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Mini-metallurgy of full cycle on the basis of the spray-emulsion metallurgical process SER — from ore to steel

This article describes the state of the industry in some countries, including Russia. The problem of development of a regional industry has been discussed at the meeting of the companies in the field of metal processing in Novosibirsk. In this regard, the processes of direct solid reduction (Midrex, HyL-3), the solid- and liquid-phase process Corex are observed. The main attention is paid to the spray-emulsion metallurgical process (SER), featuring high speed flow of physical and chemical processes, low specific volume of metallurgical units, low power consumption and low capital costs. This process is completely closed to the atmosphere and has an internal stimulus for motion of the working mixture in a reactor with a gas-dynamic locking oscillator. Implementation of metal direct reduction technologies is connected with transformation of tail gas into energetic gas or synthesis gas, so the process can be executed completely smokeless.

This new continuous metallurgical process and the unit for its realization were developed according to the classical principle of modern high technologies: conceptual and theoretical statement of the problem, creation of physical-chemical and mathematical models, methods and systems for engineering calculations of technological and designing parameters, physical simulation, testing of separate process and unit components in the production environment, designing and construction of large-scale automatic experimental unit setup for development of various technological options.

Key words: spray-emulsion metallurgical process, system of skull cooling, hot-water boiler, physical simulation, self-organization, mini-metallurgy, slag trap, slag granulator.

Not afraid to repeat ourselves again, we emphasize that metallurgy is one of the key branches of heavy industry (engineering, energy, construction, etc.) and can become a driving force for the development of the eastern regions of Russia and other small populated regions. However, it is hardly possible to expect large-scale investments in the construction of traditional full-cycle metallurgical plants, because the world steel industry is in a difficult situation because of gigantism, multi-step technologies, high energy and material costs.

For example, integrated iron and steel works in America, producing wide rolled strips and having cartel agreements with engineering companies, are characterized with rather satisfactory economic conditions. Rolled steel sections are produced mainly at mini-mills, which are much more efficient.

As for the Russian steel industry, it is aimed mainly at alliances with the acquired foreign enterprises, due to consolidation and acquisition of plants that occurred before the onset of the crisis. The main goal of large owners of iron and steel enterprises is to increase capitalization; at the same time some Russian plants have become essentially subsidiary enterprises of foreign plants. This has led eventually to a monopolism and dictate of prices; that reduces the efficiency of work at metal industry. Besides that, Russian metallurgists do not produce the metal required by the customers in many positions and it has to be imported from abroad.

Some Russian metallurgical works, including the works in Novokuznetsk, are in a difficult position. Reconstruction of these woks (as well as construction of the new integrated works) requires very large capital investments (about 700–800 USD per ton of annual capacity). It is hardly possible to hope that the owners of these enterprises will invest such money and, therefore, these plants are doomed to a gradual degradation, and the cities where these plants are located, become depressed.

At the same time in China, the significant part of metallurgy is regional. It is not connected with the world's major iron and steel "monsters" and solves mainly regional challenges. The efficiency of this metallurgy is significantly higher due to the lower transportation costs for both raw materials and finished products.

The real development tendency of the Russian eastern regions is creation of a regional metallurgy. Metal customers are gradually accepting this idea. In particular, this issue was discussed at the meeting of companies busy in the field of metal processing, occurred in Novosibirsk in August 2010. It was noted there that machine-building plants are dependent on large steel monopolies that dictate prices for steel products. Metal processors want therefore to exclude this dependence through establishment of their own steel production facilities. Therefore, small mini-mills oriented on local needs, have appeared, but the process is seemed to be delayed soon evidently due to scrap depletion and its high prices.

The processes of direct solid-phase reduction (Midrex process, HyL-3 etc.), allowing obtaining metallic pellets or briquettes, can be considered as the definite alternative of the traditional metallurgy, but these processes can refine just sufficiently rich ores. Combined (solid- and liquid-phase) Corex process is quite cumbersome; its capital intensity is commensurate with the blast one.

Recently, the rotor process ITmk 3 has been advertised, but it can be considered as an illustrative example of an extensive approach, as soon as specific volume of this unit is more than the volume in blast furnace or Corex processes. Even the authors of the process [1] displayed the data that capital expenditures for this process are twice larger than for a small-size or mini-size blast furnace. As for power engineering, we can testify that the heating scheme of solid materials in the layer by the top heat source is quite not very efficient, while the process of solid-phase reduction in pellet particles is slower at least by 10 times than the liquid-phase process. This conclusion can be made even without carrying out any quantitative comparisons, but only on the level of theoretical analysis of the known heat transfer schemes. It is expressed also in the necessity of large time of particles residence and, eventually, in the large specific volume of the unit. Low energy efficiency of this process, compared with the blast furnace practice, is also underlined by the author of the second abstract on this process [2].

Exclusion of the pelletizing stage and process transfer in the area of the gas suspension, and then the emulsion, allows to use large reaction surface of initial powdered materials. Implementation of these conditions gives opportunity of creating the units with very small specific volume. Possibility of direct processing of powdered materials with low energy costs is the important advantage of processes of this type.

The spray-emulsion metallurgical process (SER) satisfies these conditions; it is characterized by high flow velocity of physical-chemical processes, low specific volume of the units (by 10–15 times lower than the known ones), low power expenses (less by 1.5 times), low capital expenditures (less by 2–3 times).

The process [3] is entirely closed to the atmosphere and has an internal stimulus of combustable mixture motion in the form of the reactor-oscillator with gas-dynamic blocking. In the case of implementation, for example, of the direct metal reduction process, the end gas can be converted into energetic or synthesis gas, therefore, the process can be completely smoke-free.

Based on the noted advantages, this process is the most suitable for the processing of powdered metal-containing waste, because it allows direct metal reduction, without intermediate stages, via the environmentally friendly techniques and with lower energy and material expenses.

Taking into account the fact that the unit is also a boiler, as it works on the skull cooling (**Fig. 1**), and the gas can be utilized in steam or gas turbines, these unit can be made power independent and even mobile; this opens up possibility for development of new non-habited areas.

The new continuous metallurgical process and the unit were designed on the base of classical principles of modern science-intensive technologies: conceptual-and-theoretical problem statements; creation of physical-chemical and mathematical models, methods and engineering systems for calculation of technological and construction parameters; physical simulation; testing of separate elements of the process and the unit in the plant conditions; the designing and construction of a pilot large-scale unit with the automatized experiment for testing of various technological options.

During development of the process and the unit, the authors have used the basic ideas of the self-organization theory [4, 5], the research results of kinetic, hydrodynamic and thermodynamic regularities of steel-smelting reactions and processes [3, 6], the gas spray theory and the properties of dual-phase flows [7], the results of mathematical simulation and optimization of the steel-smelting processes (supplemented with original constructive and technological solutions [8]). A significant role in the development of these ideas has been performed by the Brussels school under the leadership of I. Prigozhin.

The adjustment processes of the technology and the components of the unit construction was carried out in 1992–2001 on a large-scale pilot plant that was mounted at the free site of converter shop of West Siberian Integrated Iron and Steel Works (Zapsib).

Prospective directions for application of SER-type processes and units have been substantiated on the base of the above-mentioned advantages. One can mark out the following main advantages, aimed at solving the problems of structural changes in the metallurgy.

Establishment of mini-mills of the new structure as standard technological modules independent on each other and working simultaneously instead of a sequence of large-scale units of multi-stage metallurgical production route. Technological scheme of such module is shown on the **Fig. 2**, and the scheduling options of such technological modules in comparison with the structure of the traditional metallurgical plant are shown in the **Fig. 3**.

Realization of the principle of continuity eliminates the necessity in heavy removable equipment (steel ladles, overhead leveling cranes with heavy load-carrying ability, heavy basements, etc.). The units can be placed in relatively light industrial buildings, allowing quick return of all the investment. The modules can operate independently and be stopped within few minutes. Three types of modules can be offered.

1. ***Technological mini-complex*** (see Module 1, Fig. 3): the capacity is 250–300 thousand tons of molten metal per year. It includes the SER type unit consisting of two consecutive reactors, slag trap with a slag granu-

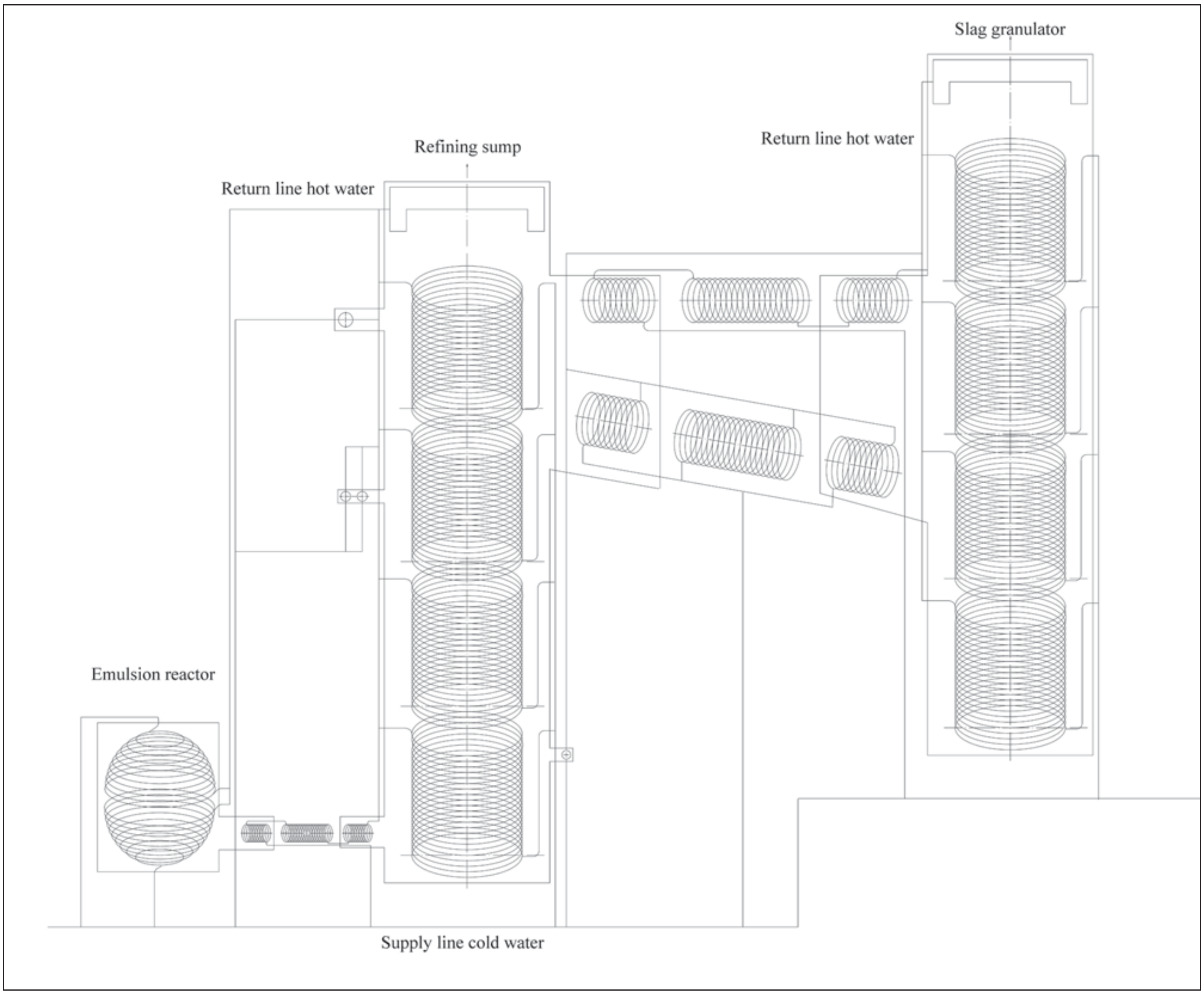

Fig. 1. The system of skull cooling unit SER

lator, refining unit, combined unit of casting and rolling or casting and continuous withdrawal of finished sections. As an example of the casting-withdrawal unit, it is proposed to use the inventions of the group of scientists from the Institute of Theoretical and Applied Mechanics of the Siberian Branch of the Russian Academy of Sciences (Novosibirsk), which uses the principle of vertical continuous casting (withdrawal) on the base of heat-transfer agents of liquid metal, allowing to increase the rate of crystallization by 15–20 times. The problem here is the choice and holding of the rate of metal withdrawal, taking into account the rate of solidification and providing of circulation of liquid-metal heat-transfer agents.

2. ***The second variant*** (see Module 2, Fig. 3) consists of the same technological scheme of direct reduction of liquid metal, but with inclusion of suspension casting and volumetric crystallization with production of e.g. fine shaped precision castings. Implementation of this tendency can principally change the attitude to cast products. Introduction of ultra-dispersed refractory modifiers in optimal amounts allows to control the amount of seeds and the crystal size within the framework of volumetric crystallization; it also allows to obtain mechanical properties of cast products on the same level as for similar properties of rolled metal products [9].

It should be remarked that metal, obtained via direct reduction method on the pilot plant (still in small quantities) is characterized by interesting (yet poorly studied) properties. In particular, it is hardly subjected to mechanical treatment; it is also hard to cut it both with a cutting-off machine and a cutting burner. This can be explained by the fact that it wasn't subjected to oxidation processing stages; it is self-deoxidized and even modified by super-equilibrium carbon content; however, these hypotheses require a detailed study. If all these properties will be confirmed, they will open interesting possibilities for obtaining products with new properties, especially in conjunction with the possibility of direct alloying.

3. ***Manufacturing a liquid semiproduct or a solid charging billet in SER-type units*** (Module 3, Fig. 3) with subsequent processing in the arc or induction furnaces

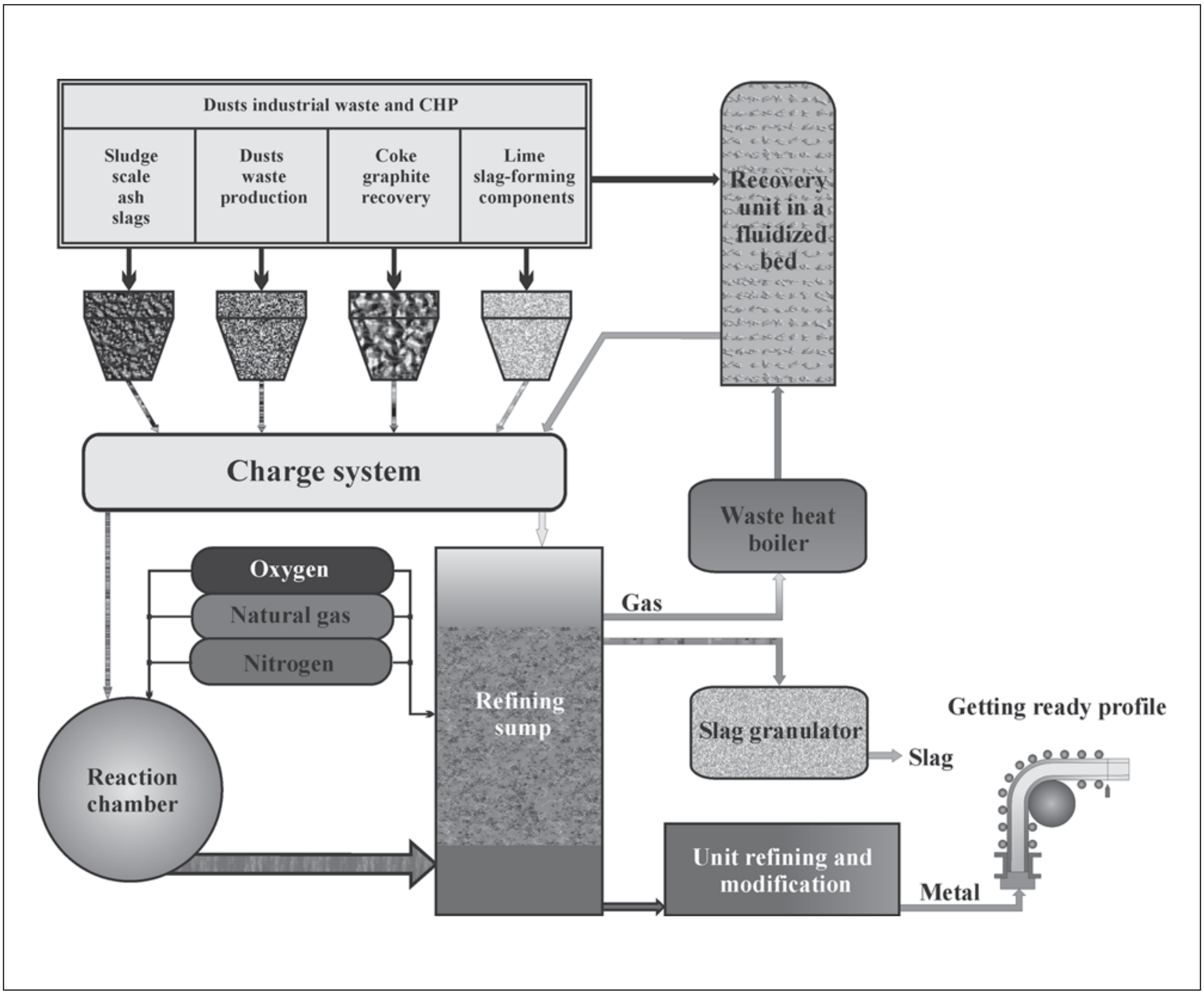

Fig. 2. Flow diagram of the module

(existing at these plants) is considered as possible and expedient variant for engineering plants. Metallurgical production at many engineering plants in Russia and other CIS countries is outdated at present time. The proposed developments offer for the regions possibility to establish their self "full cycle" mini-metallurgy, i.e. without using of scrap characterized by permanently cost elevation. At the same time the problems of production of high-purity metal without non-oxidizable impurities (copper and nickel) as well as without usage of powdered metal-containing wastes (scale, sludge, chip, etc.) are solved.

4. ***Complex, practically waste-free processing of titanium-magnetite ores.*** The enormous resources of such ores are located in the Urals, Western and Eastern Siberia, while at present time half of the raw materials for titanium industry is imported from the Ukraine to the Urals. There is only additional charging with such ores in a limited extent in blast furnaces, because of the risk to obtain viscous heterogeneous slag.

In 2001, the fundamental possibility of the technological processing of a titanium-magnetite concentrate in the SER-type unit with separation of iron- and titanium-containing components was shown on the pilot plant [10]. It is achieved due to the fact that the process in SER-type unit is occurred in the gas phase area, while slag is suspended in the upper part of refining settling tanks, and the tapping can be conducted from any level on the unit height, providing an optimal (in terms of slag flowing ability) content of Fe and Ti oxides. This task is very important for both ferrous and non-ferrous metallurgy and deserves a separate study [11].

Due to the fact that the considering unit has a certain degree of versatility, it can be implemented in a number of other technologies. In particular, we have calculated the thermodynamic and energetic possibility of autogenous processing of copper sulphide concentrates on matte or even on blister copper in this unit. This calculation has been made according to the order of the leadership of Rustavi Metallurgical Plant (Georgia) in 1996. Complete insulation of the process from the atmosphere stipulated originating of high concentrated sulfurous gas with content of sulphur dioxide about 50–60%. It makes possible to process efficiently the waste gases on

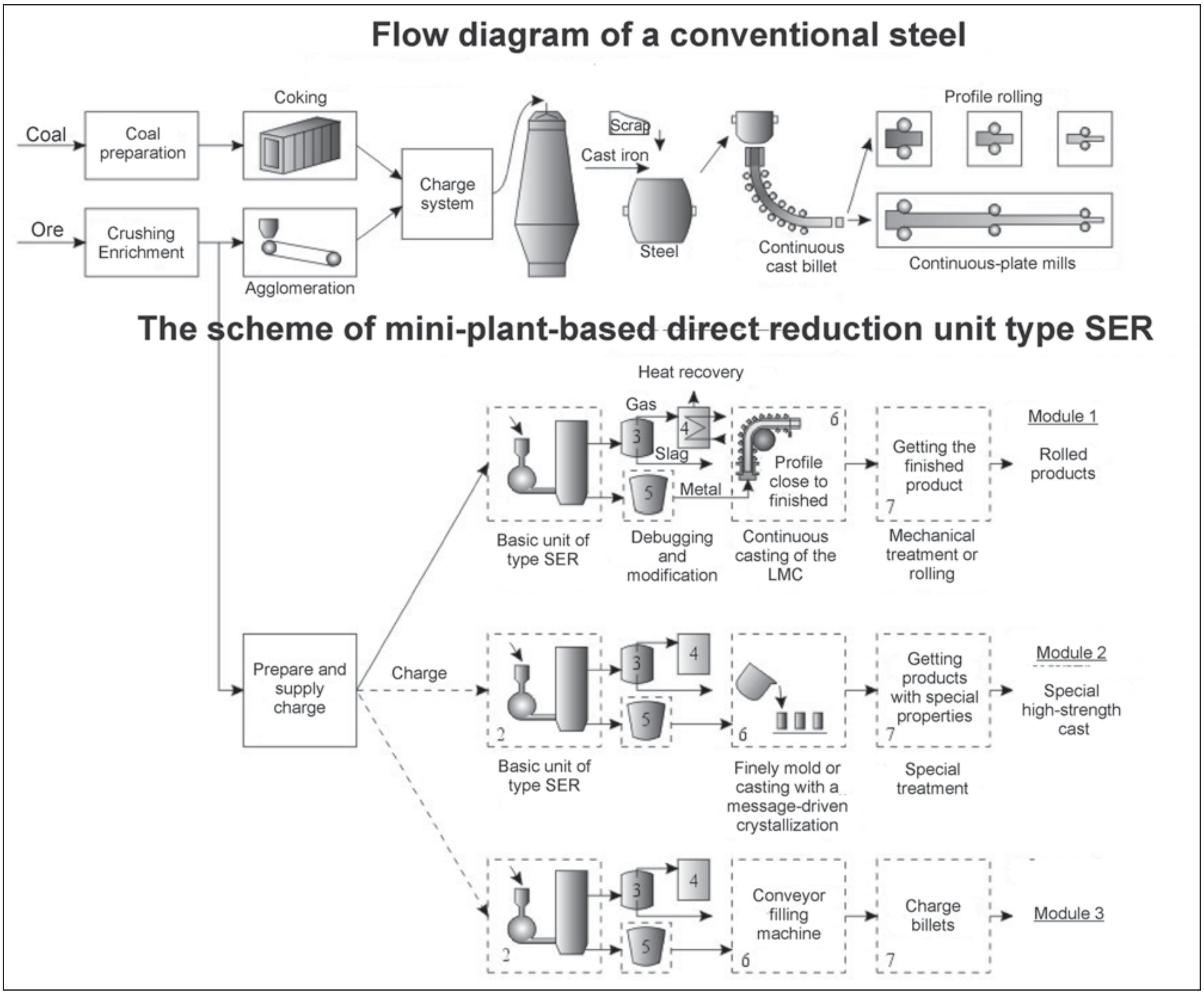

Fig. 3. Technology comparison

sulfuric acid, elemental sulfur, and other products providing full reticence of the process. Taking into consideration the fact that content of ferric oxides in slag during the production of matte and especially of blister copper is particularly about 40–45%, this slag can also be processed in the SER-type unit and, therefore, to organize practically waste-free production. Apparently, in a similar unit it is also possible to convert matte on blister copper. Naturally, to test feasibility of these technologies it is necessary to establish a pilot plant.

To accelerate the proposed development it is necessary to realize the following measures:

1. Establishment of the pilot mini-module (together with "Sibelectroterm" plant) and testing of the new technologies at this module, afterwards fabrication of the standard mini-module with capacity of 30,000 tpy for foundries at machine-building plants and the standard module with capacity of 250,000–300,000 tpy. Based of these modules it is planned to create metallurgical mini-mills with advanced scientific and technological level and with full production cycle from ore (or powered waste) to the finished metal without the use of expensive and scarce scrap metal, where content of harmful impurities is growing. In its turn, that limits possibility of producing some special steels.

2. Establishment (e.g. in Novokuznetsk) the designing-engineering center and production base for the construction and turnkey mounting of metallurgical mini-mills. At present time such opportunity is available, because a group of designers from former Sibgipromez and other designing institutes is still locating in Novokuznetsk.

Realization of this program can be carried out step-by-step, it doesn't require large investments and can be characterized with quick return of investments. Due to the high knowledge content, the units have small sizes; that allows creating even mobile energetic metallurgical plants, not requiring supply of electric power. That fact is very important in the development of sparsely populated areas. It is also possible to use these units as coal gasifiers by means of coal firing in a slag layer, to produce energetic gas or synthetic gas with simultaneous metal reduction process (metal is enriched with alloying and rare earth elements) from ashes.

In conclusion, it should be noted that change of structures of metallurgy can also follow the line of the production of metallized pellets or briquettes via direct reduction with metal fabrication in electric arc furnaces. Such technological schemes have been sufficiently developed during recent years. However, construction of such installations requires large capital expenses; additionally, conventional metallurgical route is carried out here. This route includes crushing of raw materials, concentration, pelletizing and melting and it is at variance with the principles of minimization of entropy as the global environmental condition. It should also be mentioned that possibility of processing relatively poor and fine ores has been manifested to be the advantage of the Corex process during the early stages of its development, is now not so important due to the tendency of increasing the volume of units, i.e. the tendency, that has led to a deadlock of conventional full-cycle metallurgy is repeating.

The most effective way is direct reduction of metal from collector dust without pelletizing; it reduces dimensions of units, capital costs and energy consumption.

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