PLASMA PROCESSES IN METALLURGY AND TECHNOLOGY OF INORGANIC MATERIALS

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Equipment-technological classification of plasma processes in metallurgy and material treatment is stated. It allowed evaluating the prospects of plasma process practical application and ways for structural-technological arrangement optimizing. The equipment for shaft furnaces with plasma heating and processes of plasma effect on metallurgical melts have close prototypes in classical metallurgy. Jet-plasma processes, oriented on receiving of substances in dispersed state, require development of the original equipment. The authors realized the processes of hydrogen-plasma reduction of refractory metal oxides, plasma reduction melting of oxides of iron group and production of metal compounds (carbides, nitrides, oxides, etc.) allowing manufacture of products in a form of dispersed powders. They differ by possibility of energy- and resource saving, receiving of products with specific service properties and environmental compatibility. Proposed is a concept of modular energy-technological complex joining energy generation and chemical-metallurgical production of metals, steels and alloys from natural and technogenic raw materials on plasma method basis. Such pollution-free complex allows reducing energy- and resource consumption. 15 Ref., 10 Figures.

Keywaords: *jet-plasma processes, dispersed powders, plasma-chemical installation, tungsten, energy- and resource saving, energy-technological complex, plasma-arc liquid-phase reduction of iron*

The investigations of physical-chemistry and technology of thermal influence of plasma on the material in different states of aggregation are based on scientific philosophy about effect of highly-concentrated power sources on the material [1, 2]. They are directed on development of pollution-free energy- and resource saving processes for manufacture of the materials with specific properties, including nanomaterials.

A theory of processes of metal reduction in different states of aggregation, including under effect of the thermal plasma flows [3, 4], was developed as a result of systematic investigations of thermodynamics, kinetics and mechanism of reduction of oxide systems using current methods for investigation of topochemical reactions, provisions of heterogenous catalysis and absolute reaction rate theory.

Procedure for the investigation of plasma processes was developed based on high-temperature thermodynamic analysis, mathematical modelling and experimental kinetic investigations using specially designed equipment [5].

A decisive role of heat-and-mass exchange on treated dispersed material distributed in a plasma flow and its transfer in a gas phase, i.e. level of the process homogenization [3, 5–8] was determined during the jet-plasma processes.

Equipment-technological classification of plasma processes in metallurgy and material treatment is stated. It allowed evaluating the prospects of their practical application as well as ways for structural-technological arrangement optimizing [7] (Figure 1). Domestic works in the field of plasma technique application were carried out in a number of organizations, but, unfortunately, did not receive significant development. However, application of the electric arc plasmatrons of megawatt power promotes successful application of plasma in the industrial shaft aggregates (for example, in plasma cupola in USA) or in the processes of plasma treatment of zinc-containing dusts at plant of Steel company (Sweden).

The processes of plasma effect on metallurgical melts, which are structurally arranged in a form of plasma furnaces, obtained sufficiently wide application in number of variants as refining and alloying remelts and plasma heating of metal before continuous casting. The domestic developments realized at Chelyabinsk metallurgical plant were transferred at the plant in Freital (former German Democratic Republic), where around 150 grades of quality steels and alloys were successfully manufactured. Afterwards, they were used in Austria under plant license (50-ton plasma furnace of FEST-Alpine company). We have developed and implemented a process of plasma reduction melting of oxide raw

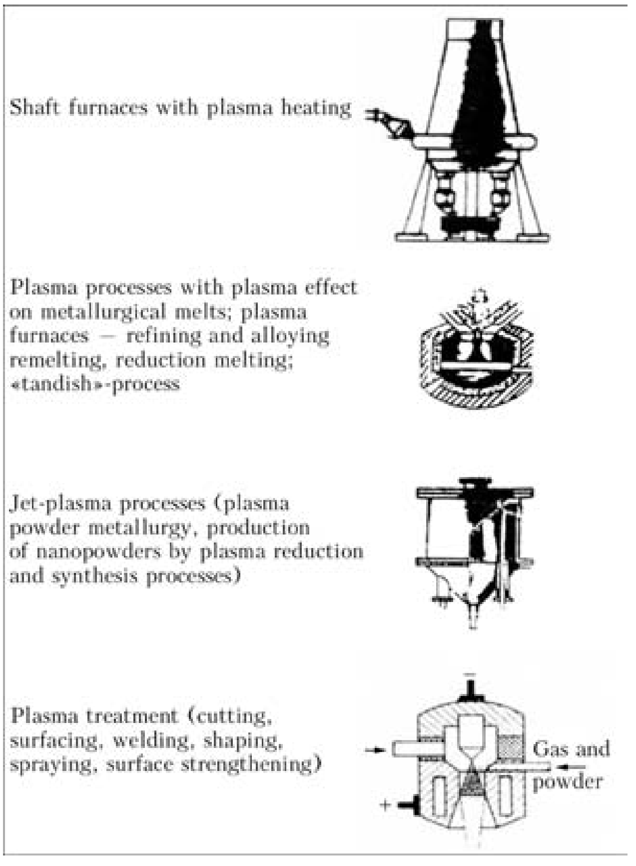

Figure 1. Equipment-technological classification of the plasma processes in metallurgy and material treatment

material, applicable to manufacture of metallic cobalt (Figure 2, 3), afterward used for nickel production, at «Yuzhuralnikel» industrial complex.

Analysis of the fourth class processes is not a subject of this paper, however, their spread in industry should be noted, for example the processes of plasma cutting and spraying. The plasma treatment of surface is highly perspective as well.

In contrast to the processes of the first two classes, where plasma equipment has similar prototypes in the classical metallurgy, development

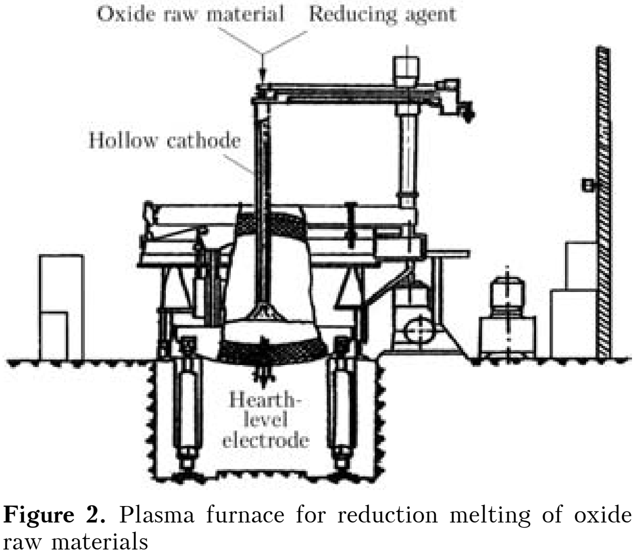

Figure 2. Plasma furnace for reduction melting of oxide raw materials

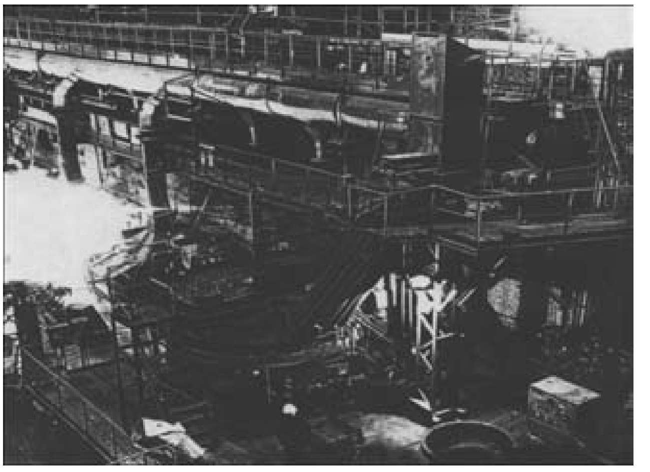

Figure 3. Industrial plasma furnace for reduction melting of oxide raw materials

of the original equipment is required for the third class processes (jet-plasma).

The jet-plasma processes are as a rule oriented on production of materials in dispersed state. The plasma processes of powder production are distinguished by a versatility (Figure 4). Spheroidized, clad powders as well as powders of elements and compounds of different dispersion, including nanosized, were produced with the help of physical and physical-chemical processes during introduction of material in any state of aggregation in the plasma, generated by different sources of various chemical composition.

For the first time in world practice, we have realized an industrial process of hydrogen-plasma reduction of tungsten oxide with production of ultradispersed tungsten powder. The materials with special service properties were received on its basis [9]. It is shown that the plasma metallurgical processes are energy- and resource saving and provide environmental compatibility under condition of rational object choice and optimization of structural-technological arrangement.

Series of practical applications based on peculiarities of ultradispersed state (reduction of temperature and energy consumption at compacting, intensifying of welding and sintering processes, obtaining of hard alloys of increased hardness and wear resistance on their basis) was demonstrated for ultradispersed products of tungsten oxide plasma reduction.

Structure of plasma-chemical installation for production of nanopowders of metals and chemical compounds at interaction of dispersed and vaporous raw material in jet of the thermal plasma generated by electric arc plasmatron (Figure 5) was developed and patented.

A number of plasma-chemical processes of production of metal and compound nanodispersed powders were investigated. Determined are the

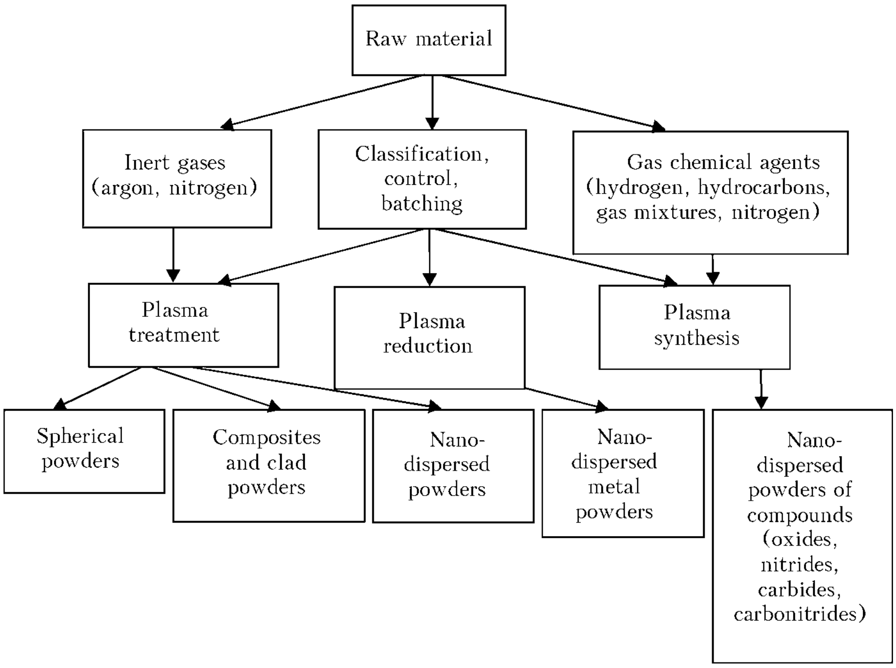

Figure 4. Scheme of plasma powder production technology

thermodynamic and kinetic dependencies and control parameters, providing production of powders of specified chemical and dispersed compositions. The methods were developed for control of average size of produced powder particles during the change of enthalpy of plasma jet, raw material consumption, structural peculiarities of reactor as well as application of gas quenching to the products of plasma-chemical interaction. Advantages of the proposed technology are shown by produced nanopowders (metals, carbides, nitrides, carbonitrides, oxides, etc), short duration of plasma processes (< 0.01 s), high performance of equipment, possibility of application of traditional raw material base without preliminary preparation and significant efficiency range (0.1 ... $n \cdot 10$ kg/h) [10–13].

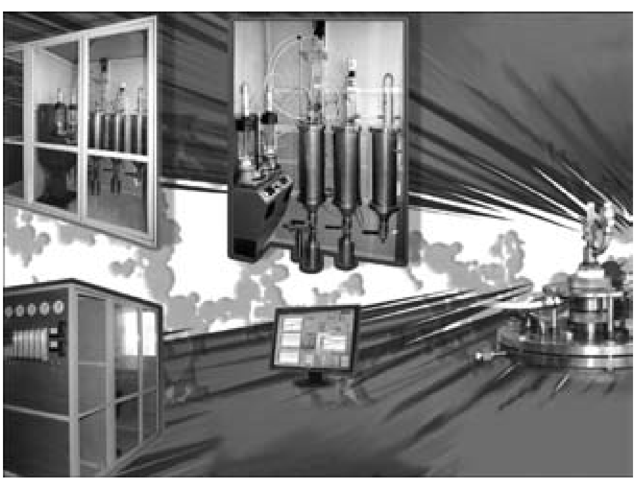

Figure 5. Plasma-chemical installation for nanopowder synthesis

Physical-chemical fundamentals and principles of structural-technological arrangement were developed for a production process based on synthesis of tungsten-carbon system nanopowders (Figure 6) in hydrocarbon plasma. The latter are used for production of tungsten monocarbide nanopowders as a basis for production of nanostructured hard alloys with significantly improved service properties (Figure 7). The urgency of this issue for domestic powder metallurgy is determined by the following factors. Today, Russian industry consumes around 3000 hard alloys (approximately 10 % of the world consumption). One third of this amount is purchased abroad, 1200 t/year are manufactured by KZTS, 300 t

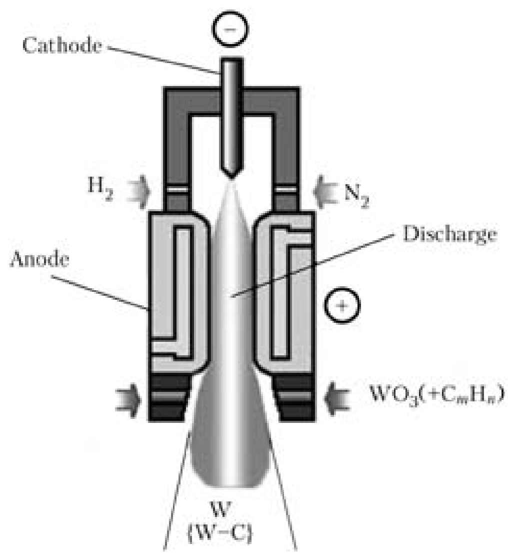

Figure 6. Principle scheme for production of tungsten and {W–C} nanopowders in arc discharge thermal plasma jet

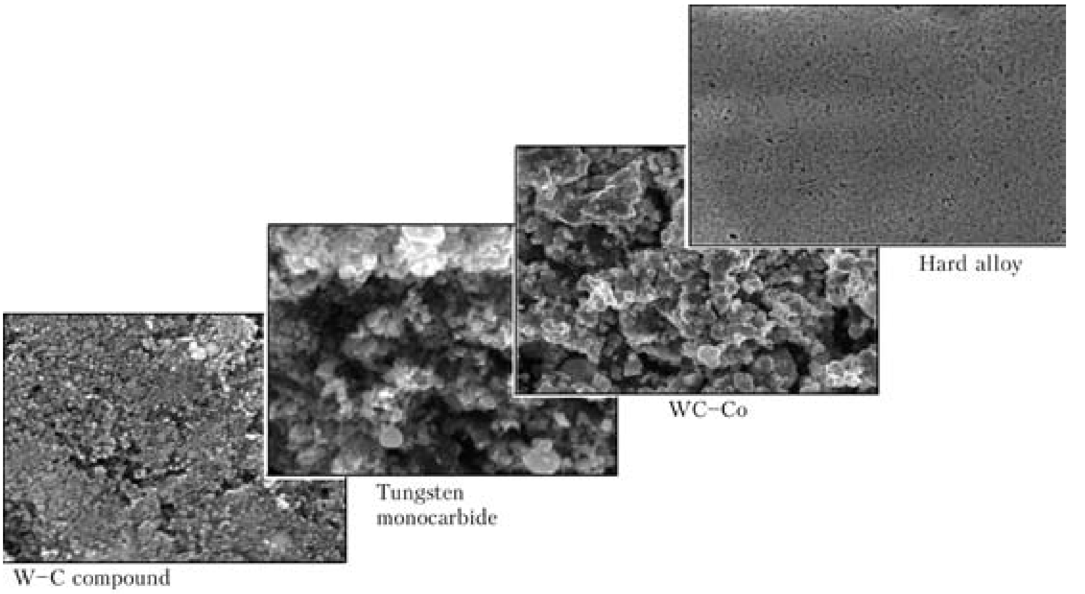

Figure 7. Stages of production of nanostructured hard alloy

are made by «Pobedit» plant, 100 t is from «ALG» company and the rest are produced by other small manufacturers. At present time, the Russian enterprises smelt only average- and coarse grain (more than 1 μm) hard alloys. All over the world, the problem of increase of hard alloy quality is solved by their nanostructuring.

Forms of perspective practical application of nanopowders for development of material with specific properties were studied and partially tested, for example in modification of cast alloys, development of effective composites and coatings, including nanostructured targets for coating deposition, powders for deposition of nanostructured coatings, components for composite materials, components of cast alloy modifiers, components of nanostructured wear-resistant coatings, nanoporous metallic and ceramic filters.

Today, our team proposes for practical realization the following scientific-and-technological developments:

• technological processes for production of nanosized powders of elements (tungsten, tantalum, niobium, molybdenum, nickel, cobalt, iron, copper) and their compounds (oxides, carbides, nitrides) as well as composites with set disperse, chemical and phase compositions in the thermal plasma of electric arc discharge.

The average size of produced nanopowders is lies in 20–100 nm range;

• fundamentals of technology for development of nanostructured hard alloys of tungsten carbide-cobalt with dramatically increased hardness and wear-resistance for application in cutting tool manufacture. Production of hard alloys in concentration range from VK-1 to VK-15 with introduction of complex grain growth inhibitors (Figure 7);

• development and manufacture of plasma-chemical installations for synthesis of metal and compound nanopowders of 30, 100, 300 kW power (efficiency 0.5–1.0; 5–10; 30–50 kg/h) using electric arc plasma generators;

• designing of shop areas for production of nanopowders on the basis of plasma-chemical units;

• investigations, directed on development of materials for production of high-capacity electrolytic condensers based on nanopowders of tantalum and niobium, nanopowder modifiers of cast iron, steel and alloys providing reduction of size of metal crystalline structure at 0.05–0.1 % weight fraction.

• composite materials with nanopowder application;

• nanopowder coloring agents;

• nanostructured coatings by means of plasma spraying of materials, manufactured with nanopowder application;

• nanostructured metallic and composite conductors with specific electro-magnetic properties;

• catalyzers of fuel elements.

Toxicological properties of nanopowder materials were investigated in order to provide safe operation of nanostructure objects. The risk and possibility of secure production, application and recycling of nanomaterials were estimated. A database of bio-safety existing nanomaterial was created. Developed were the methodological approaches to hygienic standardization and certification of manufacturers, goods and services in area of nanotechnology.

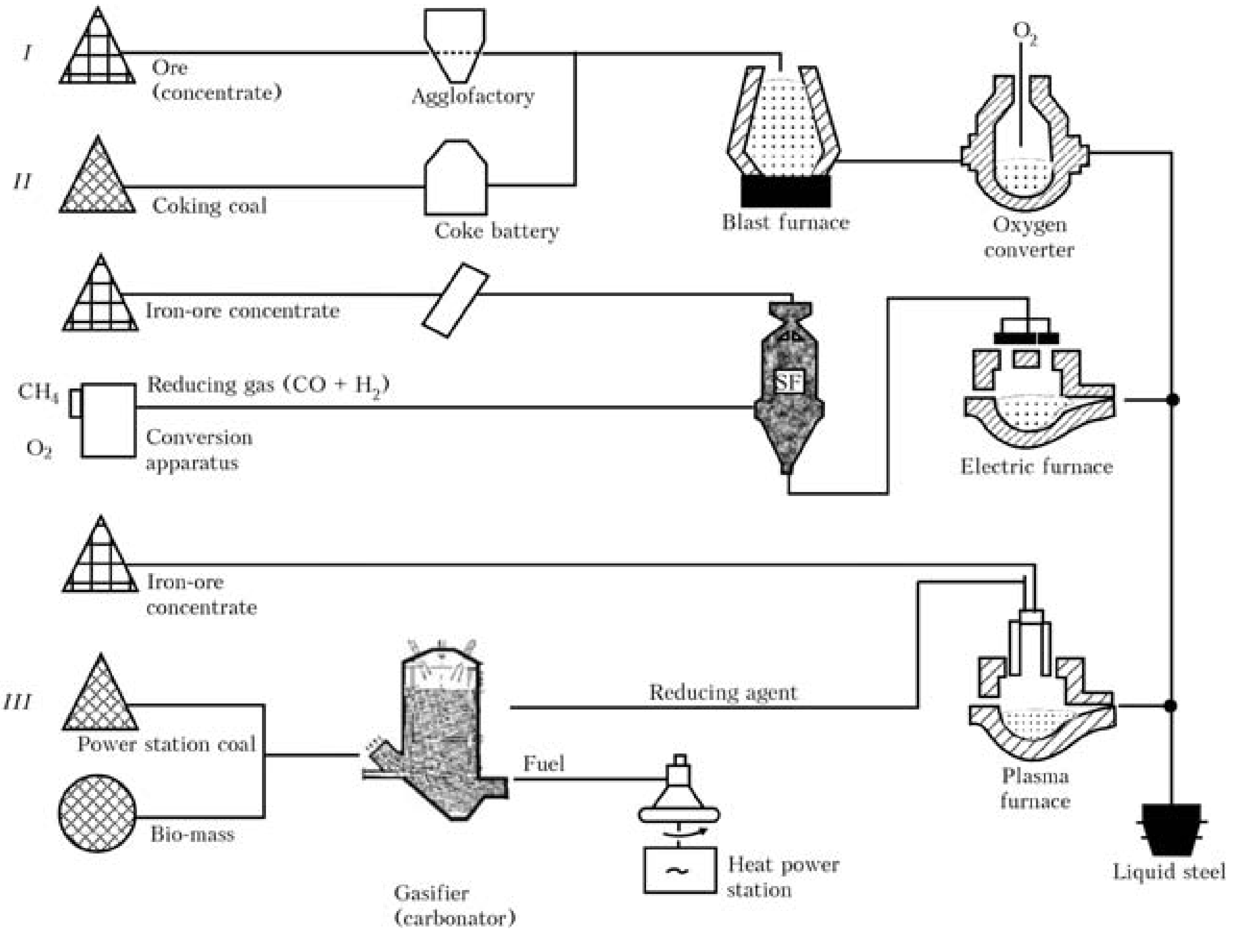

Figure 8. Steel production scheme

Some processes with the thermal plasma effect on gas media, melts and solutions, including applicable for processes of technogenic raw material treatment were investigated, among which is a plasma-catalytic reforming of hydrocarbon raw materials for production of hydrogen-containing gases and oxidation of organic additives in the water.

Current steelmaking, performed on blast furnace-converter (Figure 8) equipment-technological scheme, has series of significant disadvantages. The latter are determined by the necessity of compliance to high requirements of raw material and its special preparation, since specific nature of the blast-furnace process requires feeding in the blast furnace of the material with high level of mechanical properties in combination with gas permeability providing. The agglomeration and by-product-coke production, which use expensive and scare coking coal, not only raise the price of manufacture in whole, but cause environmental damage. It can achieve 25 % of prime cost of steelmaking based on value estimation. Proposed alternative processes, in particular the method of direct reduction, which has found industrial application in the domestic metallurgy, could not significanfly replace the traditional steelmaking technology, based on blast furnace process, by number of reasons, including due to the energy consumption. It is assumed that application of plasma technique can have a positive role in possible transformation of the steelmaking production. It can be used at the stage of production of reducing agent and fuel from low-grade organic raw material by means of its gasification for pollution-free heat power station as well as in the reducing installation.

We develop a concept of energy technology of future. It is based on development of pollution-free energy-technological complex on modular principle, combining energy production and chemical-metallurgical production of metals, alloys and compounds from natural technogenic raw materials (Figure 9) on plasma technique basis. At that, significant decrease of energy consumption is predicted in comparison with traditional and alternative methods.

Development of the plasma energy-metallurgical complex will allow 1.5–2.0 time reduction of energy intensity of steelmaking; use of power station coal and hydrocarbon-containing wastes as a primary power source; decrease the detrimental effect on environment due to absence of by-product-coking and agglomeration produc-

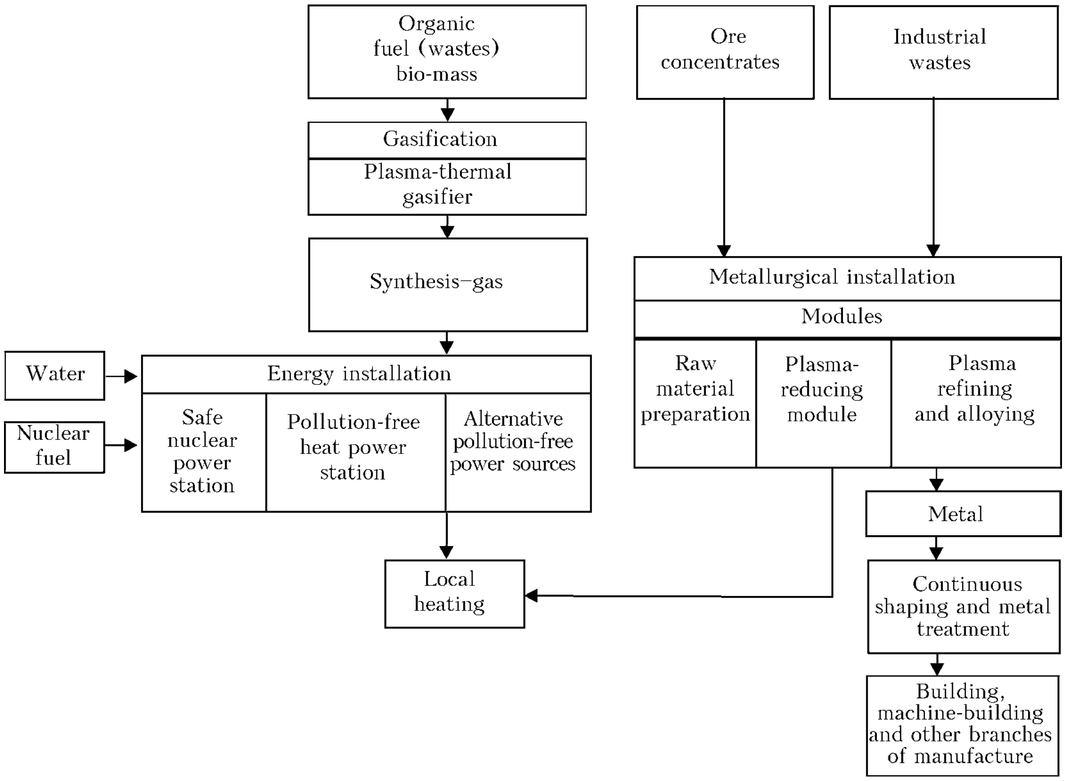

Figure 9. Principle scheme of energy-metallurgical complex

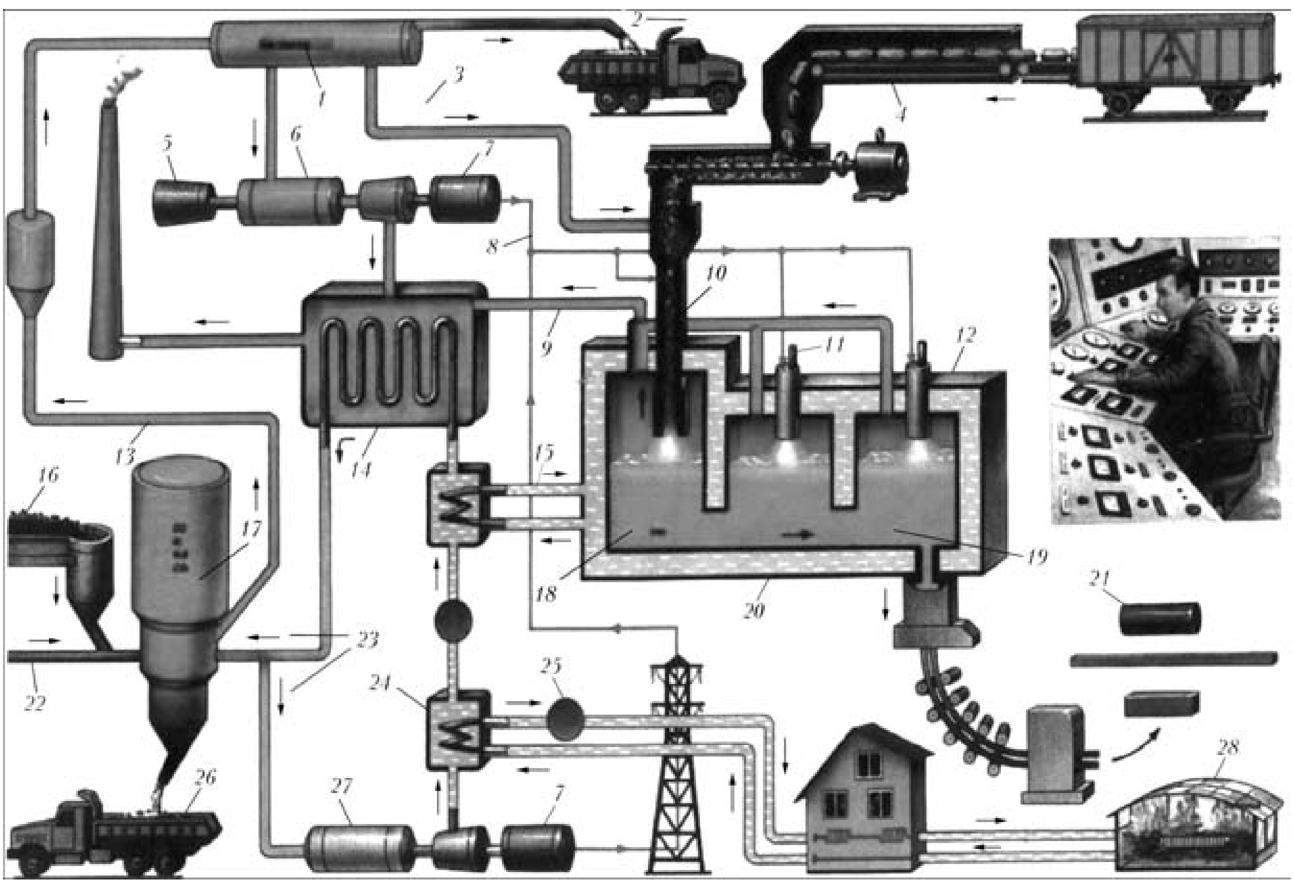

Figure 10. Scheme of predicted metallurgy of future: *1* — gas cleaning, *2* — sulfur; *3* — reducing gas; *4* — iron-ore concentrate; *5* — compressor; *6* — gas turbine; *7* — generator; *8* — electric power supply; *9* — exhaust gas; *10* — plasmatron (reduction); *11* — plasmatron (cleaning); *12* — plasmatron (alloying); *13* — gasifier; *14* — boiler; *15* — water; *16* — coal; *17* — CO, H_2, H_2O, CO_2; *18* — iron; *19* — steel; *20* — metallurgical block; *21* — rolled metal; *22* — oxygen; *23* — vapor; *24* — heat exchanger; *25* — pump; *26* — ash; *27* — steam turbine; *28* — greenhouse

tions; expand the raw material base, fully apply crude ore, develop the multi-goods metallurgical production, including nanostructured materials; create self-contained ecosystem complex — housing estate.

Physical-chemical and energy-physical fundamentals of the processes for coke-free plasma-arc production of metals of iron group from dispersed oxide raw material were developed applicable to the problem of optimization of structural-technological arrangement of the complex reducing module. Applicability of the process of plasma liquid-phase reduction to complex crude ore of titanium-magnetite type was demonstrated. Developed are the recommendations for completing of statement of work on development and manufacture of the pilot-industrial plasma-arc liquid-phase furnace of 3–5 MW power for iron reduction from titanium-magnetite concentrate.

A perspective scheme of metallurgy of future (Figure 10) is proposed for realization based on the developed concept of calculation and experimental investigations, aimed at development of the optimum structural arrangement of energy-technological processes on plasma technique basis.

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