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FLOW BIOREACTOR FOR STUDYING BACTERIAL-CHEMICAL LEACHING OF SULFIDE COPPER-NICKEL ORES AND CONCENTRATES

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Bacterial and chemical leaching of metals has established itself as an alternative technology for hydrometallurgical processing and enrichment of ore due to a reduction in capital costs and adverse environmental impact. Various bioleaching processes are successfully used for the processing of sulfide concentrates, poor sulfide and oxidized ores. One of the most important tasks for further development of this branch of biotechnology is the improvement of bioreactor installations (in particular – flow type) and installation of systems of additional control of technological parameters. The article briefly highlights the main results obtained at the GSRC of FEB of RAS within the framework of bioleaching studies of sulfide cobalt-copper-nickel ore. A description of a bioreactor for the study of bioleaching in a batch mode and a cascade type reactor for studying bioleaching in a continuous mode is given. A model of an improved bioreactor for bacterial-chemical leaching of sulfide ore is presented. A detailed description of the microcontroller control method for technological parameters is given. The field of application of the presented results is laboratory, integrated and semi-industrial tests of the technology of tank and reactor bacterial-chemical leaching of sulfide ores.

Key words: bacterial-chemical leaching; bioleaching; biohydrometallurgy; sulfide ore; nickel; bioreactor; microcontroller control; 3D-modeling; mass transfer; gas exchange; technological parameters

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Introduction. In comparison with traditional methods of mineral processing, bacterial-chemical leaching (bioleaching) is characterized by lower energy consumption and investment, along with a reduction in the harmful impact on the environment [2, 5, 9, 11]. This technology is based on the method of intensifying the extraction of valuable components (copper, nickel, zinc, gold, uranium, etc.) or harmful impurities (arsenic) from ores and minerals using the oxidizing activity of chemolithotrophic microorganisms [12-14].

The deposits of sulfide copper-nickel ores account for about 30 % of nickel reserves. Nickel-containing sulfide ores are usually concentrated and sent to high-temperature processing. However, the ores in which pentlandite ($(NiFe)_9S_8$) is found in strong intergrowths with pyrrhotite ($Fe_{1-x}S$), are difficult to yield to traditional methods of processing. The share of pyrrhotite can account for 10 to 50 % of the sulfide component of nickel sulfide ores, which explains its significant role in the chemistry of leaching. In the oxidation of pyrrhotite, both trivalent iron, oxidizing nickel-containing sulfide minerals, and ferrous iron, which serves as a source of energy for iron-oxidizing microorganisms in bioleaching pulps, are released [14].

To develop effective technological schemes for the biohydrometallurgical processing of ores and concentrates, bioleaching processes are investigated at laboratory and semi-industrial conditions in a periodic and continuous (flow) mode using two main types of reactors: a mechanically stirred reactor and an airlift percolator. On a commercial scale, along with heap and tank bioleaching, they use bioleaching in flow type bioreactors, which is a cascade of bioreactors with mechanical or aerodynamic mixing [4, 6, 8, 14].

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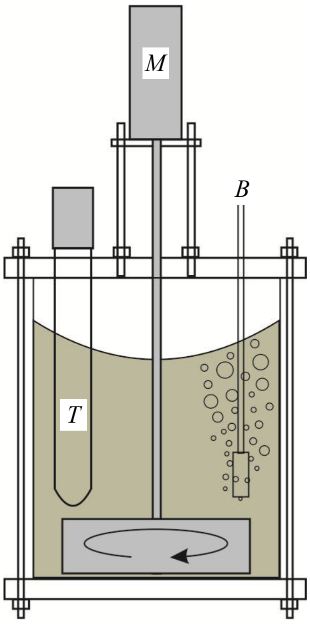

Fig.1. A scheme of reactor for bioleaching

M – mechanical mixer;
B – air supply system for pulp aeration;
T – thermocontroller

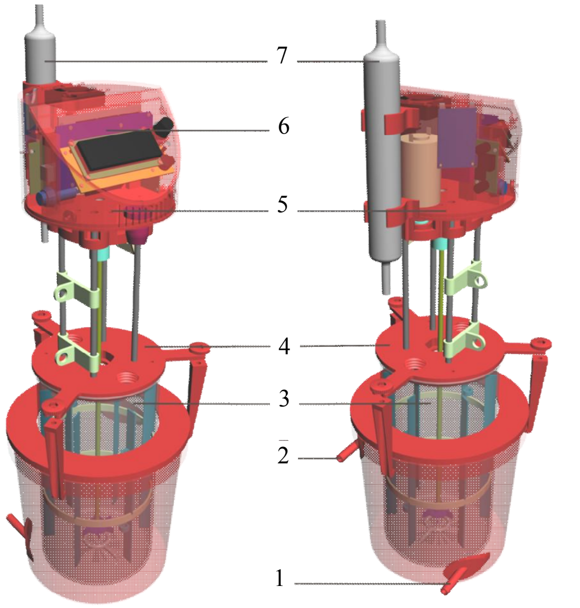

Fig.2. General view of the reactor

1 – the connection of the coolant supply to the reactor jacket from the thermostat; 2 – the connection of the coolant outlet from the jacket back to the thermostat; 3 – tank; 4 – cover; 5 – housing for electronic components; 6 – face panel with indicators and control elements; 7 – cooler for condensation of vapors during pulp aeration

Different variations of bioleaching technology have been successfully applied to the processing of sulfide concentrates, poor sulfide and oxidized ores. One of the directions for further development of this branch of biotechnology will be the improvement of bioreactor installations (in particular – flow type) by adding systems of additional control of technological parameters [15].

In the Geotechnological Scientific Research Center of the Far-Eastern Branch of the Russian Academy of Sciences, reactors and reactor units have been designed and built to conduct research on the process of bacterial-chemical leaching in batch and continuous modes:

1) a reactor for bioleaching in a heap mode, with a single loading of the pulp and its discharge after the end of the process (Fig.1);

2) a cascade type for bioleaching in a continuous (flow) mode, consisting of a conditioning tank for loading pulp from four reactors constructed according to the scheme shown in Fig. 1; the pulp from the conditioning tank is fed to the first pulp reactor through peristaltic pump with a controlled flow rate, and from the first to the second and subsequent reactors the pulp is delivered by gravity [1].

Methodology. We conducted experimental studies of the bacterial-chemical leaching of the sulfide cobalt-copper-nickel ore of the Shanuch deposit (Kamchatka) both in the periodic [3] and flow [1] regimes. The achieved indices of metal extraction in solution (80 % Ni and Co, 52 % Cu) exceed the extraction of metals from similar types of ores obtained by several foreign researchers [7, 10].

In order to optimize the research of bacterial-chemical leaching processes, a more advanced bioreactor has been developed. The most important features of the new reactor are the implementation of a microcontroller method for controlling technological parameters and their recording, as well as improved characteristics of mass and gas exchange in comparison with the previous model.

The general view of the reactor is shown in Fig.2. The reactor consists of a 2 liters tank (working volume 1.8 liters), a pulp agitation system, a pulp aeration system, a thermostatting system and a control system with a subsystem for collecting, displaying and recording information.

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The electronic control unit (Fig.3) is based on the ATmega2560-16AU microcontroller, it measures and maintains the following parameters: pulp temperature, rotation of the pulp agitation system shaft. It also provides the interface with the operator, records the process parameters and saves reports of system failures to the card memory at specified time intervals. It exchanges information with a PC, tablet or smartphone, and provides the ability to receive information and control over the system via SMS messages from mobile phone.

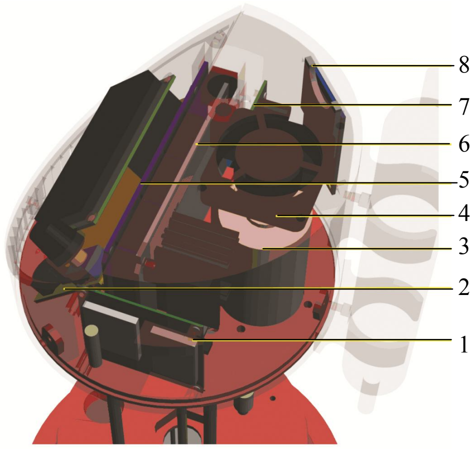

Fig.3. Elements of electronic control unit

1 – GSM-module for sending and receiving SMS-messages; 2 – LCD, control and sound board; 3 – electric motor of pulp agitator shaft; 4 – cooling fan of electric motor and power transistor for motor control; 5 – board with microcontroller; 6 – board with jacks for connection of power, sensors, electric motor, etc; 7 – unit of stabilized power supply (DC-DC-converter); 8 – SD-memory card unit

Unlike the previous version of the reactor, the thermal regulation of the contents of the working volume of the reactor is carried out not by a heater immersed in the pulp, but by an external thermostat. The thermostat is a separate container with a volume of 3 liters with a pump deliver the coolant into the tank jacket and an electric heating element (EHE) with a power of 900 W. To control the power of the heater, an AC voltage regulation device was developed and installed on the ATtiny13A-PU microcontroller, which opens the power symistor BTA41-600. At the same time, the voltage applied to the EHE varies from 1 to 95 % of the network voltage. The temperature of the contents of the reactor is controlled based on the readings of the DS18B20 digital temperature sensor. The required level of power is calculated by the microcontroller of the reactor according to the proportional-integral-differential algorithm (PID algorithm) and transmitted through the digital line to the microcontroller of the thermostat. Thanks to the use of a powerful heating element and a smooth change in its power according to the PID algorithm, rapid and accurate control of the pulp temperature is achieved. The control step and the temperature hysteresis are 0.1 °C. The control ranges are limited using construction materials and set in the microcontroller control program within a range from ambient temperature to 70 ° C.

Improving the characteristics of mass and gas exchange is achieved by using baffles for the pulp and agitator of the turbine type placed on the inner wall of the reactor tank (Fig.4, 5). This became possible due to the use of modern methods of prototyping: 3D modeling and 3D printing by the FDM method. The cover, the electronics housing, the front panel, the housing and pulleys of the agitator shaft reducer, the brackets for the heat exchanger (refrigerator) and the rotameter for the aeration system, and many other details of the unit are also manufactured using 3D modeling and 3D printing.

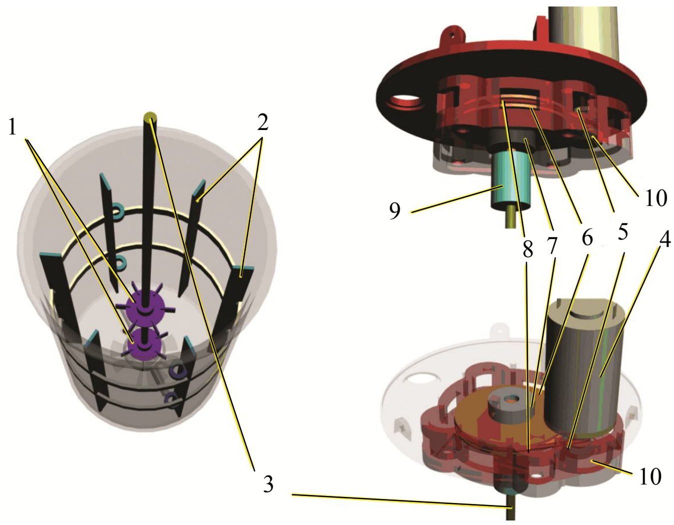

Fig.4. Pulp agitation system elements

1 – agitators of turbine type; 2 – bumpers; 3 – shaft; 4 – commutator motor; 5 – small reducer pulley; 6 – big reducer pulley; 7 – big reducer pulley bearings; 8 – reducer belt; 9 – coupler; 10 – small reducer pulley bearings

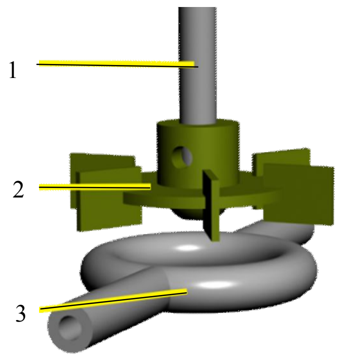

Fig.5. Pulp agitation and aeration system elements
1 – shaft; 2 – agitator of turbine type;
3 – air nozzle

The microcontroller feedback control and the presence of a reduction gearbox with a gear ratio of 1: 5 make it possible to accurately maintain the rotational speed of the pulp agitation shaft at a given level within a wide range, from 150 to 1000 rpm. The voltage applied to the windings of the motor is calculated from the current speed based on the data coming from the rotation sensor, using the proportional-integral algorithm. A slot photo-interrupter is used as a rotation sensor, it sends 1 pulse per complete revolution of the shaft.

The aeration system of the pulp (Fig. 5) consists of air supply tubes, a rotameter-regulator and a sprayer located under the agitator. The atomizer is a hollow ring with two diametrically placed underwater nozzles and 16 small diameter holes on the bottom surface. Sufficiently small air bubbles, rising to the surface, fall on the agitator's blades and, break into smaller bubbles, then they are drawn in an intense high-turbulent flow of pulp, which contributes to the intensive dissolution of gases in it.

As the gas passes through a pulp with a temperature above the surrounding medium, it is saturated with fumes (water vapor, sulfuric acid vapor), which are then removed from the reactor, the aeration system was equipped with a cooler with a forced cooling circuit to condense the vapors and return them back to the reactor. For these purposes, the reactor tank was sealed. Water in the cooling circuit is pumped by a circulation pump placed between two heat exchangers. The first heat exchanger cools the gases, the second one water transfers the heat to the Peltier elements, from which it further goes to the air radiators with fans.

The reactor is controlled through the menu on an LCD display with a text format of two 16-character lines and an incremental encoder with a button. For convenience in operation the pressing of the button and changing of the parameters of the encoder are confirmed with sound signals. The settings are saved in the NVRAM of the microcontroller and remain unchanged when the power is turned off.

The built-in SD memory card and calendar clock modules allow you to record the reactor operation parameters, such as pulp temperature, pulp agitator shaft rotation speed, ambient temperature supplied to the pulp agitation motor and the electric heating element of the voltage thermostat, at predetermined intervals. Data is saved in a file in a format suitable for later importing them into Microsoft Office Excel for analysis and plotting. In case of unintended deviation of any of the parameters from the norm, the operator's notification will be triggered by means of sending a message to one or several pre-programmed phone numbers with the date, time and value of the corresponding parameter. In addition, the same extraordinary entry will be made to the log file on the memory card.

The use of microcontroller control is especially convenient, because it allows to improve the control program in the future, thus giving the reactor new features and functions. For example, if you need to change the parameter cyclically or step by step in a certain period during a certain period of time, you can create the necessary program in advance and store it in the memory of the micro controller, and then remotely monitor the situation at any time by GSM communication and read information from the log on the memory card at any convenient time.

Conclusion. Thus, the reactor developed for the bacterial-chemical leaching of sulfide copper-nickel ores and concentrates can also be used in studies of other bacterial-chemical processes.

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