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Diversification of the production and processing of pulverized wastes and ores based on the SER jet-emulsion unit

V P Tsymbal, A A Rybushkin, I A Rybenko, V I Kozhemyachenko,
S N Kalashnikov and L A Ermakova

Siberian State Industrial University, 42 Kirova str., Novokuznetsk, 654007, Russia

E-mail: rybenkoi@mail.ru

Abstract. The principles of creating a self-organizing jet-emulsion reactor (SER) are considered, the role of dissipative structures in solving problems of controlling the metal chemical composition is shown. The technological scheme of the unit is presented, in which it is possible to process pulverized materials with a wide range of changes in chemical composition, including sludge, scale, poor pulverized ores and tailings.

1. Introduction

In the period from 1992 to 2001, thanks to the fruitful cooperation of scientists of SibSIU with specialists of the West Siberian Metallurgical Plant, a fundamentally new jet-emulsion metallurgical process and a unit was developed and implemented as a large-scale pilot plant in the second converter shop, which allows pulverized ore materials and waste in one stage without agglomeration to be processed [1, 2]. The SER process is characterized by low energy consumption and a small specific volume of the unit.

These results were achieved through the use of the basic principles of the theory of self-organization (synergetics) [3, 4] and some physical effects for their implementation, such as intense dispersion of the mixture with counter jets, gas-dynamic channel locking and others [1, 5].

The combination of these factors and measures made it possible to create dynamic dissipative structures in the aggregate, which led to a sharp decrease in the specific aggregate volume (10-15 times) and provided significant control flexibility, including the ratio of the rates of reduction and oxidation reactions, which made it possible to directly produce metal with a fairly wide range of carbon content [2].

Currently, several dozen new units for direct reduction are known in the world, but in none of them, including COREX, it is fundamentally impossible to obtain an iron-carbon alloy with a carbon content below 2%, due to the fact that the processes in them are close to a state of equilibrium, and it is impossible to control separately the composition of the metal and slag.

The article shows that the simultaneous solution of the problem of controlling the chemical metal composition and reducing the unit specific volume is achieved by constructive and mode organization of dynamic dissipative structures [2, 5], which play the role of unique “chambers” that were planned to be created in the initial designs of continuous steelmaking units.

2. Basic principles and solutions

The following principles and decisions were laid at the basis of the constructive implementation of the SER process and unit [6]:



- creation of a large reaction surface and a two-phase working mixture (gas suspension or emulsion), that is, the transfer of the process to the field of gas dynamics, which allowed high speeds of physical and chemical processes to be obtained;
- organization of the forced movement of the working (reaction) mixture in a closed system under pressure, which made it possible to create a significant deviation from thermodynamic equilibrium and at the same time solve the problem of internal transport of reaction products through all series-connected devices;
- the use of a nonlinear dependence of the flow velocity of a two-phase medium on gas content to create a pressure potential due to the effect of gas-dynamic locking of the connecting channel;
- creation of dissipative structures that are significantly deviated from thermodynamic equilibrium, which made it possible to obtain great opportunities for controlling the chemical composition of metal and slag.

3. Design and technological features of the SER unit

The unit with a very small specific volume and energy intensity was created using the approaches and principles described above [1, 5]. The technological scheme and a brief description of the SER unit (self-organizing jet-emulsion reactor) are presented in figure 1.

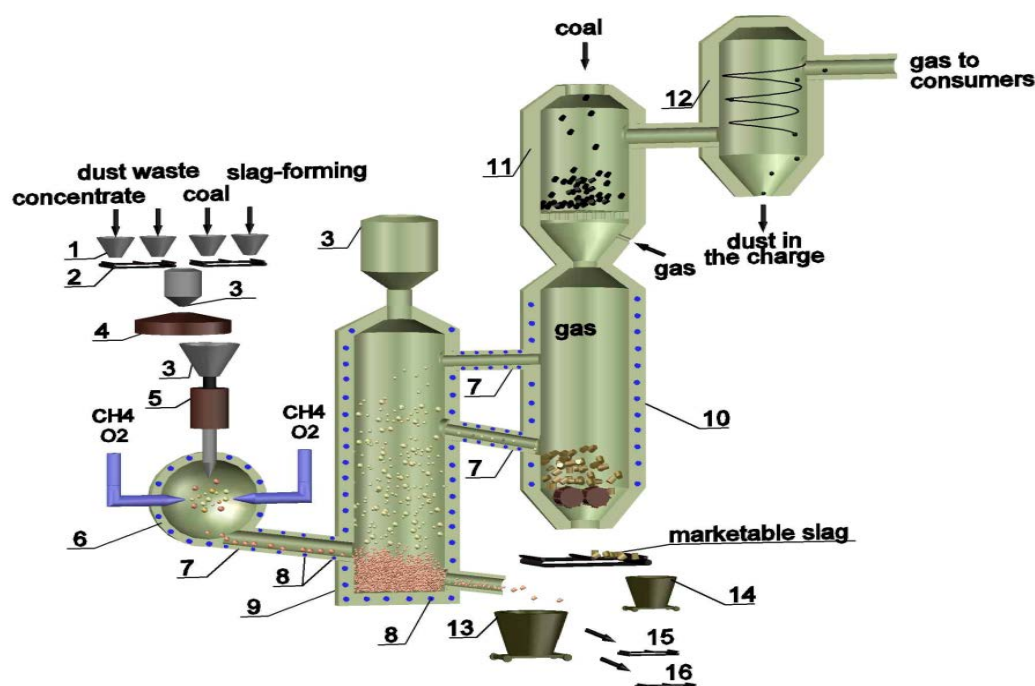


Figure 1. The technological scheme of the SER unit.

The basis of the technological scheme of the mini-module is [6]: the charge supply system 1–5, the reactor-oscillator 6, the connecting channel with gas-dynamic self-locking 7, the refining settler 8, simultaneously playing the role of the wet gas cleaning of the first stage, the receiver 9, as well as the skull cooling system 10, a channel 11 for issuing a gas-slag emulsion and a channel 12 for transferring part of the gas, a slag receiver 13 with a granulator 14, a system for heat recovery in a fluidized bed or for the transformation of flue gases into synthesis gas 17 and a gas purification system 18. The high pressure potential created in the oscillator reactor 6, as well as the complete isolation of the process from the atmosphere, allow the reaction products to be pushed through all energy recovery devices behind the main technological unit without the use of high-temperature flow factors [6].

Due to the high intensity of the gas-dynamic processes occurring in the unit, the flow of an aggressive two-phase medium, the protection of all elements of the unit is carried out on the basis of circulation skull cooling. To solve this problem, a specialized automated design and calculation system was developed that can also perform diagnostic functions when implementing this cooling system and maintaining the skull [1].

4. Development and implementation status

The process and the unit were implemented as a large-scale pilot plant in the second converter shop of ZSMK on the vacant site of cast iron overflow (figure 2). In total, more than 50 people took part in the creation of the installation and conducting experiments.

The experienced metallurgists-practitioners made a team of steelmakers under the leadership of V.P. Tyutyulnikov and played an important role in improving the design of the installation and conducting unique experiments, one of which is shown in figure 3.

In this experiment, a high-temperature two-phase jet was “shot” from a spherical reactor onto a lined area, which provided valuable data on the physical and chemical properties of particles emitted from the first reactor, chemical reaction rates, etc., as well as the identification of mathematical models.

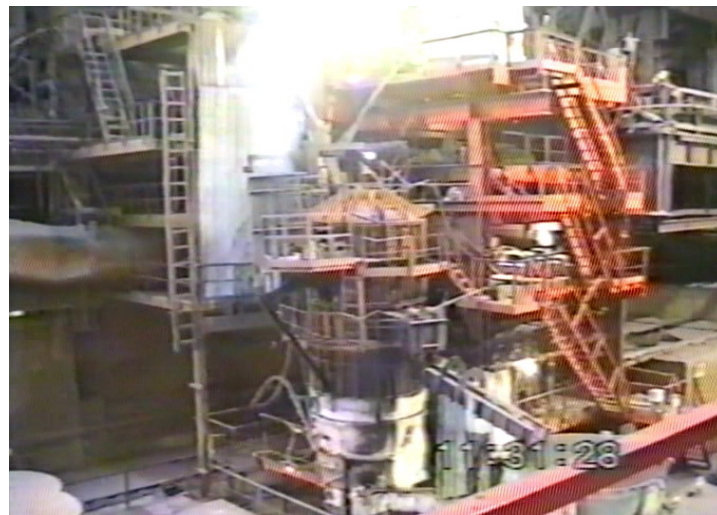


Figure 2. General view of the pilot plant.



Figure 3. High temperature jet from the first reactor.

5. Development and implementation status

Several new low-energy-intensive technologies were developed and tested experimentally, including: direct reduction of pulverized ores and waste (sludge and mill scale) without agglomeration, production of manganese alloys from lean pulverized ores, separation of titanium-magnetite concentrates into iron and conditioned titanium slag. The process was patented in the main metal-producing countries: USA, Japan, South Korea, European patent, Russia [7].

The developed process and unit has a certain degree of versatility. It is possible, by changing the blowing mode and afterburning degree of the reducing fuel, to process pulverized materials with a wide range of changes in chemical composition, including poor dusty ores and dressing tailings.

In addition, the SER unit can be used as a gasifier for pulverized coal fractions, but the most economical option is to use a mixture of coal and pulverized iron-containing waste. This facilitates the process of maintaining a stable layer of slag-metal emulsion, inside which fuel is burned, and also reduces the consumption of gaseous oxygen through the use of oxygen from iron oxides.

Besides, it becomes possible to use excess temperature, in the case when the priority is gasification of coal to produce synthesis gas.

6. Diversification of production based on new technologies

In order to implement one of the possible ways to diversify production, technical proposals have been developed for the implementation of a complex of two SER plants in the free areas of the molds shop of West Siberian Metallurgical Plant.

The development of technical proposals was a logical continuation of the design studies related to the testing of a pilot plant at ZSMK and the further steps for the introduction of a continuous metallurgical process. The proposals were aimed at developing the layout of technological complexes, the design of the main equipment and their aggregate acquisition.

In the mold shop there are certain reserves for the use of equipment (primarily hoisting-and-transport) and free production facilities. In addition, in terms of production category and spatial parameters, the mold shop fully corresponds to the intended purpose.

The issues of infrastructure energy supply, auxiliary facilities were worked out, a preliminary expert assessment of the economic efficiency of construction was carried out.

The possibility of constructing a complex for a small-tonnage installation of a continuous metallurgical process in the mold shop was considered in the current production environment and new technological processes planned for real projects. The design materials substantiated the technological and constructive prerequisites for the placement of two technological modules of the SER type in the main building of the molds workshop:

- mini-module with an annual capacity of 30000 tonnes, designed to debug new technologies and obtain manganese alloys from poor dust-like ores and concentrates;
- a technological module with a capacity of 300000 tonnes, designed to receive the original charge stock, and with the further development of other steel products.

Figure 4 shows the layout of equipment for implementing the technology in development of the above concept, designed to:

- obtaining from dusty materials a primordial (alloyed) charge billet for electric arc furnaces (first stage);
- small shaped casting with special properties by using volume crystallization;
- a small profile, including pipes of small diameter, by continuous drawing up through a mold with a liquid metal coolant (with further development of the technology).

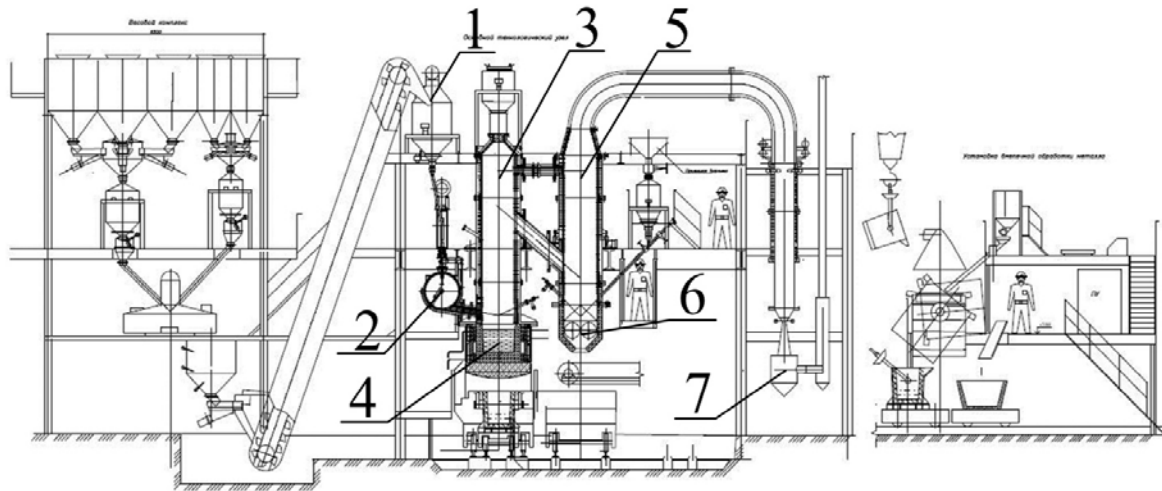


Figure 4. Equipment layout: 1 – charge loading system, 2 – spherical reactor-oscillator, 3 – vertical column reactor (refining sedimentation tank), 4 – induction-heated receiver, 5 – slag collector, 6 – slag granulator, 7 – gas purification system

6.1. Basics of technology

They are considered on the example of obtaining a billet stock or other steel products from ore and dusty metal-containing waste – sludge and scale.

A continuous metallurgical process is implemented in the form of a sequence of technological operations taking place in reactors connected to an in-line unit line (figure 5).

6.2. Equipment layout

The oscillator reactor, the refining settler, the unit for secondary metal processing, and the ingot casting machine represent the main production unit. The oscillator reactor and the refining settler are tied up with technological platforms and supports, which serve as independent load-bearing metal structures. The ball-shaped reactor-oscillator is mounted in suspension to the site at around 7100 mm with a mark in the center of the ball + 5600 mm. At the upper point of the reactor sphere (in the center), the pipe path of the bulk material supply system is connected. The bulk material supply system includes a weighing hopper (weighing funnel) for receiving and weighing the prepared charge, an activator for dosed delivery of the charge from the funnel, a vibrating feeder for loading the charge into the screw batcher.

The vertical screw metering unit is designed for gas-tight feed of the charge into the reactor. The metering unit is designed in such a way that the transported charge is compacted in the pipe channel, forming a kind of gas shutter that prevents the release of process gases from the emulsion reactor.

The refining sump is made with reference to the emulsion reactor at a distance of 1900 mm from the vertical axis. With a stiffness belt, it rests on a work platform at the level of +3900 mm and, in turn, bears the supports of the platforms +5100 mm, +7100 mm, +8300 mm.

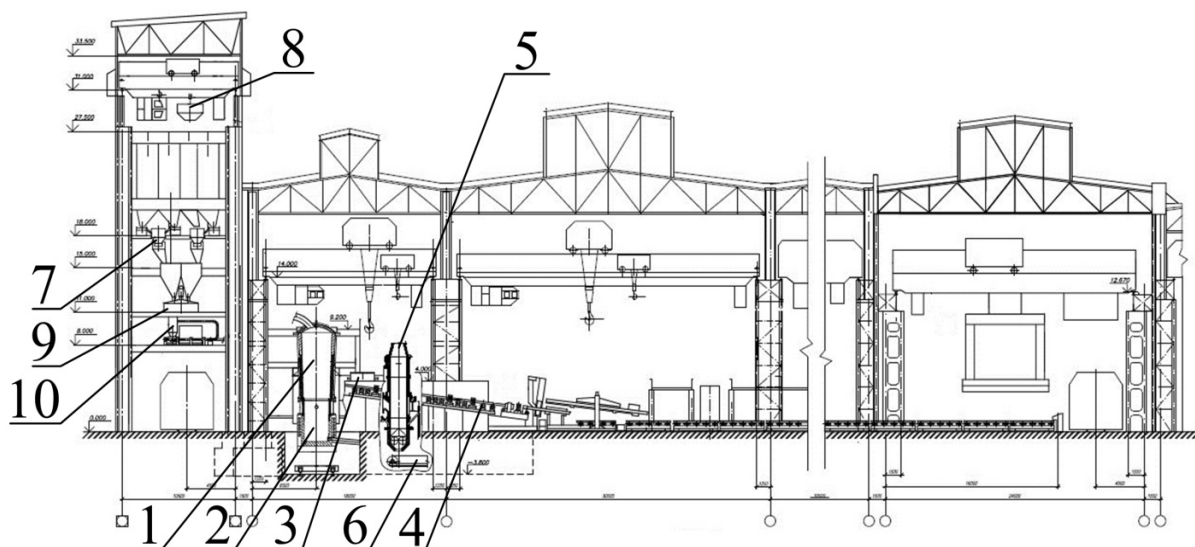


Figure 5. Cross section of the layout diagram: 1 – recovery zone of the column reactor, 2 – oxidation zone and receiver, 3 – connecting channel, 4 – metal casting machine, 5 – slag receiver, 6 – granulator, 7 – hopper block, 8 – bridge crane, 9 – mixer, 10 – vibration feeder.

A boiler-cooler leaves the refining sump from under the dome zone through the branch pipe. The tube-like panel of the boiler from the upper horizontal level (axis mark + 9100 mm) is refracted vertically down to the mark of +3000 mm and then goes to gas treatment.

The lower part of the sump is separated from the zero level of the floor by a distance of 3700 mm in order to freely approach the cart with the electric furnace or induction furnace installed to receive the liquid intermediate. An electric furnace (or induction furnace) acts as a unit for out-of-furnace metal processing. The casting machine, which is a chain conveyor with molds, is designed for casting a liquid metal product into ingots.

6.3. Construction conditions

According to an expert evaluation of the columns of the main building in the mold shop, the piles have a bearing capacity margin, which allows them to be used to absorb the corresponding additional design loads when expanding the production of the shop. The metal frame of the building makes it quite simple to mount new ones, as well as strengthen existing metal structures. A cross-section of the layout diagram is shown in figure 5.

6.4. The purpose of the production program

The purpose of the production program consists in the processing of dusty iron-containing wastes, primarily of current production. Table 1 shows the approximate amount and chemical composition of these materials.

Table 1. The composition of the pulverized waste from the current production.

Waste	Quantity, t/year	Fe ₂ O ₃	FeO	Fe _{tot.}	SiO ₂	Al ₂ O ₃	CaO
Scale	150000 (including 60 000 scale with fuel-oil residue)	16.6	65	67	1.5	0.4	0.5
Sludge (gas purification)	100 000	15	62	65	2.0	0.04	7.2
Blast furnace dust	15 000	39	14	38	8	3	6.4

The possible savings from processing pulverized wastes of only current production using an example of such a plant as ZSMK is equivalent to refusing to purchase iron ore raw materials for 15

days in the context of one year. Cost recovery will be 1.5 years after the start of production. It is necessary to emphasize the feasibility of orientation, at the first stage of the implementation of the production program, to obtain the original charge for electric arc furnaces.

The fact is that, despite the increasing difficulties in selling finished steel, the market for scrap metal remains unsaturated, and the cost of scrap is at the level of pig iron. In Russia, in recent years several mini-factories have been built and are planned to be built, in connection with which, the scrap deficit is growing. The exception is perhaps only the Ural region, where there are many old closed or reconstructed factories.

The problem of contamination of recycled scrap with non-oxidizable impurities (copper, nickel, etc.) becomes more and more acute, which does not allow smelting of some steel grades or worsens the quality of the metal. In this regard, direct reduction iron (pellets or briquettes), which is much more expensive than scrap, has to be added to the charge of electric steel furnaces, and there is a danger of spontaneous combustion during long-distance transportation. In addition, when using briquettes, energy costs and the amount of slag increase significantly.

These drawbacks are deprived of the original charge stock, which is planned to be obtained from sludge and scale using the proposed technology [1], in addition, it is characterized by low energy costs and capital intensity in comparison with the known direct reduction processes [8].

So, for example, according to the results of European studies and comparative analysis of technologies aimed at reducing carbon dioxide emissions, it is argued that the replacement of the technological route “blast furnace – oxygen converter” with direct reduction processes based on the use of natural gas and steel smelting in electric arc furnaces for the reduction CO₂ emissions is probably economically inefficient”[9]. Table 2 compares the technical and economic indicators of the SER process with the closest and most advanced analog in the world – the COREX unit [10].

Table 2. Comparative analysis of technical and economic indicators of the SER and COREX processes.

Indicators	COREX	SER	Advantage
Energy intensity, GJ/t	29	15 – 17	in 1.7 times
Specific volume, t/m ³ day.	1.1	11	in 10 times
Capital costs, \$/t year	350	120 –150	in 2.5 times

Given the above analysis of the effectiveness of direct recovery processes existing in the world, it can be argued that the implementation of the first stage of the program presented in the draft will open up opportunities for wider dissemination of the above technologies, including through the sale of licenses [7]. The unit with a capacity of 30 thousand tonnes may be of interest to foundries of machine-building plants in connection with the need to replace obsolete metallurgical production, as well as dilute scrap contaminated with non-oxidizable impurities, with original metal.

And units with a capacity of 300 thousand tonnes, taking into account the possibility of incorporating relatively small capital costs and quick payback into existing buildings, can become the basis for the creation of full-cycle mini-metallurgy, including inside reconstructed factories.

7. Conclusion

When creating an SER unit, an attempt was made for the first time in world metallurgy to use some ideas of the theory of self-organization (synergetics), such as the principles of submission and least forcing, a large deviation from thermodynamic equilibrium, etc. [6]. To implement these principles, it was possible to apply a number of physical effects, such as the dispersion of the mixture with oncoming gas jets, the creation of a self-organizing reactor-oscillator due to the use of the critical expiration of the two-phase flow and feedback on the change in the gas content of the reaction products, the lower flow of the working mixture from the reactor-oscillator to the column reactor, organization of forced movement and internal pneumatic transport of a two-phase working mixture [6]. The combination of these factors and measures made it possible to create dynamic dissipative structures in the unit (instead of physical zones), which led to a sharp decrease in the specific volume

of the aggregate (10-15 times) and provided significant control flexibility, including the ratio of the rates of reduction and oxidation reactions, which made it possible to directly obtain a metal with a fairly wide range of carbon content [6].

The project is presented for the placement and equipment layout for the implementation of the technology, first of all, obtaining the original charge from sludge and scale with fuel-oil residue for electric steel furnaces.

For more information on the status of the development of the SER process, please visit: <http://www.sibsiu.ru> (Scientific and technical developments – Self-organizing jet-emulsion reactor).

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