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7.1 Introduction

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.

7.2 Carbon-in-Pulp (CIP) Process

In CIP process, cyanide leach solution 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

separated from leach slurry by screening. CIP process minimizes costly solid/liquid separation steps.

Figure 7.1 shows the world gold production by recovery method in 2004 (Marsden 2006). CIP and CIL (carbon-in-leach) processes accounted for ~42 % of worldwide production in 2004. Separate estimates for CIP and CIL were not made as it had become difficult to make a clear distinction between these two processes as same plants had started using equipments for both processes.

Figure 7.2 shows the typical process flowsheet for CIP process (Hill 1986). The ore is crushed and ground to -100 mesh. It is then leached in cyanide at 45–50 % solids. Lime is added during leaching for maintaining the alkalinity of sodium cyanide. This is followed by counter-current carbon-pulp contact during which gold is adsorbed on activated carbon. Loaded carbon is then separated from pulp by screening. Gold is desorbed from activated carbon by stripping and recovered from preg strip liquor by electrowinning. Carbon is reactivated and recycled to the process.

7.3 Resin-in-Pulp (RIP) Process

RIP process is similar to the CIP process except that activated carbon is replaced by solid spherical polystyrene resin beads and has been

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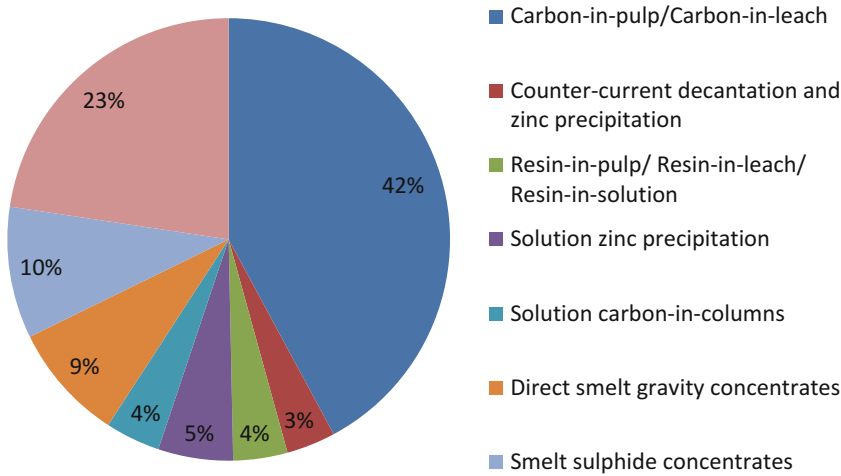


Fig. 7.1 World Gold production by recovery method in 2004, adapted from Marsden (2006)

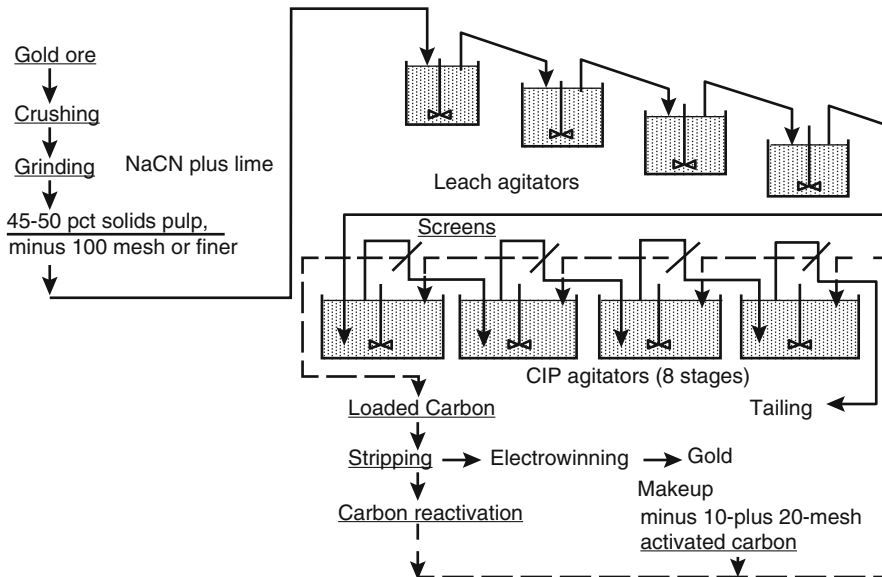


Fig. 7.2 Typical process flowsheet for CIP process (Hill 1986)

practiced in the uranium industry. Similar to the CIP process, Resin-in-Pulp (RIP) process minimizes costly solid/liquid separation steps. Traditionally, uranium ore is leached with sulfuric acid to produce uranium-rich pregnant leach liquor. The leach liquor is passed through ion-exchange resin columns, which remove uranium from leach liquor by forming a complex uranium anion. After resin is fully loaded, uranium is removed from the ion-exchange resins by passing

an eluting liquid through the ion-exchange resin columns. Regenerated ion-exchange resin is then used to treat fresh batch of uranium-rich pregnant leach liquor. 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. The RIP process eliminates the costly filtration step and reduces capital cost by

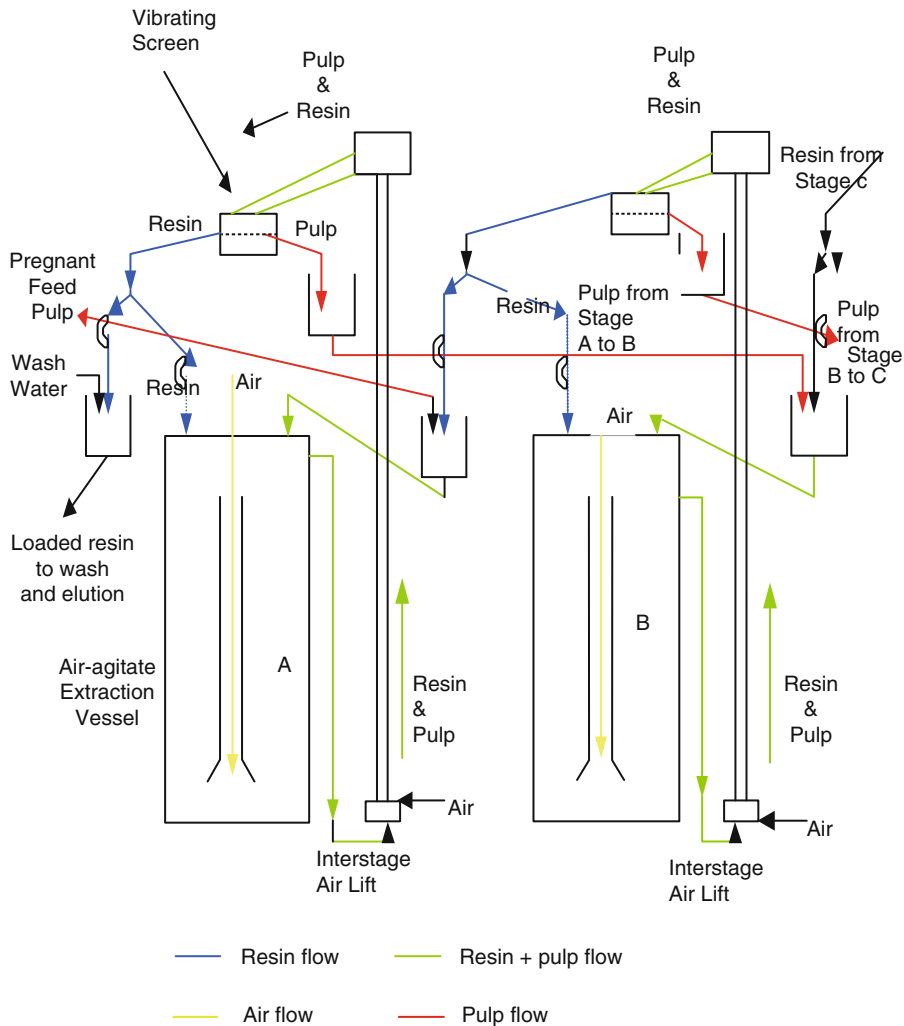


Fig. 7.3 Agitated vessel RIP process (Makhubela 2006)

eliminating the need for ion-exchange resin columns. Instead, moderately coarse resin beads are mixed with pulp and separated by screening when the ion-exchange resin is loaded with uranium. The RIP process is practiced in the USA, Russia, France, South Africa, China, and Canada for the processing of uranium ore (Mirjalili and Roshani 2007).

Figure 7.3 shows the schematic of a typical RIP process used in uranium industry (Makhubela 2006). Pulp and resin are mixed in an air-agitated extraction vessel and then pumped to a vibrating screen, which separates pulp from resin. Pulp flows to the next stage where it is again mixed

with resin. Loaded resin passes through a resin splitter, which returns a fraction of loaded resin to the same tank to increase resin residence time. Rest of the loaded resin is then washed and eluted in elution columns.

7.4 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

Fig. 7.4 Heap leach operating cost distribution (Dhawan et al. 2013)

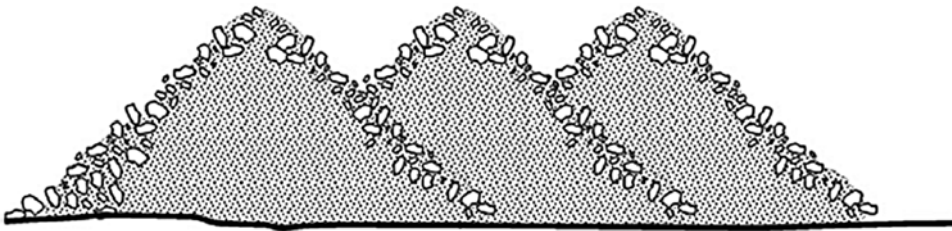
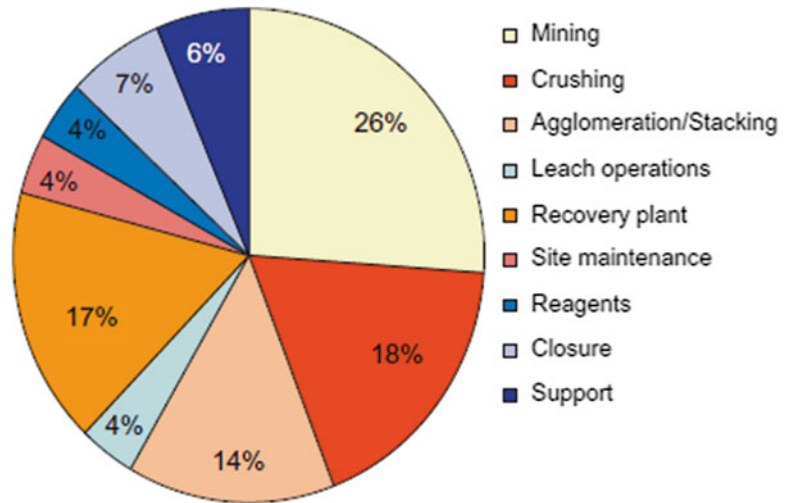


Fig. 7.5 Improper heap building resulting in segregation of coarse and fine particles (Dhawan et al. 2013)

process option for the treatment of complex 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. As shown in Fig. 7.4, agglomeration/stacking cost is about 14 % of the total cost of heap leach operation (Dhawan et al. 2013). Improper heap building can result in segregation of coarse and fine particles as shown in Fig. 7.5, which will result in poor recovery due to non-uniform percolation of the lixiviant through the ore heaps (Dhawan et al. 2013). 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 as shown in Fig. 7.6 (Dhawan et al. 2013).

Figure 7.7 shows the flowsheet of a heap leach operation (Zanbak 2012). Run-of-mine ore is crushed, agglomerated, if necessary, and made into a heap on an impermeable lined pad. It is then heap leached by passing the lixiviant solution from the top. As the lixiviant solution percolates through the heap under gravity and atmospheric conditions, leaching process may take several weeks to few months for completion. Pregnant leach solution is collected in a pond and goes for metal recovery. Pregnant solution pond is lined with double layer of composite liners and fitted with leak detection pipes and pumps for the purpose of environmental protection. Barren solution is collected in a barren solution pond, which is recycled for leaching after making up for the lixiviant.

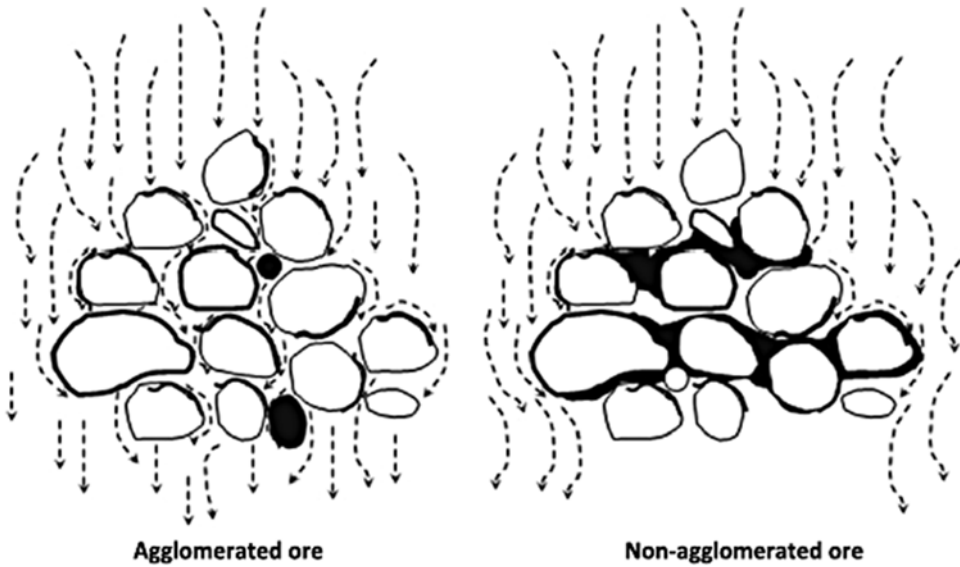


Fig. 7.6 Solution percolation in agglomerated vs. non-agglomerated ore (Dhawan et al. 2013)

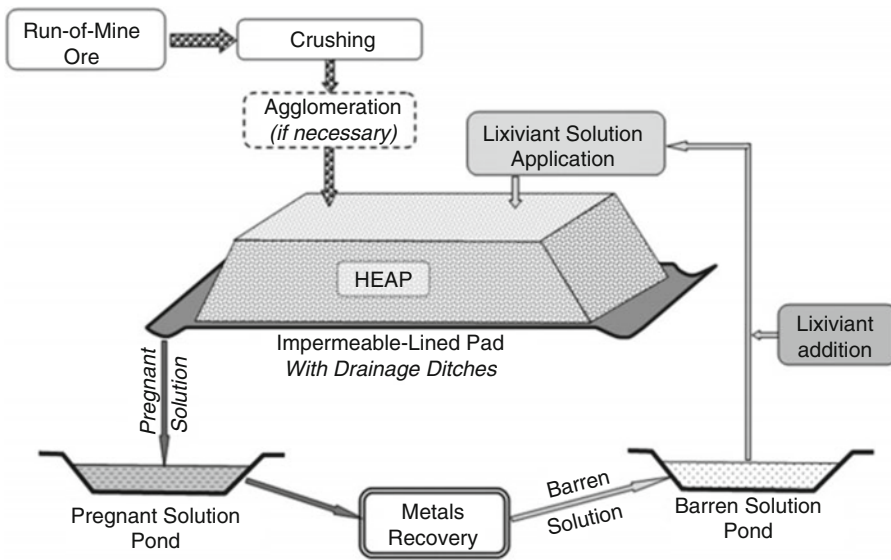


Fig. 7.7 Flowsheet of a heap leach operation (Zanbak 2012)

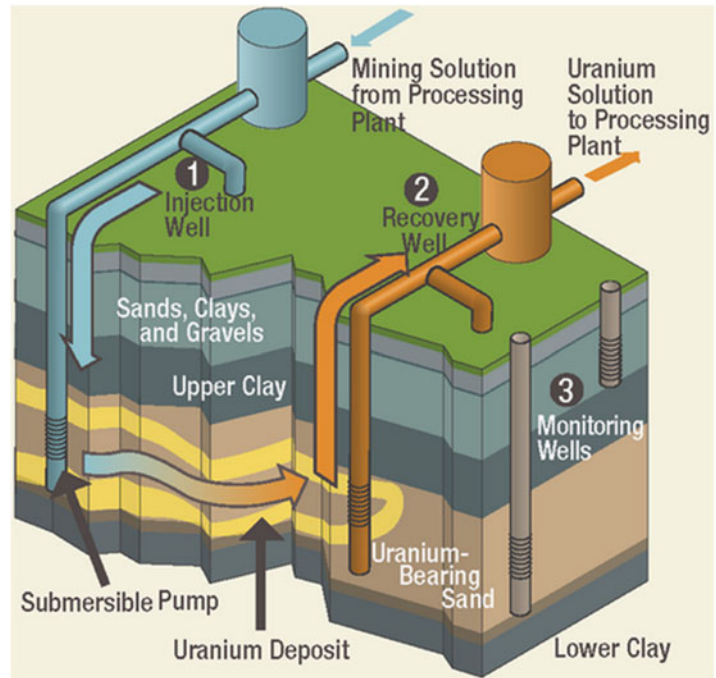
7.5 In-Situ Leaching

In in-situ leaching, the leaching solution is pumped through the ore body in-situ. In-situ leaching eliminates the need for crushing, grinding, and solid/liquid separation. In addition, in

situ leaching minimizes issues related to tailings management.

Figure 7.8 shows the flowsheet of a heap leach operation for uranium ore (US Nuclear Regulatory Commission. Information Digest 2013–2014). Lixiviant, typically a solution of groundwater with sodium bicarbonate, hydrogen

Fig. 7.8 Flowsheet of an in situ leach operation for uranium ore (US Nuclear Regulatory Commission. Information Digest 2013–2014)



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.

7.6 Mixer-Settler Equipment

Krebs mixer-settler equipment eliminates the need for multiple stages with conventional mixer/settlers. Figure 7.9 shows the schematic of an early prototype of a conventional mixer-settler (Knapp et al. 1958). The mixer settler is a rectangular box with multiple stages. Each stage is divided in two chambers: antechamber and a settling chamber. A mixing chamber is suspended in the antechamber using an overhead clamp. An impeller is provided in each mixing chamber for mixing the aqueous and organic phases. Aqueous

and organic phases flow counter-currently through different stages. Aqueous phase from next stage and organic phase from previous stage enter the antechamber through underflow and overflow ports, respectively. Both phases flow into mixing chamber and are mixed by an impeller. Mixed phases flow into the settling chamber through an overflow arm. 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 2007).

Krebs mixer-settler was developed by Krebs in France in 1970s. These mixer-settlers have been installed in many uranium solvent extraction plants and some copper solvent extraction plants. Figure 7.10 shows the schematic of a

Fig. 7.9 Schematic of conventional mixer-settler (Knapp et al. 1958). (1) Mixing chamber, (2) antechamber, (3) heavy phase underflow port, (4) settling chamber, and (5) light phase overflow port

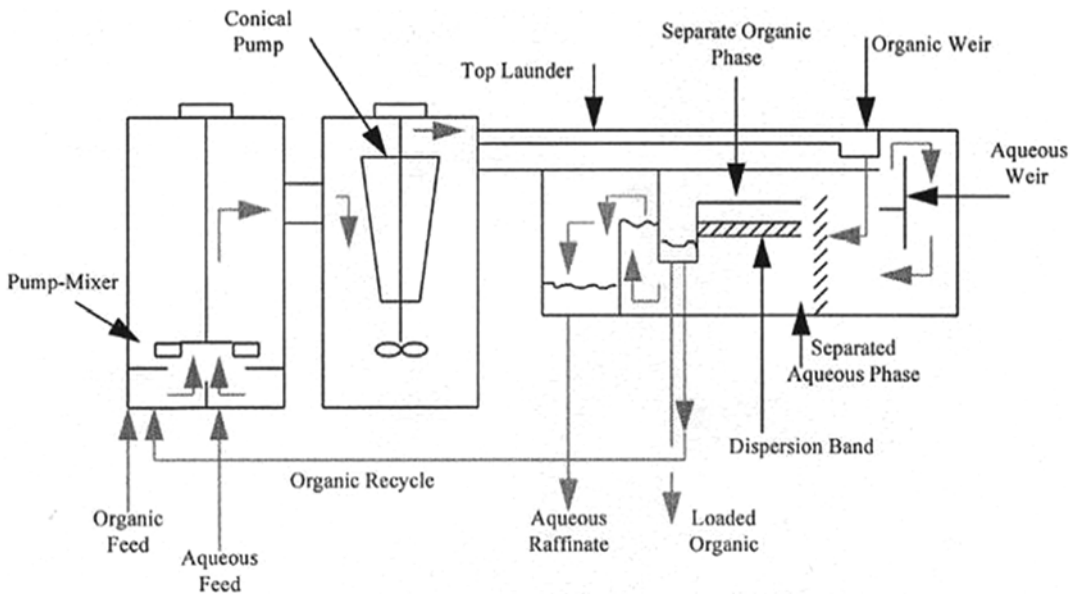
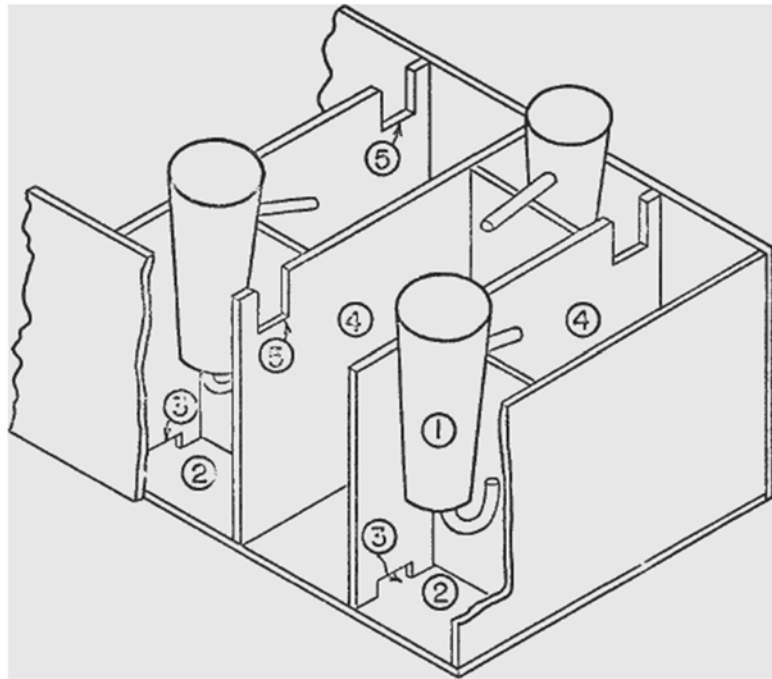


Fig. 7.10 Krebs mixer-settler elevation view (Taylor 2007)

Krebs mixer-settler (Taylor 2007). Organic and aqueous feeds pass through a pump mixer into an agitator, which is fitted with a low head, high volume, low shear conical pump. The pump consists

of a static tulip-shaped stator and a six-bladed rotor. The conical pump is used to develop the head to lift the dispersion of organic and aqueous phases to the top launder. As the dispersion

moves through the top launder, the primary separation of the organic and aqueous phases takes place. The organic and aqueous phases are then directed separately to the main settler below via a baffle system on one end. Loaded organic and aqueous raffinate are discharged from the main settler at the other end.

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 2007).

References

- Dhawan, N., Safaradeh, M. S., Miller, J. D., Moats, M. S., & Rajamani, R. K. (2013). Crushed ore agglomeration and its control for heap leach operations. *Minerals Engineering*, 41, 53–70.
- Hill, S. D. (1986). *The carbon-in-pulp process* (U.S. Bureau of Mines Information Circular No. 9059), pp. 40–43.
- Knapp, L., Schoenherr, R., Barghusen, J., & Smutz, M. (1958, January). *A polyethylene box-type mixer-settler extractor*. United States Atomic Energy Commission. Research and Development Report. Unclassified.
- Makhubela, T. R. (2006). *Base metal recovery by resin-in-pulp technology*. Master of technology thesis, Chemical Engineering, Tshwane University of Technology, Pretoria, South Africa, January 2006, based on Streat, M., & Naden, D. (1987). *Critical reports on applied chemistry*. (Vol. 19, pp. 1–50). New York: Wiley.
- Marsden, J. O. (2006). Overview of Gold processing techniques around the world. *Minerals and Metallurgical Processing*, 23(3), 121–125.
- Mirjalili, K., & Roshani, M. (2007). Resin-in-pulp method for uranium recovery from leached pulp of low grade uranium ore. *Hydrometallurgy*, 85, 103–109.
- Taylor, A. (2007). *Review of mixer-settler types and other possible contactors for Copper SX*. ALTA Metallurgical Services. Retrieved August 30, 2014, from <http://www.altamet.com.au/wp-content/uploads/2012/12/Review-of-Mixer-Settler-Types-and-Other-Possible-Contactors-for-Copper-SX.pdf>.
- US Nuclear Regulatory Commission. Information Digest. 2013–2014 (NUREG-1350, Volume 25). Section 4. Nuclear materials. Retrieved September 6, 2014, from http://en.wikipedia.org/wiki/In_situ_leach#mediaviewer/File:NRC_Uranium_In_Situ_Leach.png.
- Zanbak, C. (2012, November). *Heap leaching technique in mining*. Retrieved May 29, 2015, from <http://www.euromines.org/files/mining-europe/mining-techniques/batforheappleaching-feb2013-c.zanbak-euromines.pdf>.