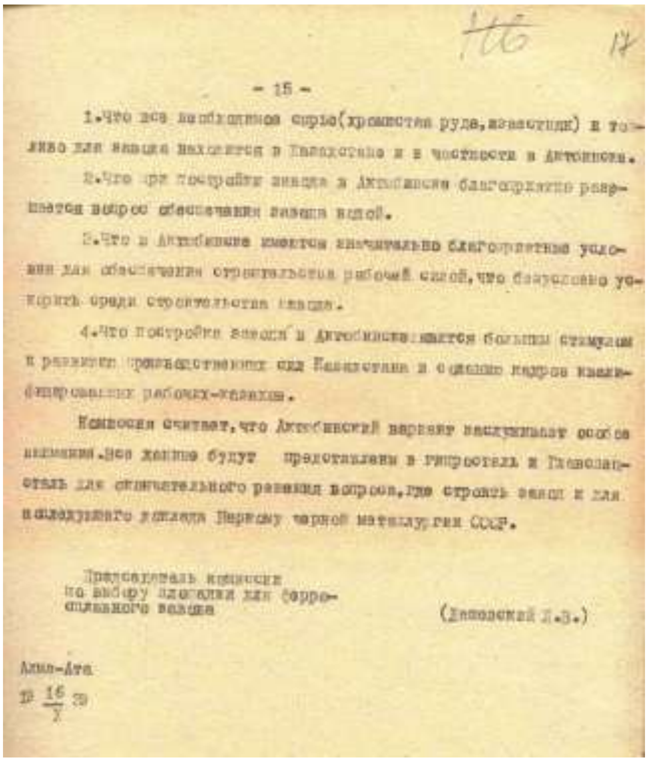
The next step in resolution of the ferroalloy supply problem for the needs of steelmaking industry was construction of Kluchevskoy and Aktyubinsky ferroalloy plants. Considering that melting ferrochrome in blast furnaces was only an interim solution that could only cover immediate metallurgic demands the new melting facilities had to be put into operation and supplied with raw materials for production of ferrochrome in ferroalloy furnaces.

In 1941 on the basis of Kluchevsky chrome processing plant that had been put into operation in 1933 and located in 50 km to the south-east of Sverdlovsk (Yekaterinburg) the Kluchevsky ferroalloy plant was built. The order no. 182/155 of the People's Commissar for Iron and Steelwork to construct the plant was dated the 16th of May 1941, and as soon as in 1941 the first industrial melting of chrome-aluminum alloys was performed which made the beginning of the ferroalloy plant operation. In 1942 started industrial production of metal chrome, and after another two years the plant produced low-content ferrotitanium.

The peculiarity of this enterprise was production of 'small' ferroalloys and pure metals. In 1941-1945 the plant started industrial production of chrome-aluminum alloy, metal manganese, metal chrome and low carbon ferrochrome using out-of-furnace aluminothermic melting without utilization of metallurgic devices.

Total product output for that period comprised 2.1 thousand tons. Hence, Kluchevskoy plant did not resolve the problem of ferrochrome production, its worked at different disciplines. The new source of ferrochrome was prepared in Kazakhastan in the same period of time.

Originally (in the late 1930s) construction of the plant for production of ferrochrome and ferrotungsten was planned to meet the opening of Kuybyshev (Samara) river power station that could supply power to the new facility. However, exactly as in the case of Dniepro power station the construction completion dates did not satisfy the metallurgic plans that assumed start of the production by the end of the 3rd 5-year plan. By that time the chromite deposit in Aktobe (Kazakhstan) was explored and made the main base for chrome ores of the USSR substituting the small and fading deposits in the Urals.



Last page of the committee report on selection of construction site for ferroalloy plant

After survey of possible construction sites, a place near Aktubinsk was chosen in 1939 (sites near Dombarovka, several sites near Orsk and Kimpersay were declared as inappropriate due to a number of reasons). The date of putting the plant into operation was scheduled for 1942. According to the design the plant had to feature annual production of 30 thousand tons of carbonized ferrochrome, 15 thousand tons of low- and medium-carbon ferrochrome and 3 thousand tons of ferrotungsten. Apart of production purposes the plant should have become a driver for industrial development of Kazakhstan.

Despite of sufficiently escalated demands in ferrochrome due to military activities in the war the yard was put into operation only in January 1943 because of poor infrastructure. The base of raw materials for the plant became a chrome mine with worker’s camp Chrometau both built up in an inhabited desert.

Thus, in early 1943 the new bases for raw materials and ferroalloy industry had been completely organized.

. *Aktyubinsky ferroalloy plant*

Section 18. Final arrangements of ferroalloy industry in the post-war USSR

After the war the development of ferroalloy industry was continued. The work was carried out in two directions: provision of ferroalloys to the industrial facilities in the Urals and reconstruction of destroyed or evacuated plants in Ukraine.

Zaporozhsky ferroalloy plant

When Zaporozhe was regained after the war, the Zaporozhsky plant’s workshop #1 organized melting of calcium carbide already in 1944, and one year later one furnace for melting ferrochrome was put into operation. The other 4 furnaces of workshop #2 had been consequently rehabilitated within 1947-1951.

In addition to ferrochrome the reconstructed plant also started production of ferrosilicon. The first furnace in workshop #1 started the release of the metal in 1948, and the rest 5 furnaces of the workshop were put into operation by 1950.

After that metal manganese production was organized at the Zaporozhsky plant. In 1951 workshop #2 became the first in the world to produce metal manganese by electric silicothermal process, and in 1955 workshop #3 was handed over for production of metal manganese in 4 furnaces.

Further development of the plant was associated with active use of vacuume that became contemporary of that time/ In 1960 workshop #2 was the first to feature vacuum thermal furnace for production of ferrochrome with especially low carbon content using the technology of Dniepropetrovsk metallurgic institute. In 1973 another department with two vacuumetric furnaces was put into operation for production of nitride metal manganese that was aimed to substitute rare and expensive nickel.

In 1964-1966 the last phase of the plant was workshop #4 with its eight powerful close-type electric furnaces, wet gas cleaning systems, and a set of molding machines for automated molding of ferroalloys. In 1990s workshop #3 passed through a rehabilitation project.

Serovsky ferroalloy plant

On the 15th of January 1951 the Council of Ministers of the USSR issued decree no. 203-75 ofor construction of an electric furnace ferroalloy plant in the north of Sverdlovsk, in Serov town using the design of Kharkov institute ‘Giprostahl’. Significant power consumption of electric furnace process was a prerequisite for allocation of the plant’s construction site near the power source, Serovskaya District power station. Selection of the site was also based on convenient proximity to the railroad.

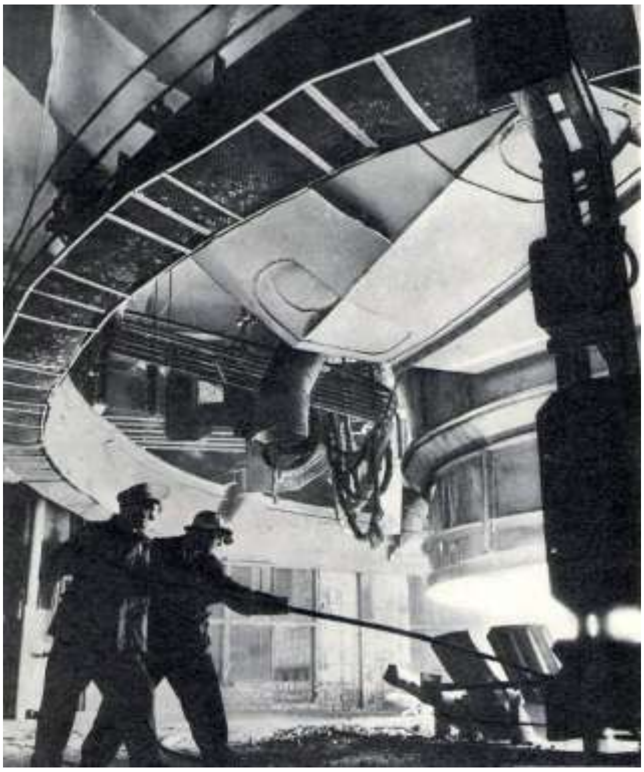
Construction of Serovsky ferroalloy plant involved the experience of building other enterprises of the same sphere. Young specialists, the graduates of Moscow steel institute, Ural polytechnic institute and Diepropetrovsk, Ural and Siberian metallurgic institutes were delegated to support the construction. The technicians were trained by Serovsky metallurgic technical school. At the same period the plant delegated its specialists to be trained at Aktyubinsky, Chelyabinsky and Kuznetsky ferroalloy plants.

On the 22nd of June 1958 in workshop #1 in furnace #1 the first 45% ferrosilicon was produced. In December of the same year the first construction phase of the first melting shop was completed. The shop included six ore thermal furnaces each of 10.5 MVA, where 45% and 75% ferrosilicon was produced. In December 1961 the first furnace of the second waorkshop was put into operation and by the end of 1962 the workshop already contained 9 tilting furnaces each of 3.5MVA capacity where medium- and low carbon ferrochrome was produced. Starting from that moment the plant became a special enterprise for melting chrome alloys which production comprised 30% of total country’s ferrochrome production by a certain moment later.

The project of expanding workshop #1 with three more furnaces, wet gas cleaning systems started from 1963 to enable production of limestone. Melting of ferrochrome with high carbon content in close type furnaces was started in 1965 for the first time in the USSR at the Serovsky plant.

Later the plant developed and introduced a new process of producing low carbon ferrochrome by mixing the smelts. Introduction of the process allowed production of low carbon ferrochrome in sufficient amounts at a lower prime cost as compared to the traditional technology. Later this process was used to produce industrial batches of chrome manganese and chrome nickel foundry alloys. In 1976 the plant experimented and introduced a process for making low carbon ferrochrome by pouring liquid ferrosilicochrome into the furnace.

Stakhanovsky ferroalloy plant



In 1952 the decision to build a new Stakhanovsky ferroalloy plant in the eastern part of Donbass was taken in order to satisfy the constantly incrementing demand of domestic metallurgy in ferrosilicon.

The construction began in 1959 after surveys in the steppe near Almaznaya village in Voroshilovgrad region, very close to town Kadiyevka which was later renamed to Stakhanov. Erection of the plant in that region was stipulated by two important circumstance: proximity of other metallurgic enterprises and existing transport infrastructure. The first melt was done already on the 10th of April 1962. The last two furnaces #7 and #8 were put into operation in November 1962.

The design of the plant stipulated for high level of automation and mechanical advancement of the production processes, and the close-type electric arc furnaces each featuring power capacity of 16.6 MVA were selected as melting devices. They were of principally new design as compared to any previously used furnaces. The design production output comprised 193.2 thousand tons of 45% ferrosilicon. In 2004-2005 most of the plant’s furnaces were overhauled.

Yermakovsky ferroalloy plant

The plant was built in 1965-1986. The necessity in construction of new plant was based in the world’s increase of quality steel output and respective deficiency in ferroalloys.

The construction site for the plant was chosen by governmental committee on the basis of such criteria as proximity to sources of raw materials and fuel, to end users, as well as on the basis of availability of required water resources (the Irtysh river). The significant argument for selection of that construction site was availability of cheap electric power (thermal power stations working on Ekibastuz coal). The specification for construction of the plant was developed by institute ‘Giprostal’ in Kharkov and approved in 1958.

First construction camp of Yermakovsky ferroalloy plant

The beginning of the plant's construction is traditionally associated with arrival of the construction train to Yermak village in 1959. The train started construction of the railway route Sputnik – Yermak. Starting from 1963 the construction of industrial facilities of the future plant was at its peak. Building of ferroalloy workshop #2 was commenced in 1965.

The first metal melting was performed in the previously constructed experimental workshop on the 30th of December 1966. Specialists from many similar enterprises arrived to the plant to share their great experience. By the end of 1967 the number of the plant's employees reached 1800 people. In the same year arrangement of the city's technical school #164 took place. 105 people were trained in the technical schools and higher institutions. First furnaces of workshop #2 were put into operation in 1968.

The first silicon melting in furnace #21 was carried out on the 18th of January 1968. This date is the traditional day of founding the Yermakovsky ferroalloy plant. On the 2nd of February 1968 the first batch of metal was released from furnace #22. At the same time installation of furnaces #23 and #24 was performed which ended in their first melting on the 7th and the 11th of July 1968 respectively. The acceptance and handover certificate for the whole first construction phase of Yermakovsky ferroalloy plant was signed on the 16th of July.

Service medal for the first melt at Yermakovsky plant

Construction of ferroalloy workshop #4 was started in 1970. Furnaces #41 and #42 were put into operation on the 31st of December 1971, and the first melting sessions with those furnaces were carried out on the 30th of January and the 27th of February 1972.

The first million tons of ferroalloys was melted on the 5th of October 1972. In the end of the same year construction of ferroalloy workshop began. Construction of workshop #4 was completed in 1974 where the last two furnaces #47 and #48 were made of closed type with wet gas cleaning systems. Thus, throughout the seven years the plant was expanded by two ferroalloy workshops with 16 furnaces, each featuring 16.5 MVA capacity.

In course of construction it was revealed that the country’s demand in semi-products and ferrosilicomanganese significantly decreased, hence all furnaces of workshop #4 were transferred for melting ferrosilicon. In April 1976 the plant melted the second million ton of ferroalloys, However the productivity of the plant was still increasing. On the 13th of August the first melting was made on furnace #11 of workshop #1. Furnaces # 12 and #13 were put into operation in 1977. Construction of another two furnaces for workshop #1 was completed in 1978. The last furnace of workshop #1 was put into operation on the 26th of February 1979.

After that began construction of the plant’s biggest workshop #6 with 4 furnaces type RKZ-63I1 each featuring capacity of 63 MVA with total transformer power capacity of 80 MVA. The last installed furnace #64 melted its first metal on the 5th of October 1982. When construction of workshop #6 had been completed the introduction of new ferroalloy production facilities was ceased.

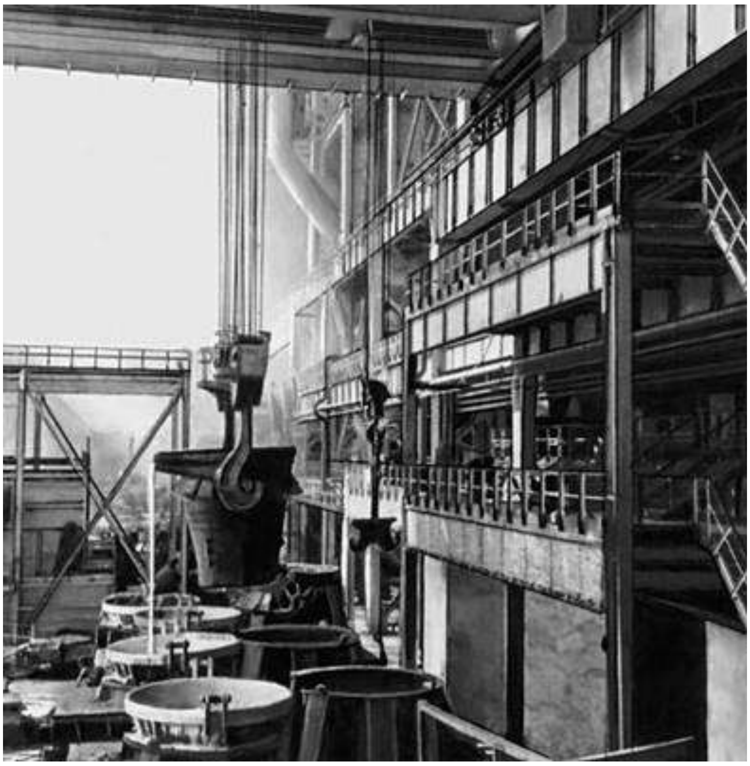
In 1995 the plant was incorporated into international company ‘Kazchrome’ and obtained a new name ‘Aksu ferroalloy plant’ (two years before that the Yermak city was renamed into Aksu). Rehabilitation project of the plant’s facilities was carried out in 2005.

Nikopolsky ferroalloys plant

On the 8th of May 1958 the Council of Ministers of the USSR approved the decree to prepare a design for construction of a manganese alloys plant in Nikopol. A special decree of the Council of Ministers of the USSR dated December 1961 approved the project. The construction sites for building the first facilities (a fire station and a pump station) were allocated as early as in late Autumn 1962.

An important piece of infrastructure – an automobile road to Nikopol with a bridge over the railway was put into operation in the end of 1963. Construction of the workshops for flux melting, electrode mass preparation and railroad car tilting was commenced the next year.

Excavation of the pit for the flux melting shop (for welding flux production) was started in March 1964. The plant's director A. Sukhorukov suggested building a small furnace for training and mastering the process. The furnace was maintained 24 hours a day and the flux melting specialists could practice their skills. Furnace №1 for melting of flux type ANF-6 was put into operation on the 6th of March 1966.



Workshop at Nikopolsky ferroalloy plant

Construction of the flux shop was finished by the end of June 1967, and one year later, on the 27th of August 1968 the ferromanganese workshop №2 started its operations.

In 1975 workshop №2 was upgraded with furnace №16 and an agglomeration line with two agglomeration machines. Upgrade was also performed in workshop №1 where furnace №1 and other important facilities were installed. Furnace №4 started operations in December 1976.

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Nikopolsky ferroalloy plant

Kluchevskoy ferroalloy plant

In 1945-1950 the plant started utilizing the technology for melting low carbon and nitride ferrochrome. In the post-war years the extensive development of special steels and alloys for space and defense industries required significant increase of the plant's output of the alloys. In 1947 when melting of ferroniobium with low silicon content was initiated the main product assortment line of the plant was finalized.

In 1953 the government took a decision to rehabilitate or actually, build a new Kluchevskoy plant for ferroalloys. In 1954-1957 the ferroalloy shop №2, aluminum powder workshop, processing line, gas generation site, boiler house and water treatment unit were put into operation, i.e. the first phase of construction was completed.

In 1961 the new ferrotitanium line was handed over within workshop №1, and in 1965 the foundry alloy line was opened in the same shop. In 1972-1975 workshop №2 was rehabilitated and equipped with new electric furnaces and gas purification units. In 1972-1977 the plant started production of aluminous semi-products to be used for melting synthetic slag.

Ferroalloy workshop №5 was also put into operation where ferroniobium was melted according to electric furnace process. The workshop also produced foundry alloys with rare earth elements, modifiers, various types of silicocalcium including silicocalcium with active additives. In 1984 a new shaft-type furnace was built for limestone calcination.

Further development of ferroalloy facilities

Thus, by the early 1980s the main ferroalloy facilities were started up and rehabilitated being still the contemporary basis for the industry. In the same period the design of Eastern Siberian ferroalloy plant was commenced. The feasibility study of construction of the Eastern Siberian ferroalloy plant was performed by the State Committee with participation of the leading specialists from the Academy of Science of the USSR, Ministry of Geology and Iron and Steel Metallurgy.

After inspection several potential sites, including those in Kuzbass the Committee selected the resources of raw materials in sufficiently big and rich Porozhnensky and Nizhne-Udinsky manganese deposits located in Krasnoyarsk region to the north-east of Lesosibirsk. This area was chosen for construction of the Eastern Siberian ferroalloy plant. However in the 1990s the construction was stopped and additional exploration of the two above mentioned deposits was ceased.

Further development of ferroalloy facilities of the USSR and later CIS countries was based on current rehabilitation and upgrade of major companies and creation of small enterprises and workshops (Bratsky, Tikhvinsky, Kingisepp, Yurga and other ferroalloy plants).

Section 18. Outstanding organizers of ferroalloy industry and representatives of scientific schools

As it has already been mentioned before, ferroalloy industry became a completely new sphere in the industrialization period of the USSR. Due to organization of this production the issue of training respective specialists became especially paramount. Textbooks and manuals for production of ferroalloys were completely unavailable as well as any practical experience which contributed to the difficulties in development of the industry.

Establishment of a new production and scientific field was carried out in Russian traditional manner: future specialists were delegated abroad for training. Moreover this is especially characteristic of theoretical research where the specialists were supplied from the sidelines of science, i.e. electric metallurgy.

Very significant role in this process, especially in the initial period was played by the specialists from the chair of electric metallurgy at Moscow Steel Institute named after Stalin which was established not long before on the basis if Moscow Mining Academy. One of such specialists was Professor Konstantin Grigorovich who became one of the organizers of the Soviet electric steelmaking industry and the domestic science school of electric metallurgists.

Konstantin Grigorovich

Konstantin Grigorovich

Konstantin Grigorovich was born on the 18th of September 1886 to the family of a gymnasium teacher. Two of the four sons chose metallurgy as their specialty, Konstantin and his brother entered the St. Petersburg polytechnic institute.

After assistance in organization of a meeting devoted to death of Leo Tolstoy and a protest actions against violence in prisons Konstantin Grigorovich was exiled to Olonetsk province for two years. Since then he had never been into politics. When his exile period was over Grigorovich reconstituted his studies in the institute and could continue his research. In 1912 he was invited to join Putilovsky plant.

Even in the times of his deportation he published one of his first works, and a famous metallurgist Nikolay Belyaev (the pupil of the "father" of metal science D. Chernov and one of the creators of alloyed steel production) offered Grigorovich to take part in engineering and introduction of the first electric furnaces. Already by 1917 in the eve of the revolution the first workshop started operations at full capacity.

After such huge achievement Belyaev was invited to give lectures in Moscow Mining Academy and he, in his turn, suggested Grigorovich to create his own courses in metallurgy. The courses outgrew into a chair that was headed by Konstantin Grigorovich.

After the Civil War metallurgy experienced great development, the metallurgy chair prepared many famous specialists who later became directors of various plants. When G. Ordzhonikidze was appointed the Lead of the Supreme Council of National Economy it turned out that he had not had almost any knowledge in heavy industry. His additional courses he took from Konstantin Grigorovich.

All-union congress for high quality steels, 1933. Speech of People's Commissar Ordzhonikidze

The family legend tells that Ordzhonikidze took individual lectures from Grigorovich, wrote them down, and when the courses were over when ‘comrade Sergo’ was appointed the People’s Commissar for Heavy Industry he presented Grigorovich a Rolls-Royce.

In summer 1938 Grigorovich was promoted to the full member of the Academy of Science of the USSR, and in September he was arrested. Konstantin Grigorovich was shot in 1939 upon the sentence of the military division of the Supreme Council of the USSR. And only after Stalin’s death Grigorovich was rehabilitated postmortem.

Grigorovich was also a lead of group of authors who wrote the first ferroalloy textbook in the USSR that was aimed to fill the knowledge vacuum and simplify the way of young specialists to theory and practice of ferroalloy production.

Проф. К. П. ГРИГОРОВИЧ, инж. В. А. БОГОЛЮБОВ, В. П. ЕЛЮТИН,
А. Н. САМАРИН и В. А. ЯЗЫКОВ

ФЕРРОСПЛАВЫ

ТЕОРИЯ И ПРАКТИКА ВЫПЛАВКИ
ФЕРРОСПЛАВОВ
В ЭЛЕКТРИЧЕСКИХ ПЕЧАХ

ГОСУДАРСТВЕННОЕ НАУЧНО-ТЕХНИЧЕСКОЕ ИЗДАТЕЛЬСТВО
ПО ЧЕРНОЙ И ЦВЕТНОЙ МЕТАЛЛУРГИИ
МОСКВА • ЛЕНИНГРАД • СВЕРДЛОВСК

Jakov Dashevsky

Jakov Dashevsky was born to a poor family with many children on the 20th of February 1902 in village Dmitrovka of Yelisavetgradsky district of Kherson province. In parallel with work he attended courses and then between 1921 and 1928 he studied at the mining faculty of Yekaterinoslavsky mining institute. He combined his studies with work as a technician in locomotive workshops of Yekaterinoslav Railroad.

After graduation from the high-school Dashevsky was delegated to work to Ukrgipromes institute where he participated in engineering of Zaporozhsky ferroalloy plant to be powered from Dniepro river power station. In 1929, in order to become familiarized with ferroalloy production processes Dashevsky was sent to a scientific trip to Germany, Austria, Norway, Sweden, Czech Republic and Poland. Upon return from his trip he was transferred to ‘Gipromez’ institute and appointed a chief engineer for design of Zaporozhsky ferroalloy plant. In 1933 after putting the plant into operation (which was a part of ‘Zaporozhstahl metallurgic works) Dashevsky was appointed the director of the plant.

At the same period of time he started his career as a major organizer of ferroalloy industry of the USSR. In 1936 he was approved as a member of the Council at the People’s Commissar of Heavy Industry G. Ordzhonikidze. In 1937 he was delegated as a technical director to Zestafoni ferroalloy plant. Since 1938 he was the head of the capital construction department in ‘Glavspetsstahl’ for the Council of People’s Commissars for Iron and Steel Industry of the USSR. From 1939 to 1940 he was the head of the committee to select construction sites for future ferroalloy plants of Siberia and Kazakhstan. After approval of the selected sites locations Dashevsky became lead technologist for designs of Kuznetsky and Aktubinsky ferroalloy plants.

In July 1941 Jacov Dashevsky became a volunteer and joined the Army in the war. However, very soon he was reverted upon instruction of the People’s Commissar for Iron and Steel Industry of the USSR Ivan Tevosyan. Dashevsky was needed for technical construction management of Kuznetsky and Aktyubinsky ferroalloy plants. In the same period Dashevsky was engaged into evacuation of metallurgic enterprises of Zaporozhye.

In October 1943 when the left bank of Zaporozhye was set free from German occupation Dashevsky was delegated there to survey the condition of local metallurgic plants and to organize technical and economic activities for their restoration. In October 1944 he was appointed a director of Zaporozhsky ferroalloy plant. In 1944 Dashevsky received a scientific degree of a PhD in Technical Science for his work “Parameters of ferroalloy furnaces in the melting shop of Zestafoni ferroalloy plant”.

Until 1950 he was occupied with scientific and organization work for implementation of new ferroalloy production technologies at Zaporozhsky plant. He was also busy with his social activities: he was a deputy of Zaporozhsky city council, a presidium member of regional trade union committee, a member of presidium of regional department of all-union community for promotion of political and scientific knowledge.

In 1950 at the peak of the ‘fight with cosmopolitanism’ he was accused of ‘negligence to the soviet party’. Jakov Dashevsky lost his position of the plant’s director and only thanks to management of the Ministry of Iron and Steel Industry he avoided a worse fate. He returned back to Novokuznetsk to the ferroalloy plant where he worked for a long time dealing with many issues including loading charge mixtures into ore thermal furnaces.

Starting from 1962 Jakov Dashevsky worked in metallurgic department of the State Committee of the Council of Ministers of the USSR for co-ordination of of scientific and research works, and in 1967 he started working in Metallurgic Institute of the Academy of Science of the USSR named after A. Baykov where he continued working with the problem of producing low phosphorus manganese ferroalloys from the manganese ores mined in the USSR.

Ivan Tevosyan

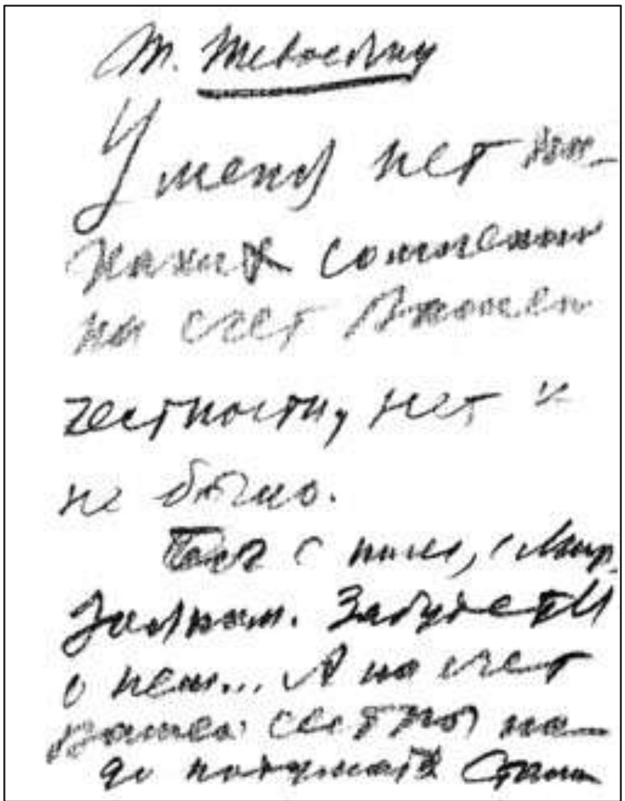
Ivan Tevosyan was born on the 4th of January 1902 to the family of a tailor in Shusha town of Yelisavetpolsky province. In 1906 the family ran from Shusha and settled down in Baku. Tevosyan graduated from a Russian orthodox church school and attended a three year course of a Trade school in Baku. After graduation he worked in Volga-Baku oil company as a clerk, book-keeper and accountant assistant. In parallel he was a distant student of a gymnasium.

On the 28th of April 1920 after reinstatement of Soviet regime being an active member of Bolshevistic ideology Tevosyan was appointed executive secretary of the City regional committee of the Russian Communist Party and the member of Central administration of the labour union of oil and metallurgic industry of Baku.

From 1921 he studied in Moscow Mining Academy at the metallurgic faculty (graduated in 1927), he was a secretary of the soviet party bureau in the Academy. After graduation from the Mining Academy Ivan Tevosyan was appointed engineer to ‘Electrostahl’ plant in the Moscow region. In 1929-1930 he did his business trips to metallurgic plants in Germany, Czech Republic and Italy.

After his return from the trip in November 1930 he was appointed a head of electric steelmaking workshops, and then a lead engineer of ‘Electrostahl’ plant. In 1930 on the 16th party congress he was elected as member of the Central Control Committee at the workers’ and peasants’ inspectorate and was approved as the lead of iron and steel metallurgic department. However upon consent of Ordzhonikidze he refused the appointments and stayed at ‘Electrostahl’ plant. In April 1931 Ivan Tevosyan was delegated to Germany to invite major foreign specialists in quality steels to the USSR.

Starting from August 1931 Tevosyan was a manager of the new joint enterprise ‘Spetsstahl’ that included such metallurgic plants as ‘Electrostahl’, ‘Hammer and Sickle’, ‘Krasny Oktyabr’, ‘Dnieprospetsstahl’, ‘Verkh-Isetsky’ and ‘Nadezhdinsky’ in Sverdlovsk region, and ‘Chelyabinsky’ and ‘Zestafoni’



Т. Тевосяну

У меня нет никаких сомнений на счет Вашей честности, нет и не было.

Говор с ним, (с [illegible] [illegible]. Забудьте о нем... А на счет [illegible] [illegible] надо подумать. Сталин ferroalloy plants.

The main task of the joint enterprise was to initiate production of ferroalloys and steels in continuously growing amounts and varying grades. Doing this work Tevosyan received assistance from his deputies: technical director of the joint enterprise Professor K. Grigorovich, lead engineer I. Subbotin (who worked in this position even before the revolution at Nadezhdinsky plant and then at Moscow plant ‘Hammer and Sickle’) plus from a foreign specialist Dr. Kritz. Their management created ferroalloy and metal production for the needs of aviation, shipbuilding and other industries.

Later Ivan Tevosyan took positions of the Head of the 7th (armour) Directorate at the Council of People’s Commissars for heavy industry, the 1st deputy of the Commissar of the defense industry of the USSR, People’s Commissar of shipbuilding industry, Commissar and minister of iron and steel industry, minister of metallurgic industry, deputy of the lead of council of ministers of the USSR.

In 1956 Tevosyan declaimed the territorial principle of economic management proposed by Nikita Khrushchev and suggested adaptation of some progressive methods of industrial management from the USA. The reply was devastating declarations of Khrushchev, and in December 1956 Tevosyan lost his position of deputy of the lead of council of ministers of the USSR and was appointed as Ambassador of the USSR in Japan. Soon, in 1958 Ivan Tevosyan died.

Among other matters Tevosyan became a prototype of the main character in Alexander Becks novel ‘The new assignment’.

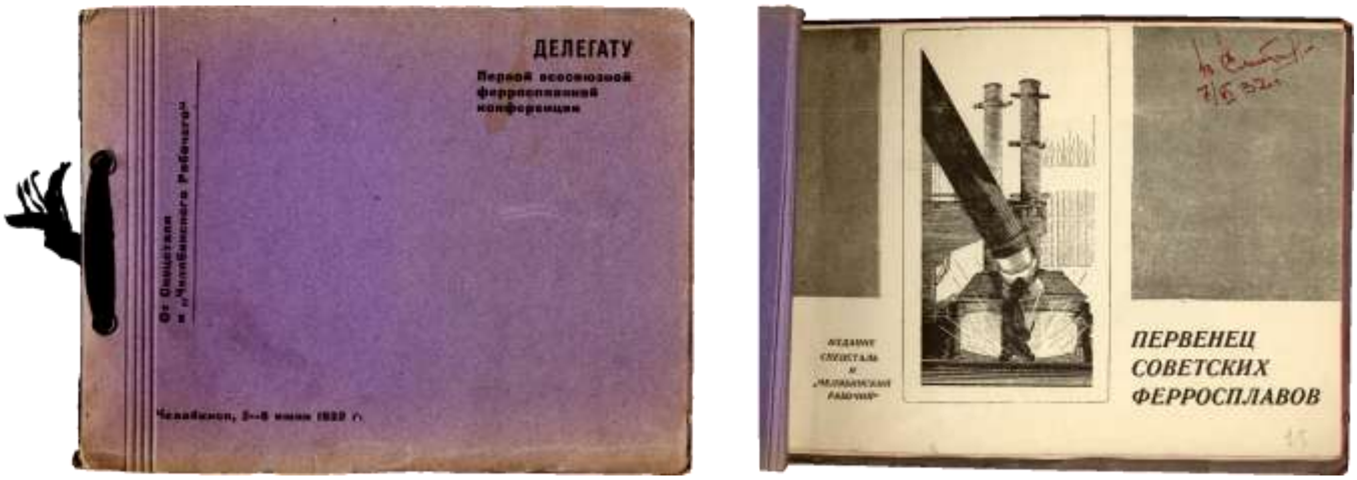
Alexander Samarin

Alexander Samarin was born on the 14th of August 1902 to the family of a peasant in village Sakony in Nizegorodsky province. In 1926 he left Nizhegorodsky university and was transferred to Moscow Mining Academy to metallurgic faculty.

From 1930 to 1934 A. Samarin was an assistant at the chair of electric metallurgy of steel and ferroalloys in the Moscow Steel Institute. In 1932 his lecture notes were used by the head of the chair Professor Konstantin Grigorovich in preparation and edition of the first Russian work in electric metallurgy.

In 1932 Samarin worked as consultant in construction of Chelyabinsky ferroalloy plant where he participated in creation of the process for high quality low-carbon ferrochrome and ferrovanadium. He reported the results of his research at the 1st all-union ferroalloy congress in 1932. The research was very important for mastering the processes and electrical equipment at a new Zaporozhsky ferroalloy plant that was put into operation in 1933.

In 1934 became one of the authors of the above mentioned textbook for ferroalloy production. In the same year he was sent to a business trip to the USA where he worked in the laboratory of the chemical faculty in Michigan university under the guidance of a famous metallurgist J. Chipman. In the USA Samarin studied the details of ferroalloy production at local plants.



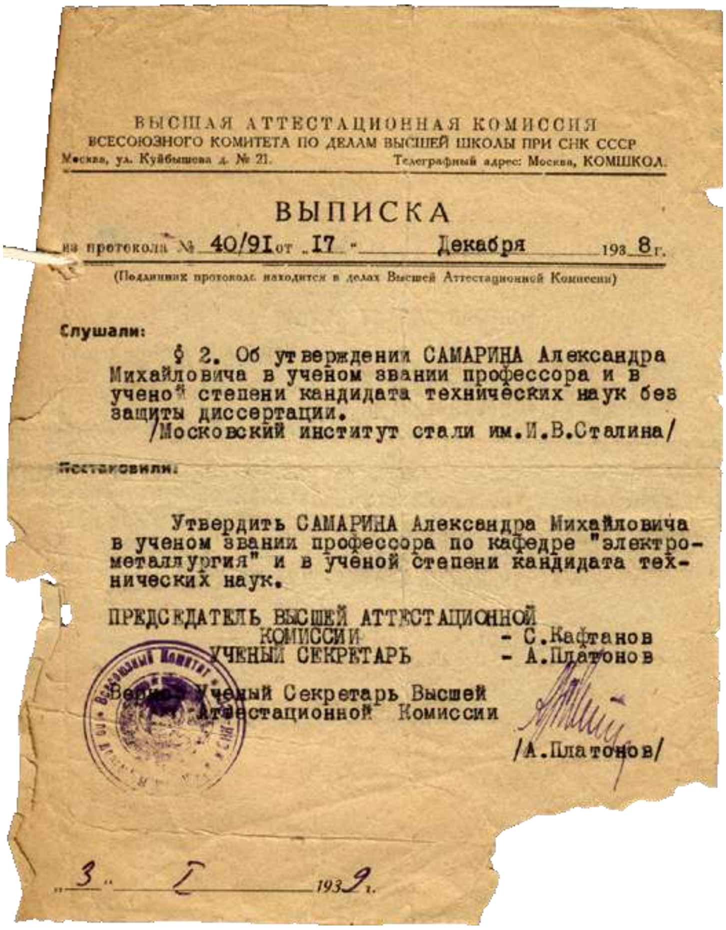
Notebook of the member of the 1st all-union conference for ferroalloys

Information declared in Samarin’s reports of his trips to ferroalloy plants of the USA and Norway were used in organization of local out-of-furnace ferromolybdenum processes and in redesigning of ferroalloy furnaces for operation with self baking Søderberg electrodes. Alexander Samarin was the leading designer of the first close-type ferroalloy furnace that was supposed to be built in Zestafoni ferroalloy plant in 1939.

In the 1930s he was the first in the Soviet Union to develop a technology for using complex deoxidants (aluminum-manganese-silicon, manganese-silicon and calcium-manganese-silicon) in steelmaking processes. On the 1st all-union congress for high quality steels that was held in 1932 the decision was taken to expant production of complex deoxidants in the USSR. In 1931-1933 Samarin was the lead of works for seeking rational methods of using naturally alloyed iron ores of Orsko-Khalilovsky region.

Further activities of Alexander Samarin were mainly devoted to development of high quality steelmaking processes and increase of effectiveness in using ferroalloys for reduction and alloying.

In 1943 Samarin issued his monograph ‘Electric metallurgy. Steelmaking’ that had been a top book of Soviet production people and students for many years. Experiments with vacuum that were held in Samarin’s laboratory in 1965-1970 revealed that under pressure of 0.5…2.0 mm of mercury carbon becomes a more effective deoxidant than silicon which allowed for thorough de-carbonization and deoxidation of metals without expensive deoxidants.



ВЫСШАЯ АТТЕСТАЦИОННАЯ КОМИССИЯ
ВСЕСОЮЗНОГО КОМИТЕТА ПО ДЕЛАМ ВЫСШЕЙ ШКОЛЫ ПРИ СНК СССР
Москва, ул. Куйбышева д. № 21. Телеграфный адрес: Москва, КОМШКОЛ.

ВЫПИСКА

из протокола № 40/91 от „17" Декабря 1938 г.
(Подлинник протокола находится в делах Высшей Аттестационной Комиссии)

Слушали:

§ 2. Об утверждении САМАРИНА Александра Михайловича в ученом звании профессора и в ученой степени кандидата технических наук без защиты диссертации.
/Московский институт стали им.И.В.Сталина/

Постановили:

Утвердить САМАРИНА Александра Михайловича в ученом звании профессора по кафедре "электрометаллургия" и в ученой степени кандидата технических наук.

ПРЕДСЕДАТЕЛЬ ВЫСШЕЙ АТТЕСТАЦИОННОЙ КОМИССИИ - С.Кафтанов
УЧЕНЫЙ СЕКРЕТАРЬ - А.Платонов

Верно: Ученый Секретарь Высшей Аттестационной Комиссии
/А.Платонов/

„3" I 1939 г.

Works of A. Samarin and his school of thermodynamics and kinetics of liquid nitrided ferroalloys of manganese, chrome and other elements led to development and industrial implementation of unique processes at the Zaporozhsky ferroalloy plant. Nitrided ferroalloys were produced on the basis of interaction between atmospheres with nitrogen content and ferroalloys in the powder form, i.e. without melting of metal. In 1956, at the same plant Samarin's followers – the representatives of Ukrainian school of ferroalloy production – developed a technology for vacuum deoxidation of liquid ferrochrome and metal manganese. Later, in 1960 they developed a technology of solid phase refining of ferroalloys in vacuum resistance furnaces.

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Alexander Samarin was the member of the Academy of Science of the USSR, he worked as director, chairman and pro-rector of research in the Institute of steel, he was the deputy minister for higher education of the USSR, a director for Institute of Metallurgy of the Academy of Science named after Baykov.

Vyacheslav Yelutin

Vyacheslav Yelutin was born on the 26th of February 1907 to the family of a railroader in Saratov. In 1930 he graduated from Moscow Steel Institute and then worked at Chelyabinsk ferroalloy plant where he headed the group of engineers and developed a technology for ferrochrome melting.

In 1933 Yelutin finished post-graduate training in Institute of Steel, and in 1933-1935 he performed the duties of professor assistant there. During the same period he participated in writing the first Soviet textbook for ferroalloy production.

In 1935 he was appointed the dean of faculty and the deputy director of Industrial Academy named after Stalin. He performed these duties before the beginning of the World War II. From 1941 till 1943 Yelutin served as armament artificer, and in 1943 he was appointed the professor assistant in the Moscow Steel Institute.

НКТП
СПЕЦСТАЛЬ
ВСЕСОЮЗНОЕ ОБЪЕДИНЕНИЕ КАЧЕСТВЕННЫХ И ВЫСОКОКАЧЕСТВЕННЫХ
СТАЛЕЙ И ФЕРРОСПЛАВОВ

В. П. ЕЛЮТИН

ВЫПЛАВКА ФЕРРОМОЛИБДЕНА
ИЗ РУД ЧИКОЙСКОГО
МЕСТОРОЖДЕНИЯ

МАТЕРИАЛЫ
К ПЕРВОЙ ВСЕСОЮЗНОЙ КОНФЕРЕНЦИИ
ПО ФЕРРОСПЛАВАМ

ВЫПУСК XIII

Подготовлено к печати инж. А. М. Самариным

ОНТИ НКТП СССР
ГОСМАШМЕТИЗДАТ
1932

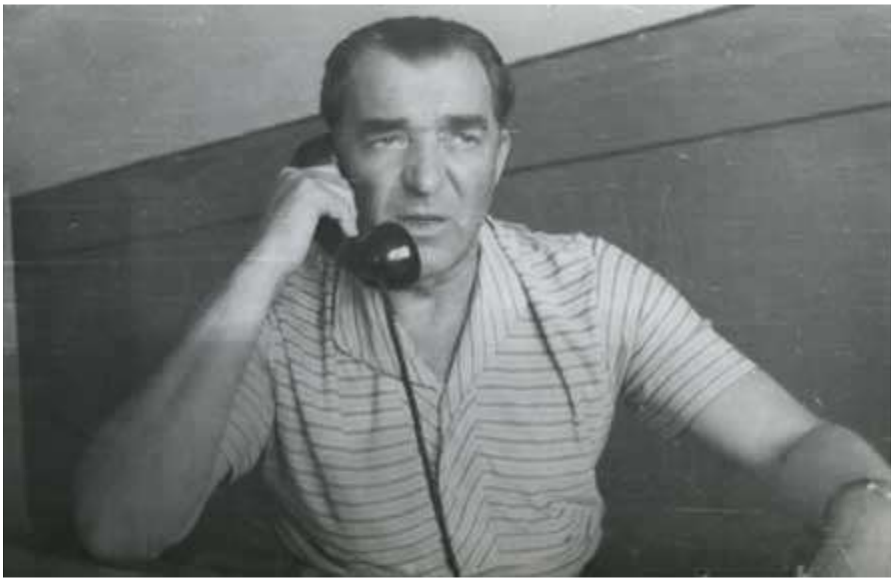
Further career of Vyacheslav Yelutin was associated with organization of education, including professional education. From 1945 till 1951 he was the director of Moscow Steel Institute. During the same period, in 1957, comes out the second edition of the textbook ‘Ferroalloy Production’ that Yelutin wrote together with Y. Pavlov, B. Levin and E. Alexeyev.

In 1951 became the deputy minister, and in 1954 the minister of higher education of the USSR, from 1959 he worked as minister of higher and secondary education of the USSR. From June 1985 till 1993 he received the personal awarded pension of the state significance. He was a member of the Academy of Science of the USSR.

Vassily Nakhabin

Vassily Nakhabin was born on the 1st of January 1909 in village Deniskovichi in Bryansk province in the large family of a peasant. In 1923 he started working at a felt factory first as a weaver assistant, then as a weaver. He combined his work with his studies in Smolensky Work Faculty, and after graduation in 1929 being the best student he was delegated to the Moscow Mining Academy to the metallurgic faculty.

After graduation from this high-school in 1923 the 23-year old electrical metallurgist Vassily Nakhabin was sent to work at joint enterprise ‘Spetsstahl’ where he was engaged for preparation to the 1st all-union conference for ferroalloy industry. Same year he was delegated to France to master his knowledge in the new sphere. After his return from France Vassily Nakhabin was given the task to take the leadership in construction completion of Chelyabinsky fer-



roalloy plant which had been already in operation by that time.

In 1934 Nakhabin moved to ferroalloy plant in Zaporozhye where he had worked 5 years as a lead of the workshop for production of low carbon ferrochrome and had become one of the leading ferroalloy specialists in the USSR. In 1939 Nakhabin was delegated to construction site of Aktyubinsky ferroalloy plant as a lead construction engineer, and when construction was completed he was appointed director of the plant.

In 1951 the Council Ministers of the USSR issued the instruction to construct a ferroalloy plant in the town Serov in the North of the Urals. Upon recommendations of the Minister of iron and steel industry Ivan Tevosyan Vassily Nakhabin went to Serov for construction of the new plant as a lead construction engineer. After putting the plant into operation Vassily Nakhabin worked there as director of the plant for another 23 years.

Jakov Schedrovitsky

Jakov Schedrovitsky was born on the 5th of June 1907 in Smolensk. He graduated from Leningrad Metallurgic Institute and moved to work at Chelyabinsky ferroalloy plant, Dnieprovsky and Uralsky aluminum plants. In 1959 he became the head of ferroalloy department in Chelyabinsky Scientific and Research Institute for Metallurgy.

His main scientific discipline was improvement of the ferroalloy melting processes.

At Chelyabinsky ferroalloy plant Jakov Schedrovitsky took active part in development and implementation of technology for producing any type of ferrosilicon. Later he participated in development of processes for production of broad variety of ferroalloys in high-power close type furnaces at Yermakovsky ferroalloy plant.

Alexander Morozov

Establishment of steelmaking scientific school in Chelyabinsk is closely associated with an outstanding metallurgic scientist and specialist in theory and practice of steelmaking, Alexander Morozov who organized a chair of metallurgy in Chelyabinsk polytechnic institute in 1952.

The results of Morozov’s research works that he performed as early as in 1935-1938 were utilized in 1960-70s at scientific and production enterprise ‘Tulachermet’ in course of development and implementation of a complex vanadium slag processing technology to obtain ferrovanadium. Morozov made a great contribution to international standardization of ferroalloys. In 1969 the ISO council took a decision to create technical committee ISO TC132 ‘Ferroalloys’, and the administrative work was delegated to the Scientific and Research Institute of Metallurgy as a base institution of Ministry of Metals of USSR for standardization of ferroalloy products.

Morozov developed a series of international standards, and the experience of the committee was used to forecast development of domestic ferroalloy industry and to improve official codes and standards. To a certain extent successful activities of TC ISO were supported by supreme scientific and technical background of the chemical laboratory of the Scientific and Research Institute of Metallurgy which Alexander Morozov considered as one of the main departments of the institute.

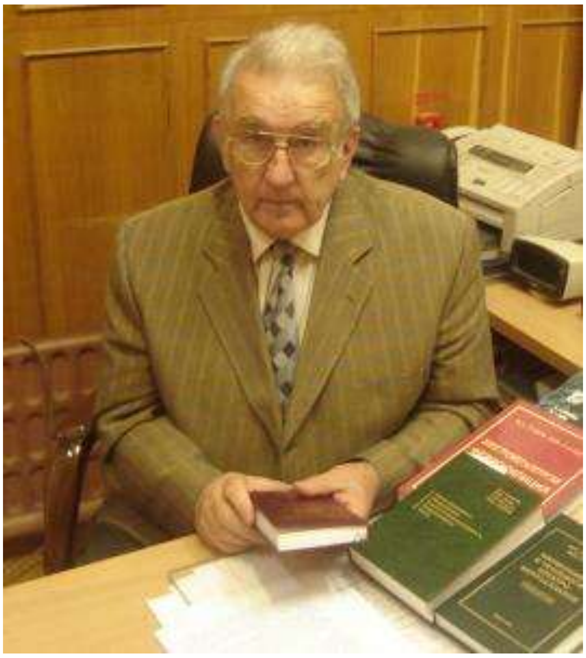
Mark Ryss

Mark Ryss was born in 1927 in Zhitomir. He graduated from Moscow Steel Institute in 1948 and then he had been working for many years after at Chelyabinsky ferroalloys plant: in 1948-1949 he was a foreman assistant, in 1949-1953 he became a foreman, in 1953-1958 he was a senior foreman, in 1958-1960 he worked as deputy lead of technical department, in 1960-1975 he was the lead of central plant laboratory and in 1975-1988 he was a lead engineer of the technical department.

For about 30 years long Mark Ryss headed the research works for development of progressive technologies in ferroalloy industry. He wrote a textbook titled ‘Production of ferroalloys’ (issued in 1975 and 1985) that became one of the best manuals for students and practicing metallurgists.

Mikhail Gasik

Mikhail Gasik was born on the 30th of June 1929 in village Semenovka of Pologovsky district in Zaporozhye region. In 1949-1954 he studied in Dniepropetrovsky metallurgic institute (presently National metallurgic academy of Ukraine) that he devoted all his professional life to. In 1954 he was a junior research assistant, in 1958-1961 he was a post-graduate and assistant, in 1961-1971 he became a professor assistant at the chair of electric metallurgy and in 1971 he was a professor. From 1973 he was the head of the chair for electric metallurgy and at the same time (1973-1986) he worked as a dean of the faculty of electric metallurgy.



Gasik is the author and co-author of a huge number of monographs and manuals, including ‘Manganese’ (1990), ‘Chrome metallurgy’ (1999), ‘Manganese metallurgy in Ukraine’ (1996), ‘Manganese silicothermic process’(2000), ‘Chrome of Kazakhstan’ (2001), ‘Theory and process of ferroalloys production (1989), ‘Design and equipment of electric steelmaking and ferroalloy workshops’ (2004), ‘Physics, chemistry and technology of electric ferroalloys (2005).

Section 19. Current situation and perspectives of ferroalloy production

Before 2009 the world's annual output of ferroalloys comprised about 35 million tons. In 2009 due to the world financial crisis production of ferroalloys decreased by 25% down to 22.6 million tons. The most common of the produced ferroalloys is ferrochrome comprising 24% of all world ferroalloy production. The second place is held by silicomanganese comprising about 21%. Ferrosilicon takes the third position with its 20% followed by ferromanganese with 13% of the world's output. The above mentioned ferroalloys altogether take 78% of their world's production.

Main producers of ferroalloys are China with about 46% of the world's output and South African Republic with 14.2% respectively. Notable producers are also Ukraine, Kazakhstan, India, Japan, Norway and France. Russia is also a significant producer of ferroalloys although it is somehow dependent on the imported products. Russia occupies about 5% in the world's production. Up to 65% of Russian ferroalloys are produced in the Urals and 29 in Kemerovo region.

The contemporary list of domestic ferroalloy producers remains almost unchanged from the times of the former Soviet Union. Main producers are concentrated in the Urals. These are Chelyabinsky electric metallurgic plant, one of the biggest enterprises in CIS to produce ferrosilicon, ferrochrome, silicocalcium, ferrotungsten, ferromolybdenum, chrome and nickel foundry alloys, graphitized electrodes, electrode mass, silicomanganese and ferrosilicomanganese. Another big producer is Serovsky plant that provides carbon ferrochrome, silicochrome, non-carbon ferrochrome and is planning to start production of silicomanganese. Klyuchevskoy plant offers a various scope of products like ferrotitanium, ferrochrome, ferromolybdenum, rare earth metal alloys, tungsten alloys and metal chrome (98%).

Unfortunately the Russian raw materials basis for production of chrome and manganese alloys is represented by ores of poor quality that makes the ferroalloy plants dependent on supplies from abroad.

One of the biggest and newest of all ferroalloy enterprises is Yurginsky ferroalloy plant, the manufacturer of ferrosilicon, one of the members of Chelyabinsky electric metallurgic plant. The first ferroalloy furnace in Yurga was put into operation in July 2006 and it pioneered the growth of the new metallurgic enterprise. Despite of the world financial crisis the second furnace was constructed in January 2010. Another two furnaces started production in 2011 altogether comprising the first phase of the plant's construction project.

Klyuchevsky ferroalloy plant specializing in 'exotic' small-series and small batch supplies of ferroalloys for making special alloyed steels reached the top of the list as a producer of ferrotitanium being even ahead of the acknowledged leader – VSMPO-Avisma.

Another two new manufacturers of ferromolybdenum were established in 2005 and 2006 on the basis of Sorsky (Khakasia Republic) and Zhirekensky (Chita region) process plants being the affiliates of the base element of the company 'Soyuzmetalresource'.

Another new manufacturer is Tikhvinsky ferroalloy plant in Leningrad region. Its construction stated in April 2001 and the last phase of the project was put into operation in 2009. The plant is a member of 'Mechel' group and it produces ferrochrome out of chromites from Kazakhstan. In addition to this plant 'Mechel' group is the owner of Bratsky ferrosilicon plant that was created in November 2003 on the basis of ferrosilicon workshop of the Bratsky aluminum plant.

Construction of Yeniseisky ferroalloy plant is now under preparation in Krasnoyarsk for production of manganese ferroalloys. However active opposition of local citizens prevents the investor from construction commencement.

In addition to standalone ferroalloy plants some ferroalloy production facilities are available at a number of metallurgic and casting enterprises, and producers of ferromanganese in blast furnaces form their separate group of plants, these are Satkinsky cast iron plant, Kosogorsky metallurgic plant and Alapayevsky metallurgic plant. The latter has not used its furnaces for a number of years, however NOVAM company that purchased the plant out in February 2011 is planning to reinstate production in November 2011 and reach the design productivity level by Summer 2012.

As for perspectives of ferroalloy production, the first fiddle is played by China. The increase of steelmaking output results in respective growth of ferroalloy production.

However there are some possible reasons that way slow down the rates of ferroalloy production, and some particular circumstances the overall output may even decrease. First of all this is associated with possible decrease of steel production and this is extensively negotiated by the Chinese government. In such case the demand in ferroalloys for deoxidizing and alloying will decrease. Another reason can be changes is steel grading after completion of the next phase of Chinese industrialization. This means that the alloyed steel production output will decrease while production of carbon steel for civil construction will grow. The total scope of production in this case will also decrease and settle at a certain level which is now characteristic of countries with developed economies.

Another factor that may contribute to decrease of the world's ferroalloy production is changes to the concept of steel alloying in the industrialized countries. The essence of the new approach is producing steel without impurities followed by microalloying with niobium or vanadium of less that 1% content. It is obvious that in such approach the demand in ferroalloys will decrease rapidly.

However, use of this concept in the nearest future is hardly probable because it demands supreme production practices, extensive technological upgrade and, primarily, organization of comprehensive use of metal products throughout their whole lifetime.

Still, use of up-to-date metallurgic technologies that are not so difficult to implement as microalloying will contribute to the effectiveness of using ferroalloys and, respectively, to decrease of demand in them.

As for ferroalloy production processes, the principle changes here are hardly expected because the only economically effective deoxidant for melting the majority of ferroalloys is carbon. Any other deoxidants require pre-reduction from compositions themselves which assumes power expenditures. Here an electric arc provides necessary temperature mode to ensure deoxidation. Thus, development of ferroalloy production technology may only go in direction of equipment upgrade (first of all, increase of their power capacity) without changes in physics and chemistry of the processes.