PROCESS COMPRESSION AND FLOWSHEET DEVELOPMENT FOR THE MINING AND METALLURGICAL INDUSTRY

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Abstract

Process compression is the elimination of a process step to make the process more economical. It helps in cutting the cost of production without affecting the quality of the product. Some examples of process compression are Carbon-in-Pulp process, Resin-in-Pulp process, heap leaching, in-situ leaching and development of Krebs-Mixer-Settler equipment for metal recovery. In contrast, development of a flowsheet starts with identification of raw material(s) and potential product(s) and by-product(s). First step in the development of flowsheet is to consider various process options and prepare a conceptual flowsheet. The conceptual flowsheet is then tested at bench scale for feasibility of the concept followed by pilot scale testing to optimize the operating parameters and to conduct detailed mass balance, energy balance and water balance to obtain design criteria for preliminary capital (CAPEX) and operating cost (OPEX) estimation. Before the construction and commissioning of full-scale production plant, the flowsheet can also be tested in a demonstration plant to further minimize technical, operational and financial risks.

Keywords: Process compression, flowsheet development, carbon-in-pulp, resin-in-pulp, heap leaching, in-situ leaching and Krebs-Mixer-Settler.

1. Process compression

Falling commodity prices along with rising production costs is putting a squeeze on the bottom line of the mining and metallurgical industry. In order to stay competitive, production costs need to be minimized without affecting the quality of the product. One of the innovative ways to achieve this goal is by process compression. Process compression is the elimination of a process step to make the process more economical. Many times technology available in other process industries can be applied to mining and metallurgical industry to eliminate certain process steps, if sustainable. Some examples of process compression are provided below:

1.1 Carbon-in-pulp (CIP) process

Carbon in pulp (CIP) is a part of gold cyanidation process which has been used for the recovery of gold from ores/concentrates. In this process, cyanide leach slurry containing gold is mixed with activated carbon in an agitation tank or in a counter current manner through a series of tanks. Gold cyanide complex is adsorbed on the activated carbon, which is then separated from leach slurry by screening. Figure 2 shows the typical process flowsheet for CIP process (Hill, 1986). Gold is desorbed from activated carbon by stripping and recovered by electrowinning. Carbon is reactivated and recycled to the process. CIP process minimizes costly solid/liquid separation steps.

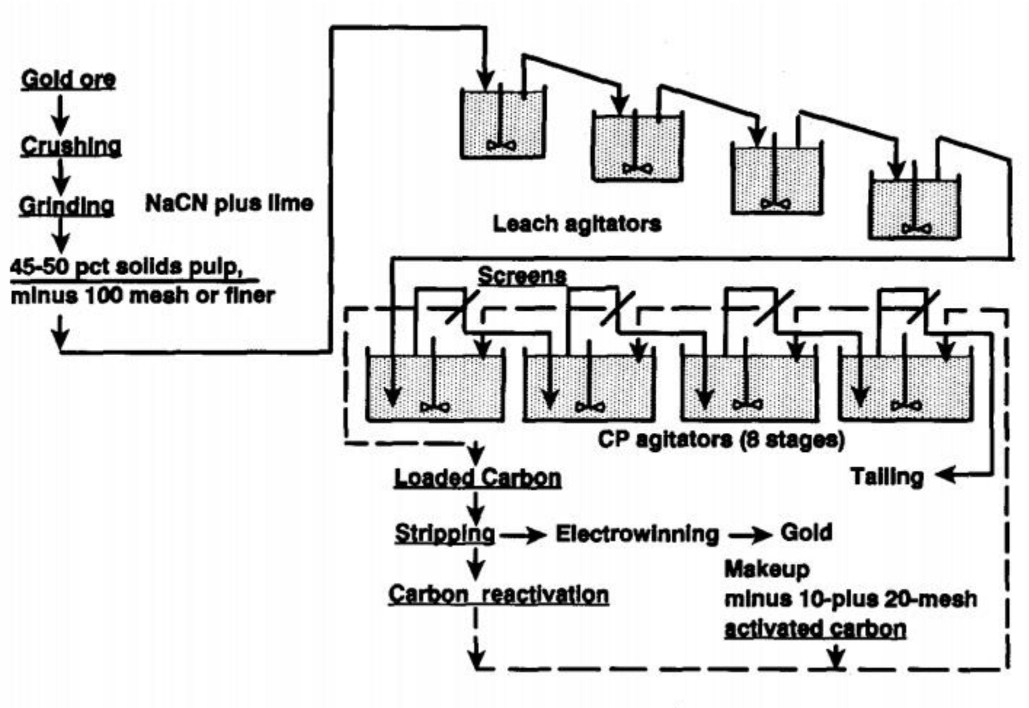

Figure 1: Typical process flowsheet for carbon in pulp (CIP) process (Hill, 1986).

1.2 Resin-in-pulp (RIP) process

Resin-in-Pulp (RIP) process is similar to the CIP process except that activated carbon is replaced by solid spherical polystyrene resin beads and has been practiced in the uranium industry. Generally, uranium ore is leached with sulphuric acid followed by solid/liquid separation to produce uranium-rich pregnant leach liquor. The leach liquor is then passed through ion exchange resin columns to extract uranium from leach liquor. The loaded uranium is removed by passing an eluting liquid through the ion exchange resin columns. Due to low grade of uranium ore, process requires separation of pregnant leach liquor from large amount of residue by filtration, which adds significantly to the process cost. In addition, resin-packed columns also involve high capital cost. In contrast, moderately coarse resin beads are mixed with pulp and separated by screening when the ion-exchange resin is loaded with uranium. This RIP process eliminates the costly filtration step and reduces capital cost by eliminating the need for ion-exchange resin columns. The RIP process has been practiced in USA, Russia, France, South Africa, China and Canada for the processing of uranium ore (Mirjalili and Roshani, 2007).

1.3 Heap leaching

Heap leaching is used for low grade ores. Ore is crushed and made into a heap on a pad. After leaching, leach liquor is pumped out for further processing. Heap leaching eliminates the need for grinding, which makes it an economical process option for the treatment of low grade ores. Heap leaching has been used for the treatment of copper, uranium, nickel, silver and gold ores. Poor recovery due to non-uniform percolation has been faced by many heap leach operations, particularly the ones with significant clay content in the ore. To overcome this problem, modern heap leach operations include agglomeration/stacking as one of the process steps before leaching. Agglomeration of ore particles results in agglomerates of similar size particles avoiding the problem of segregation. This results in uniform percolation of the lixiviant through the ore heaps. **Figure 2** shows the flowsheet of a heap leach operation (Zanbak, 2015).

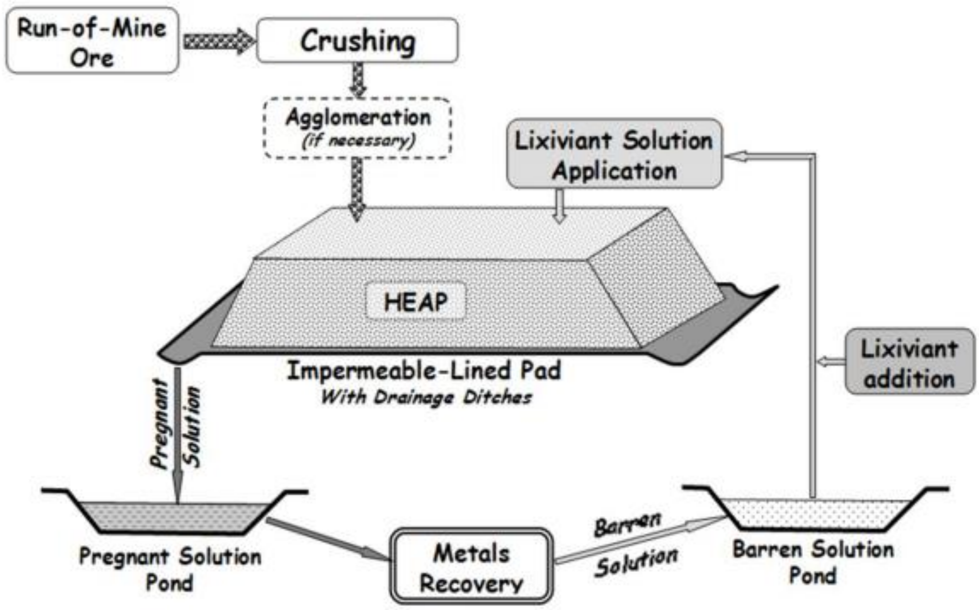

Figure 2: Flowsheet of a heap leach operation (Zanbak, 2015).

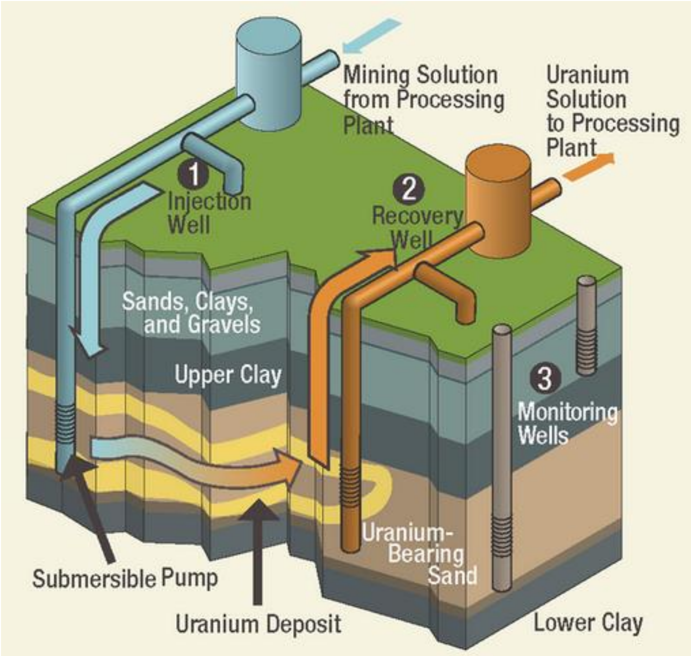

Figure 3: Flowsheet of an in-situ leach operation for uranium ore (US Nuclear Regulatory Commission, 2014).

1.4 In-situ leaching

In in-situ leaching, the leaching solution is pumped through the ore body in-situ. This leaching process eliminates the need for crushing, grinding and solid/liquid separation. In addition, in-situ leaching minimizes issues related to tailings management. Figure 3 shows the flowsheet of a in-situ leach operation for uranium ore (US Nuclear Regulatory Commission, 2014). Lixiviant, typically a solution of groundwater with sodium bicarbonate, hydrogen peroxide and oxygen, is pumped into the layer of earth containing uranium through injection wells. Uranium is leached in-situ and the pregnant leach liquor is pumped back to the surface using recovery wells. Pregnant leach liquor is sent to the processing plant to make yellowcake. Samples from monitoring wells are checked regularly to ensure that uranium and chemicals are contained within the drilling area.

1.5 Mixer-settler equipment

Krebs mixer-settler equipment eliminates the need for multiple stages with conventional mixer/settlers. The conventional mixer settler is a rectangular box with multiple stages and aqueous and organic phases flow counter-currently. Aqueous and organic phases are separated in the settling chamber by gravity and flow to adjoining stages through appropriate ports. Advantages of the conventional mixer-settler include relatively simple low cost design, stable operation, low maintenance, reliable scale-up, relatively good visibility of the process, and easy access for crud removal, while disadvantages include large settlers and footprint area, large organic inventory and lengthy piping (Taylor, 2014).

Krebs mixer-settlers have been installed in many uranium solvent extraction plants and some copper solvent extraction plants. Advantages of the Krebs mixer-settler include smaller footprint area, simplified plant layout, shorter inter-stage and recycle piping, and lower CAPEX, while disadvantages include limited access for crud removal, higher power consumption, higher reported organic entrainment and proprietary design subject to license fee (Taylor, 2014).

2. Flowsheet development

Flowsheet should be economically viable and environmentally sustainable. A new flowsheet may be required if the type of ore changes. As non-refractory gold ores are exhausted, the need to extract gold from refractory and double refractory ores has arisen. Gold producing companies are responding to the challenge by developing new flowsheets for processing refractory and double refractory ores. A new flowsheet may also be necessitated to comply with stricter environmental regulations. A new flowsheet for production of zinc using pressure hydrometallurgy was developed to avoid the emission of sulphur dioxide resulting from the roasting of zinc. A new flowsheet may become feasible with advances in materials of construction. The development of polymeric materials has led to development of flowsheets with aggressive lixiviants such as chlorides.

Development of a flowsheet starts with identification of raw material(s) and potential product(s) and by-product(s). First step in the development of flowsheet is to consider various process options and prepare a conceptual flowsheet. The conceptual flowsheet is then tested at bench scale for feasibility of the concept, to obtain a good understanding of the process chemistry and to investigate the operating parameters. The pilot scale test work is then performed to optimize the operating parameters and to conduct detailed mass balance, energy balance and water balance to obtain design criteria for preliminary capital costs (CAPEX) and operating costs (OPEX) estimation. Pilot scale test work also generates samples for market evaluation and testing for compliance to environmental regulations. A demonstration plant may be commissioned to test the process before the construction and commissioning of full-scale production plant. Running a demonstration plant provides an opportunity to further minimize technical, operational and financial risks.

2.1 Initial Conceptualization

A key to successful flowsheet development is to ensure that the feed materials tested are representative of what will be processed in the commercial process. The preliminary activity for development of an innovative process flowsheet is to carry out the following desktop investigation to identify potential process options (Lakshmanan et al., 2015).

- Mineralogical characterization of the feed material;
- Physical, chemical or thermal separation techniques;
- Evaluating the whole range of physical characteristics including:
    - particle size;
    - specific gravity;
    - magnetic; and
    - flotation;
- Evaluation of chemical separation techniques including:
    - acid/base treatment and, for each, a range of different chemicals;
    - temperature and pressure;
    - ion exchange and solvent extraction for solution purification;
    - precipitation and electrolysis for final product generation;
- Evaluating the thermal separation techniques including:
    - roasting;
    - smelting;

The evaluation of different process options will typically include a database search for existing operations of a similar nature, but for different products. Once a number of potential process options are identified, then testing of the processes is required to establish which of them offers the potential to be viable.

2.2 Bench Scale Testing

Bench scale testing is conducted to understand the process chemistry involved and to investigate the operating parameters for the process. This phase applies to the development of both existing and new innovative processes. However, for existing processes, there is a historical background that provides a good starting basis for selecting the optimal operating conditions, whereas for innovative processes, it is necessary to start at a more preliminary stage thereby increasing the amount of work required. In bench scale study, a large number of tests can be carried out quite readily to investigate a wide range of operating parameters for a modest cost while the number of process options that need to be taken forward for further evaluation at the pilot plant scale can also be reduced. This study is typically performed by testing organizations that are well-established with the required equipment, analytical facilities and personnel.

2.2.1 Scoping study

First step in the bench scale test work is to carry out a scoping study. In this stage, key steps of the conceptual flowsheet are tested using selected process parameters. For example a hydrometallurgical conceptual flowsheet involves crushing, grinding, acid leaching, solvent extraction and precipitation. For this case, a limited number of bench scale leaching tests will be carried out at certain grind sizes and acid concentrations to evaluate the recoveries of elements of interest. If the recoveries are poor, then a decision has to be made whether a new conceptual flowsheet is required or few more tests are to be conducted by varying process parameters further. If the recoveries are acceptable, few more tests may be conducted by varying process parameters to improve the recoveries of elements of interest. A fixed number of leaching tests are then conducted using the selected process parameters to generate enough pregnant leach liquor to be used for solution purification such as solvent extraction or ion exchange. Now a limited number of solvent extraction tests will be conducted with an organic phases at different contact times and organic/aqueous ratios to evaluate the recoveries of elements of interest. If the recoveries are acceptable, a limited number of precipitation tests will then be conducted at different precipitation temperatures. At the end of scoping tests, it will either be decided that conceptual flowsheet is not feasible or a preliminary flowsheet will be constructed, which will be further defined during detailed bench scale test work.

2.2.2 Detailed bench scale testing

Extensive testing is conducted in detailed bench scale study to investigate the effect of process variables and to optimize the process. The bench scale tests are typically carried out on a batch basis. The problem with batch testing is that it does not investigate the impact of recycle streams. One way that is used to overcome this problem for hydrometallurgical operations is to set up a mini scale continuous circuit with the necessary streams recycled as required. It is particularly useful to start developing a computer model of the process at this stage and to progressively incorporate the results of the test work into the model. The model can also be used to investigate some different possible flowsheet options and to provide direction to the test work program. At the end of detailed bench scale test work, a detailed process flowsheet is constructed, which is tested under continuous operation at a much larger scale than bench scale test work during pilot scale test work.

2.3 Pilot Plant Testing

In pilot plant study, the circuit is set up to operate the plant continuously in order to confirm the flowsheet developed during detailed bench scale testing. There is no standard size for a pilot plant, but, obviously, the larger the plant, the larger the quantity of sample required for the test work program. Data generated during the pilot plant run is used to make process flow diagram and carry out detailed mass, energy and water balances, which form the basis for estimating capital and operating costs and developing plant design criteria. Pilot scale test work also generates samples for product evaluation and testing for compliance to environmental regulations.

Pilot plant testing is usually carried out at the facilities of established metallurgical testing organizations as they have a large inventory of small process equipment items that can be installed to form a representative circuit. Also, the organizations have the required analytical facilities and the operating staffing that are required for a continuous pilot plant operation working 24 hours/day. Solid-liquid separation is typically a very important part of both mineral processing and hydrometallurgical processes and so it is essential that settling and filtration test work be carried out on samples from the pilot plant. The samples should be fresh to obtain the most realistic results, so it is usual that the solid-liquid separation tests are performed at the facility where the pilot plant campaign is being carried out. The solid-liquid separation test work is typically performed by vendors of this type of equipment or by organizations that specialize in this type of test work.

Running a pilot plant is a very important step towards reducing the risk of any unforeseen complication in operating the actual plant. It provides an opportunity to minimize technical, operational and financial risks. Pilot plant can be run with a variety of feed stocks and under different operating conditions to check the robustness of the flowsheet. Pilot plant can also be used for training the employees for full scale production plant. After the pilot scale test work is completed, next step could be either the construction of a full scale production plant or a demonstration plant.

2.4 Demonstration Plant

A demonstration plant is often required for an innovative process for verification of the metallurgical characteristics and the equipment required including materials of construction, and special designs. Once again, there is no standard size for a demonstration plant. Some of the factors that influence the capacity and degree of complexity of the demonstration plant are as follows:

- concerns regarding the scaling-up of the process from the pilot plant to the commercial plant capacity;
- size required to satisfy the requirements of financing organizations;
- ability to produce sufficient product to supply samples to potential users;
- concerns with the process consistently producing a product of satisfactory quality;

Development of an innovative process will often require the construction of a demonstration plant. As the process is not well established, it may require specialized equipment and design and it may be a good idea to test the process at demonstration scale before the construction and commissioning of full-scale production plant. Running a demonstration plant provides an opportunity to further minimize technical, operational and financial risks.

3. Summary

Process compression helps in reducing the cost of production by eliminating process step without affecting the quality of the product. For example sustainable resin-in-pulp and similar carbon-in-pulp processes have been developed to recover uranium and gold from low-grade ore bodies, where resin and pulp are contacted counter-currently in a series of agitated contactors. The loaded resin is separated from the pulp over screens, washed, and transferred to elution. The eluted resin is then returned to the adsorption circuit. This process provides an attractive and economical option by avoiding solid/liquid separation step, which is usually problematic. This also reduces the wash water volume and minimizes the loss of value metals.

Flowsheet should be economically viable and environmentally sustainable. Flowsheet needs to be robust and forgiving. It should be viable for a wide range of parameters. First step in the development of flowsheet is to prepare a conceptual flowsheet by considering various process options. The conceptual flowsheet is then tested at bench scale for feasibility of the concept, to obtain a good understanding of the process chemistry and to investigate the operating parameters. The pilot scale test work is then performed to optimize the operating parameters and to obtain design criteria for preliminary capital costs (CAPEX) and operating costs (OPEX) estimation. Pilot scale test work also generates samples for market evaluation and testing for compliance to environmental regulations. A demonstration plant may be commissioned to test the process before the construction and commissioning of full-scale production plant. Running a demonstration plant provides an opportunity to further minimize technical, operational and financial risks.

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