ALTA

REVIEW OF MIXER-SETTLER TYPES AND OTHER POSSIBLE CONTACTORS FOR COPPER SX

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CONTENTS

1. INTRODUCTION

Historically the conventional mixer-settler has been the workhorse of copper solvent extraction (SX) operations. However, a number of other designs have been commercialized, and are gaining in popularity in recent years. These include:

- Krebs
- Reverse flow
- Outokumpu VSF

Other mixer-settler designs which have been used commercially for applications outside of copper such as uranium include:

- CMS
- Lurgi
- IMI
- Kerr-McGee

There have also been some mixer-settler designs which have been piloted but did not reach the commercial scale. Examples are:

- Circular Segmented
- Electrostatic

Column and centrifugal contactors have not when found favour for copper, though they have been used for other applications such as such the separation and extraction of nickel-colbalt, uranium and zircinium-hafnium.

- Pulsed column
- Karr reciprocating plate column
- Oldshue-Rushton (Mixco) column
- Podbielniak centrifugal contactor

2. MIXER-SETTLERS TYPES USED IN COMMERCIAL COPPER SX PLANTS

Mixer-settlers were first utilised in the nuclear industry because of their low headroom, which minimized the amount of shielding required. Other attractive features included simplicity and low maintenance. Typically, the nuclear mixer-settlers consisted of partitioned “boxes” to avoid interstage piping, and relied on density differences to provide driving force for liquid flows. Based on this, they became a natural choice for SX circuits in uranium ore processing plants in the nineteen fifties and sixties followed by the initial copper SX plants in the late nineteen sixties and early seventies. Since then the use of mixer-settlers has been standard practice for copper SX due to their simplicity, ease of operation, stability under a wide range of flows, accessibility for clean-out, reliable scale-up and suitability for very large scale plants. Consistent effort has been made to improve efficiency and reduce capital and operating costs for the basic design, which has led to the development of new designs.

2.1. CONVENTIONAL MIXER-SETTLER

Organic phases are contacted in mix boxes typically equipped with slow speed, large diameter, low shear pump-mixer type agitators, which provide interstage pumping as well as mixing. Pump-mixers commonly have variable speed drives, and are designed to avoid fine droplet formation and air entrainment which hinder coalescence in the settlers. Auxiliary mix boxes with agitators can be used for large plants to avoid mixing inefficiencies which can occur with large mix boxes, and to achieve a lower profile.

In the adjoining settler, the phases coalesce and separate by gravity, and are removed via separate weir boxes. The overall solution level is generally set by a fixed organic weir, while the depth of the top organic layer is set by an adjustable aqueous weir or by an adjustable sleeve on the discharge pipe in the aqueous weir box.

The mix boxes can be operated either with the organic or the aqueous as the continuous phase. Typically organic continuous is used for the final extraction and first stripping stages as it generally results in lower organic entrainment in the raffinate and strong electrolyte streams respectively. Aqueous continuous is commonly, though not exclusively, used for the other stages. An organic or recycle stream from the settlers back to the mix boxes is commonly incorporated to obtain and maintain the operating phase ratio in the mix-boxes required for stable operation at the specified phase continuity.

Mix boxes can be cylindrical or "square"; settlers are generally rectangular (though circular settlers have been used). Mix box retention times are typically 2-3 minute for extraction units, and 2 minutes for strip units. Devices such as flow distributors, picket fences and various coalescence aids are installed in the settler to improve performance.

Phase separation rates in the settlers are relatively slow, and the specific area is typically 3–5 m^3/h (of combined aqueous and organic) per m^2 of settler area, depending on operating temperature, aqueous feed composition and concentration of extractant in the organic phase.

Materials typically used include:

- Self supporting stainless steel (higher alloys considered for chloride levels > 1 g/L).
- Concrete lined with stainless steel (higher alloys considered for chloride levels > 1 g/L).
- Self supporting FRP.
- Concrete lined or coated with FRP.
- Concrete lined with HDPE.

Covers are generally fitted for outdoor units to minimize organic evaporative losses, keep out dust and minimize heat loss.

Extensive ongoing development work has been carried out on numerous aspects of the conventional mixer-settler to improve performance, and reduce capital and operating costs. These include:

- Mix box feed arrangements.
- Mix box anti-vortex baffles.
- Multiple mix boxes.
- Design of pump-mixers and auxiliary agitators.
- Settler feed systems.
- Design, number and location of picket fences in the settler.
- In-settler baffles to accelerate coalescence and reduce entrainment.
- In-settler packing to accelerate coalescence and reduce entrainment.
- Settler configuration including depth and floor slope.
- Settler design velocities.
- Design of settler discharge weirs to minimize turbulence.
- Design of settler weir boxes and recycle systems.
- Settler crud removal systems.

Figure 1 shows a typical two mix box arrangement set up for aqueous phase recycle.

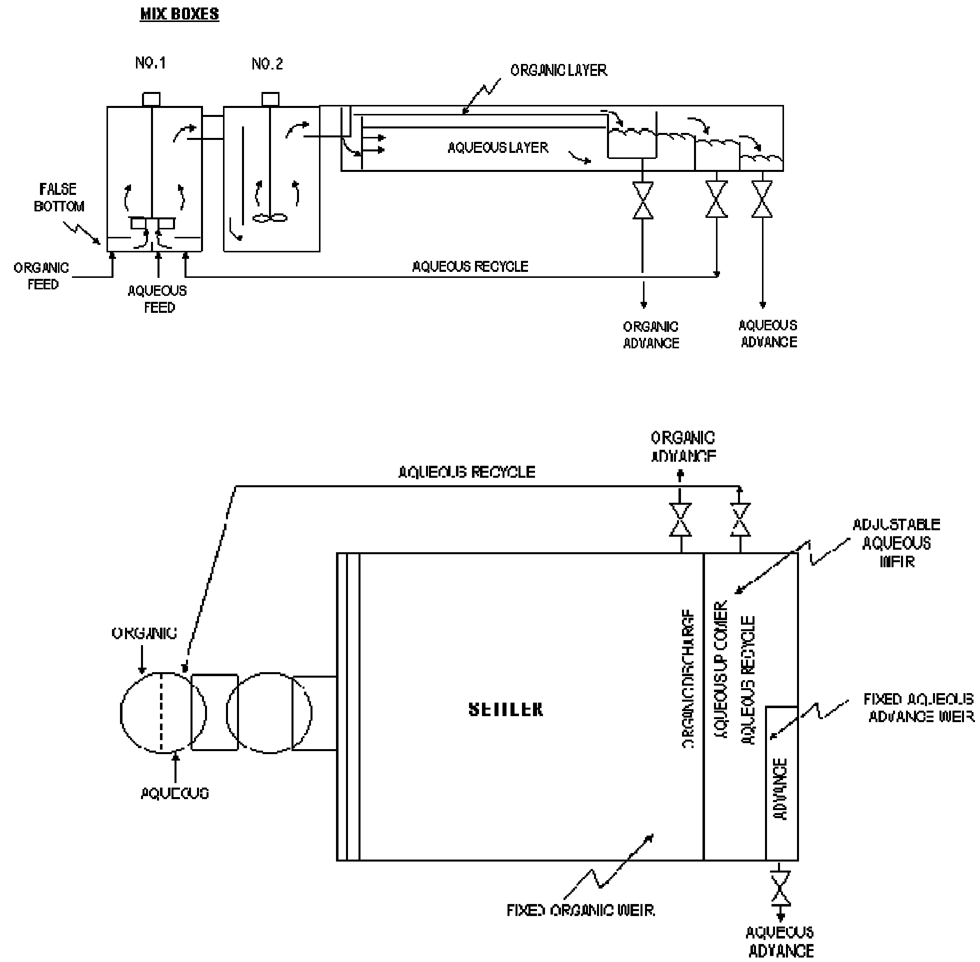

Fig.1: Conventional Mixer-Settler Elevation and Plan Views

Advantages include:

- Relatively simple low cost design.
- Generally stable, robust and predictable operation.
- Low maintenance.
- Reliable scale-up from small scale test units.
- Can handle a wide range of flow rates and large turn down.
- Self regulating pump-mixers avoid need for interstage level control.
- Relatively good visibility of the process for operators.
- Relatively simple to control pH and other operating conditions in the various stages.
- Easy access for crud removal.
- Low profile means low solution pump heads and minimizes roof heights for indoor construction.

Disadvantages include:

- Large settlers needed to separate organic and aqueous between stages.
- Large footprint area.
- Large organic inventory.
- Lengthy piping runs due to mix boxes being located at alternative ends of settlers.

- Large diameter interstage piping needed to minimize pressure drop because of limited head generated by pump-mixers.
- Crud tends to collect in settlers, requiring periodic removal to avoid process upsets.
- Not suitable for systems with a large number of stages.

2.2. KREBS MIXER-SETTLER

Developed by Krebs in France in the nineteen seventies, and subsequently installed in numerous uranium and a fewer number of copper SX plants including the initial Olympic Dam operation in South Australia which came on stream in 1993. (The later expansion used conventional mixer-settlers for copper SX.)

Like the conventional mixer-settler, there can be one or more mix boxes per stage depending on the solution flow rates and the required retention time. For a single box, the agitator is fitted with a low head, high volume, low shear conical pump, consisting of a static tulip shaped stator and a trapezoidal, typically six bladed, rotor. This is used to develop the head to lift the dispersion up to the pre-separation launder positioned above the settler. If two mix boxes are used, the first is equipped with a pump-mix type agitator, similar to the conventional mixer-settler, but designed for less head generation because of the adjoining conical pump.

Typically the primary separation of the organic and aqueous phases is 90% complete at the discharge of the upper launder, which enables the phases to be directed separately to the main settler below, entering via a baffle system. The organic and aqueous discharge weir boxes and weirs are similar to the conventional design.

Materials of construction options are similar to the conventional design. However, because of its smaller size, there is greater opportunity for shop fabrication and transport to site. The unit is totally covered to keep dust out and minimize organic evaporative losses.

Fiure 2 illustrates a Krebs mixer-settler with two mix boxes, arranged for organic phase recycle

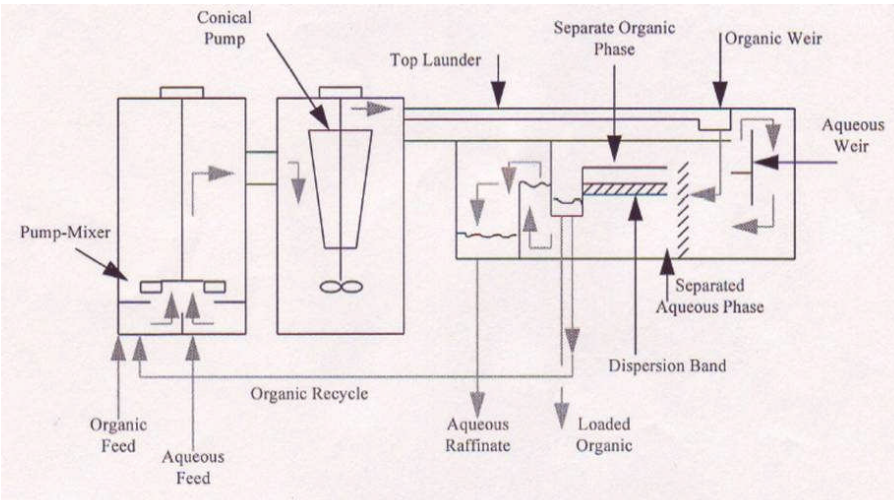

Fig. 2: Krebs Mixer-Settler Elevation View

Table 1 presents an economic comparison with the conventional mixer-settler taken from from 'Krebs and Solvent Extraction" by Roger Williams and Alain Sonntag presented at the ALTA Copper Hydrometallurgy Forum 1995.

Characteristics	KREBS	CONVENTIONAL
Typical settler specific flow $m^3/h/m^2$	8-12	3 - 5
Relative solvent inventory	1	1.3 – 1.5
Organic entrainment losses ppm	30 – 100	30 - 100
Relative Capital Costs		
Equipment ex works	1	1 – 1.2 (depending on size)
Transportation/Erection	1	1.3 – 1.5
Piping/Cables	1	1.3
Civil work – outdoor	1	1.2
– indoor	1	1.8-2

Table 1: Comparison of Krebs with Conventional Design*

***Notes:** 1. Some operations have reported higher organic entrainment losses for Krebs.

2. License fee for Krebs design must be taken into account in the capex comparison.

Advantages include:

- Smaller footprint area.
- Smaller building for indoor plants.
- Simplified plant layout.
- All piping at one end
- Shorter interstage and recycle piping.
- Fewer pipe trenches needed for large plants.
- Reduced instrumentation and electric cabling runs.
- More convenient layout for operators.
- Lower capex.

Disadvantages include:

- Top launder limits access for crud removal and maintenance.
- More difficult for operators to visibly monitor internal operating conditions.
- The pumping function introduces additional power consumption.
- Some operations have reported higher than predicted organic entrainment, said to be due to the conical pump.
- Proprietary design subject to licence fee.

2.3. REVERSE FLOW MIXER-SETTLER

The reverse flow concept is being increasingly used in large scale copper, nickel/cobalt and zinc SX operations since the mid-nineteen nineties. It is now available through a number of engineering firms as an alternative to conventional mixer-settlers.

The main difference from the conventional mixer-settler is the use of a side mounted launder to direct the dispersion from the mix boxes to the opposite end of the settler via turning vanes which redirect the flow across the width of the settler. The mix boxes and settler are essentially same as conventional units.

Figure 3 shows a plan view schematic of the reverse flow concept.

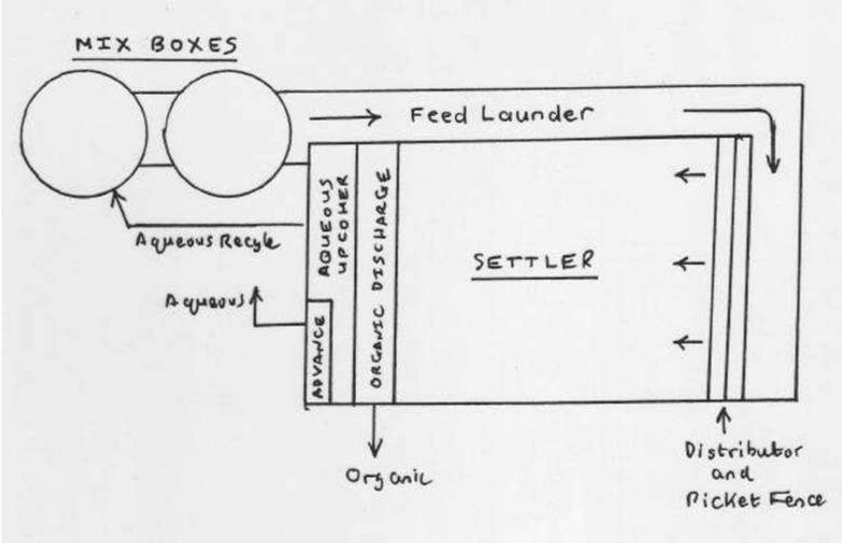

Fig. 3: Plan View of Reverse Flow Mixer-Settler

Advantages include:

- The discharge weirs, piping and valves are all at one end, thus gaining similar advantages to the Krebs design over the conventional design.
- Some phase separation occurs in the launder.
- Provides for distribution of the dispersion across the settler width.
- Has similar access and operator viewing advantages as conventional design.
- Offers some capex advantage over conventional mixer-settlers.

Disadvantages include:

- Larger foot print, larger organic inventory and longer interstage piping than the Krebs design.
- Similar size based disadvantages as the conventionl design.

2.4. VSF (VERTICAL SMOOTH FLOW) MIXER-SETTLER

Proprietary mixer-settler design developed by Outokumpu. It originated in the nineteen seventies in the Kokkola cobalt plant in Finland, and has been adopted for a growing number of large scale copper SX projects since 1995.

Mixing and pumping actions of the conventional pump-mixer are split between a DOP pumping impeller and one or more double helix SPIROK mixers which provide relatively low shear agitation.

The dispersion enters the settler via a central vertical uptake and flows through a primary distributing fence, followed by two sets of non-jetting picket fences. The settler depth gradually increases towards the weir boxes at the discharge end to decrease velocities and reduce entrainment.

If aqueous recycle is required, it is taken from a header located part way down the length of the settler. Organic recycle is taken from the side of the organic weir box.

Figure 4 shows a schematic with two mix boxes as well as the DOP bpx.

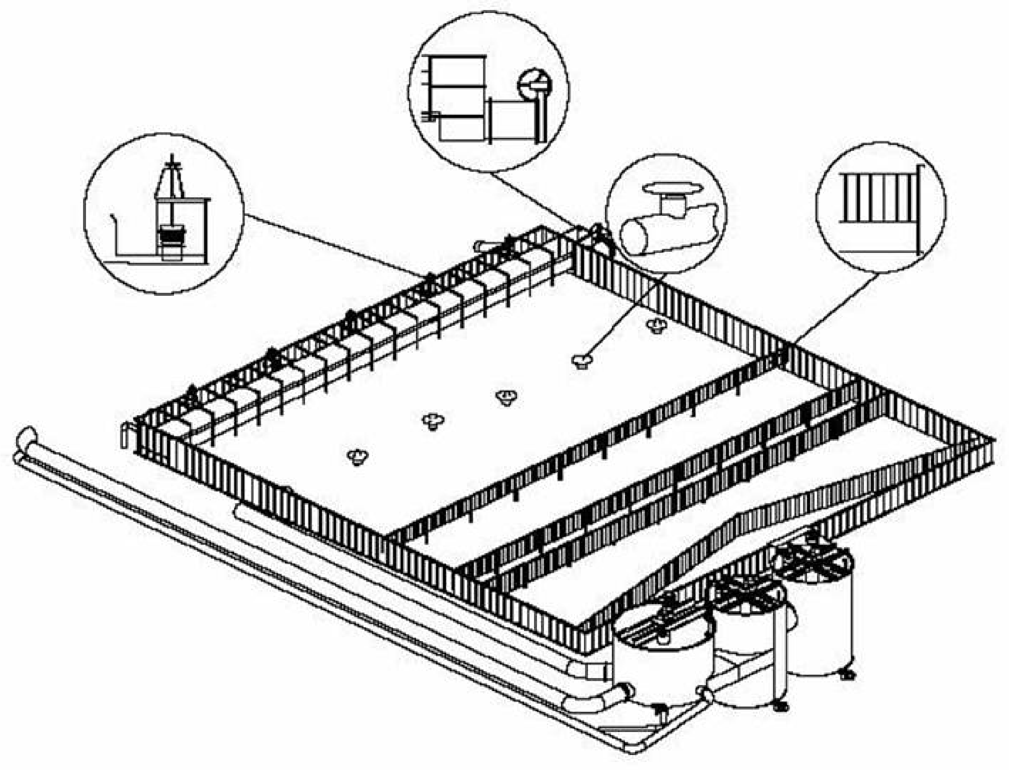

Fig. 4: Schematic of VSF Mixer-Settler

Advantages include:

- Reduced entrainment due to low shear, uniform drop size, and the deep settler discharge end.
- Reduced crud formation due to gentler mixing.
- High stage efficiency.
- Suitability for very large capacity units.

Disadvantages include:

- Higher capex than conventional mixer-settlers.
- Similar size based disadvantages as the conventionl design.
- License fee payable.

3. MIXER-SETTLERS TYPES USED FOR COMMERCIAL SX PLANTS OTHER THAN COPPER

A variety of alternative mixer-settler designs have been developed and commercially applied in non-copper applications such as uranium extraction. These include:

3.1. COMBINED MIXER-SETTLER (CMS)

Developed by Davy Mckee (now Aker Kvaerner) in England in the late nineteen seventies, and subsequently installed at two commercial uranium plants for JCI in South Africa which came on stream in the early nineteen eighties.

Mixing and phase separation are carried out in one vessel. During operation there are 3 zones:

- upper zone comprising the separated organic phase.
- lower zone comprising the separated phase.
- central zone comprising the dispersion.

The O:A ratio within the dispersion is controlled by adjusting the heights of the aqueous and organic discharge weirs, and is independent of the overall organic and aqueous feed solution ratio. No recycle of either phase is needed.

The elimination of recycle reduces the combined solution flow through the unit compared with a conventional mixer-settler and other designs involving separate mix boxes and settlers. This means that the area required for phase disengagement is reduced.

CMS units were only used for the extraction circuit in the two commercial plants, as the economic benefit was much less for the much smaller scrub, strip and regeneration mixer-settlers.

Up to 300 pm of solids in the aqueous feed solution can be accommodated which eliminates the need for feed clarification equipment. A self regulating layer of crud forms which acts as a ‘filter”, and reduces the organic entrainment in the raffinate. Intermittent surges of very high solids can also be tolerated, in which case crud can be readily tapped off.

The organic entrainment tends to be larger than for conventional mixer-settlers, in the range of 200-400 ppm compared with about 200 for conventional mixer-settlers in uranium applications, and organic recovery equipment is normally used such as flotation or filtration systems.

Figure 5 illustrates the CMS concept.

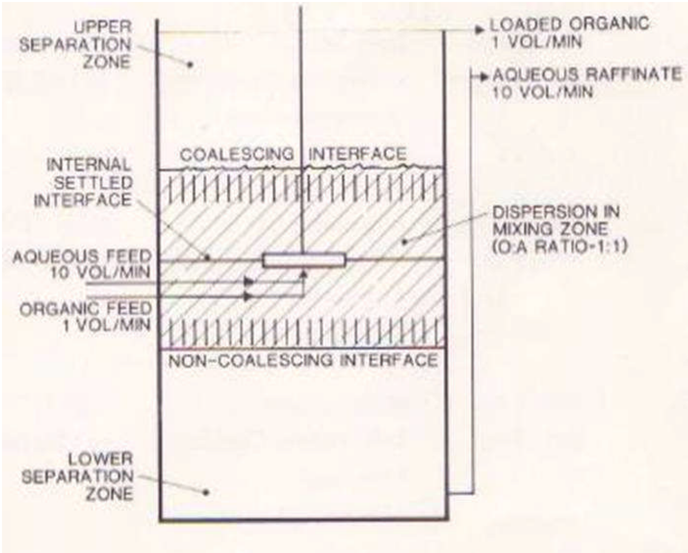

Fig. 5: Elevation View of CMS Concept

Table 2 presents a capex comparison with a conventional plant taken from “The Combined Mixer-Settler: A New Development in Solvent Extraction”, by CF Bonney and GR Rowden, presented at the 110th AIMI Annual Meeting, Chicago, 1981”.

	% Breakdown	
	Conventional Plant	CMS Plant
ENGINEERING AND COMMISSIONING	11.3	11.3
CLARIFICATION	6.0	0.1
MIXER-SETTLERS	13.2	10.0
COALESCERS & CRUD TREATMENT	5.8	6.3
PUMPS, TANKS & OTHER EQUIPMENT	2.2	2.0
PIPING & VALVES	4.2	3.1
INSTRUMENTS & ELECTRICS	3.9	3.4
STRUCTURES & CIVILS	8.1	5.1
BUILDING INC. SPACE HEATING	13.8	8.1
FIRE PROTECTION	10.5	7.0
ORGANIC INVENTORY	2.8	1.5
ERECTION	18.2	12.2
TOTAL	100.0	70.1
COST SAVING:	—	29.9%

Table 2: Comparison of CMS Plant with Conventional Mixer-Settler Plant*

***Note:** License fee for CMS design must be taken into account in the capex comparison.

Advantages include:

- Much Smaller footprint area.
- Lower capex.
- Smaller building for indoor plants.
- Simplified plant layout.
- Can be totally enclosed.
- Short interstage piping; no recycle piping; no trenches
- Pump-mix agitators for CMS units are lower head and lower speed than the conventional design.
- Reduced instrumentation and electric cabling runs.
- More convenient layout for operators.
- Can handle unclarified feed solutions.
- Self regulating crud layer.
- Not sensitive to changes in feed solution flow rates.
- Can cope with intermittent surges of very high solids in the feed solution.

Disadvantages include:

- Higher organic entrainment requires organic recovery equipment.
- Only applied to uranium extraction circuit as yet.
- Area advantage is reduced as overall solution O:A ratio approaches 1:1. Therefore would likely be more applicable to copper stripping than extraction.
- Proprietary design subject to licence fee.

3.2. LURGI MIXER-SETTLER

Developed by Lurgi in Germany. It was used at 3 commercial uranium plants in South Africa. The President Brand plant shown above.

Involves multiple trays (5-20) in the settler, fed by distributor, to enhance the coalescence rate. Coalescence and separation occurs on each tray.

The footprint area is typically 15-40% of conventional mixer-settler design. Capex is lower than conventional, though dependent on materials used. Tends to have higher organic entrainment than the conventional design, and requires a coalescer to reduce entrainment losses.

Figure 6 shows a view of the instllation at the President Brand uranium plant in South Africa.

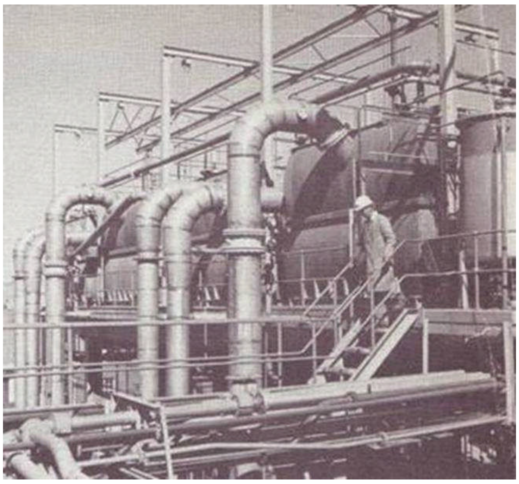

Fig.6: Lurgi Mixer-Settler at President Brand

3.3. IMI MIXER-SETTLER

Developed by Israeli Mining Industries (IMI), Haifa, Israel, in the late nineteen sixties, and commercially applied at Western Deep Levels uranium plant in South Africa. It is currently available through the Bateman Group.

The mix box is equipped with a mixing impeller plus a pumping axial flow impeller shrouded in a draft tube which lifts the dispersion to a collecting launder. The dispersion is fed to the centre of a cylindrical settler, enters via a distributor, and flows radially outwards.

The separated organic phases discharge via a top perypheral launder, while the aqueous leaves via a bottom channel fitted around most of peryphery. Baffles are fitted in the settler to reduce turbulence and promote coalescence.

Figure 7 illustrates the the IMI concept.

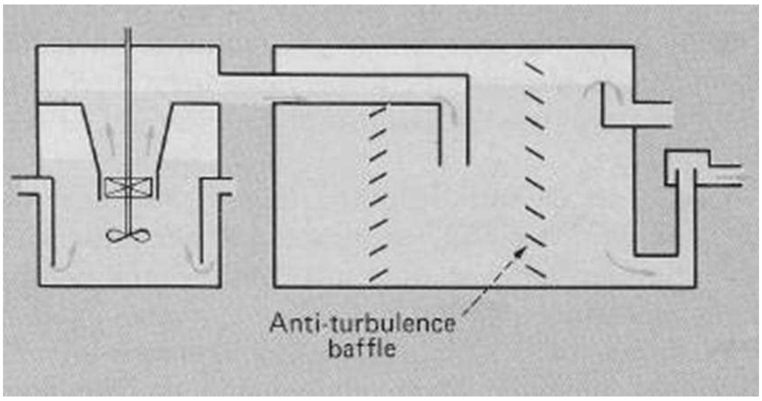

Fig. 7: Elevation View of IMI Mixer-Settler

IMI claimed 50% reduction in settler area, 30% reduction in footprint area and 33% lower capex compared with conventional mixer-settlers, as shown in Table 3, prepared by IMI in 1967.

	Conventional System	I.M.I. L.L.C. System
Settler area	4,200 sq.ft.	1,900 sq.ft.
Investment	$ 300,000	$ 200,000
Required total floor area	11,200 sq.ft.	8,000 sq.ft.

Table 3: Comparison of IMI System with Conventional Mixer-Settler System

Advantages include:

- Low velocity at periphery helps to improve phase separation, minimise velocity at the discharge weirs and reduce entrainment losses.
- Flexibility to optimize plant layout and minimise piping runs.
- Smaller settler area.
- Reduced plant footprint.
- Lower capex compared with conventional units.

Disadvantages include:

- Needs careful distribution to ensure even distribution in settler (others found this difficult to achieve with this type of design).
- Additional power needed for pumping impeller.

3.4. KERMAC MIXER-SETTLER

Installed at Kerr-McGee's Grant's operation in New Mexico in 1958. Utilized a cylindrical settler with the mix box located at the centre.

In extraction, aqueous flows through the circuit by gravity, and is discharged from each settler via 4 jacklegs. Organic is pumped to each mix box and overflows via a perypheral launder, with a recycle pipe provided back to the mix box.

At Grants, the extraction mix boxes were 8ft diameter by 9.5 ft high in stainless steel, while the settlers were 40 ft diameter by 9 ft high in wood. The strip mixer-settlers were similar but smaller.

Figure 8 illustrates the Kermac concept.

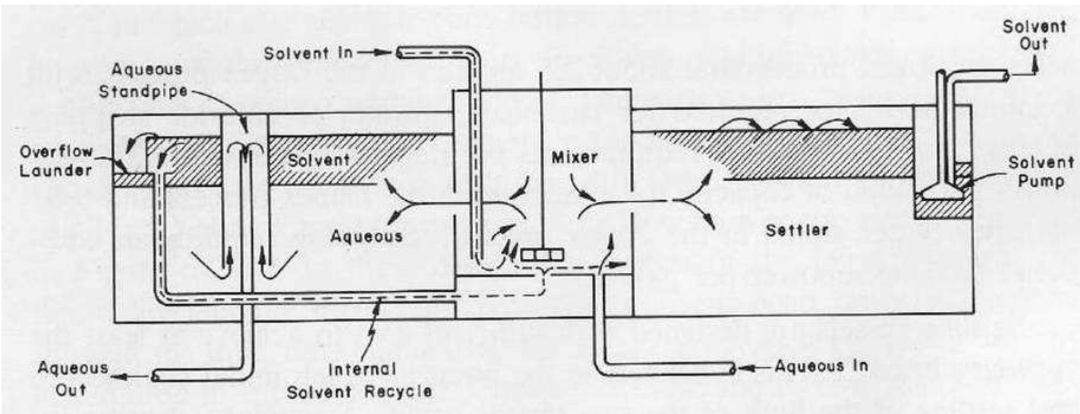

Fig. 8: Elevation View of Kermac Mixer-Setller

3.5. IN-LINE MIXER SYSTEM

Developed in late nineteen seventies by Kenics Corp, Massachusetts. An 11.4 m^3/h pilot plant operated at Kerr-McGee uranium ore treatment operation at Grants, New Mexico in 1978.

It was then proposed for a number of other uranium processing projects, and was adopted for the Earth Sciences' commercial uranium from phosphoric acid operation at Calgary, Canada, in 1980.

It consists of a Kenics static mixer followed by a baffled cylindrical settling vessel. The baffles serve to reduce the risk of flooding and to reduce entrainment. They are typically located in the dispersion zone downstream of the entrance zone where there is turbulence and back mixing.

The organic flow is pumped from stage to stage, while the aqueous flows under gravity. Organic recycle is achieved using a split from the organic pump discharge.

Crud can be removed from just below the interface by periodically opening valves on the side wall and discharge end of the settler.

Viewing "windows" are fitted into the settler wall for level control purposes.

In 2002, Koch-Otto York in the USA piloted a similar concept – "Plant in a Pipe", and installed a four stage (2 extraction,1 scrub, 1 strip) demonstration plant for copper recovery at the Phelps Dodge Morenci operation in 2002 to treat 22.7 m3/h of aqueous feed solution. The Koch-Otto York system incorporates a reactor between the mixer and the settler to provide additional contact time. The required contact time for copper extraction is higher than that for uranium.

Fig. 9 illustrates the Kenics system.

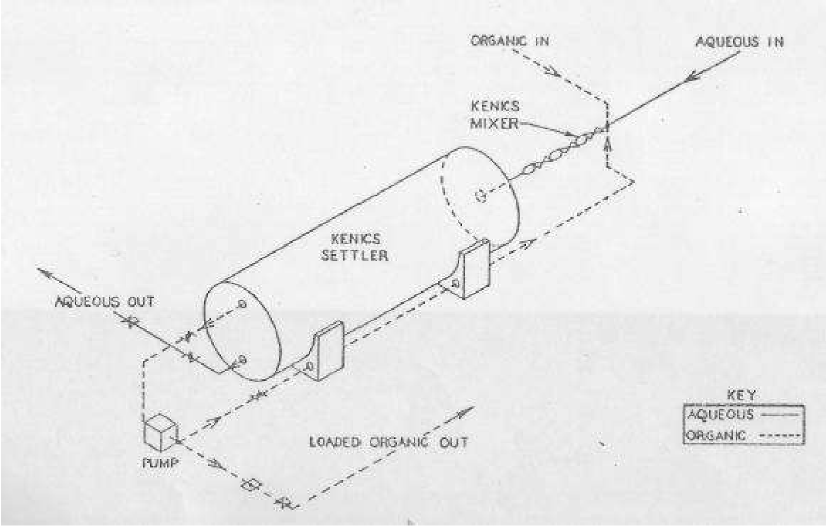

Fig. 9: Schematic of Kenics In-Line Mixer System

Advantages include:

- Totally enclosed system, which excludes dust, minimizes evaporative losses, improves fire protection and excludes air.
- Narrow droplet size distribution due to static mixer, which leads to rapid phase disengagement in settler.
- Plug flow mixer; no back mixing
- Low organic entrainment; Kenics claimed 10 ppm.
- Lower foot print area.
- Smaller organic inventory than conventional mixer-settler design.
- Lower capex than conventional design.
- Now moving parts except pumps, low maintenance.
- Simple construction; facilitates use of plastics.

Disadvantages include:

- Use of interstage organic pumps, which make flow control through the system more complex, and risks affecting phase disengagement through air entrainment and possible fine haze formation.
- Interface level control more challenging than conventional settles. Visibility through windows may deteriorate.
- Overall operation more complex than conventional plant, and more dependant on instrumentation.
- Turn down in feed flow limited to about 30%, after which efficiency falls away.
- Limited access removes excessive crud accumulation.

4. MIXER-SETTLERS TYPES PILOTED FOR COPPER SX BUT NOT COMMERCIALIZED

A number of other novel mixer-settler designs have been developed for copper SX and tested at pilot plant scale without finding application in commercial plants. Examples include:

4.1 SEGMENTED CIRCULAR MIXER-SETTLER

Developed by Davy Mckee (now Aker Kvaerner) in England and patented in 1974. It has a conventional mix box at the centre of a relatively small cylindrical settler. As the mixed phase leaves the mix box and enters the settler it passes through pads of a dual media of knitted metal and plastic (DC Knitmesh supplied by KnitMesh Ltd) to accelerate coalescence. Periodic cleaning of the pads is necessary to remove accumulated solids and crud if present. Pilot plant tests were carried out in Zambia, Zaire and Chile, and demonstration tests were carried out at S.E.C. Corporation in Texas. Cost comparisons with conventional mixer-settlers indicated an installed cost saving of 30-35% and a solvent inventory saving of 30-40%. He perceived problem of plugging has hindered it's progress to commercial application.

Advantages

- Compact design, area 25% of conventional settler.
- Reduced capital.
- Fabrication in FRP or other materials.
- Reduced construction time.
- Reduced fire risk due to fully sealed units.

Disadvantages

- Potential blockage of pads if crud formation or feed solids is excessive.
- Potential high cleaning frequency in dirty feed systems.
- Entrainment losses same as conventional plant.
- Proprietary design subject to licence fee.

The design is illustrated in Fig. 10.

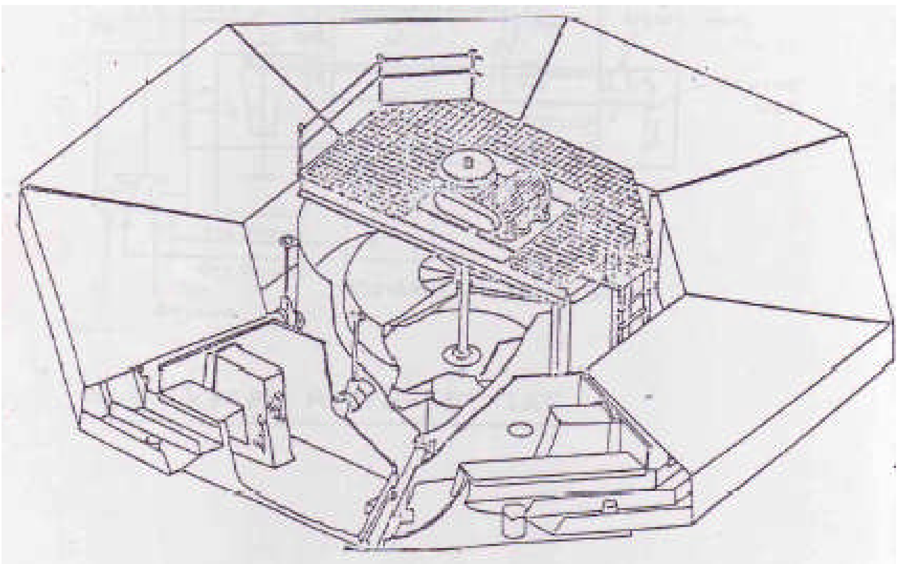

Fig. 10: Segmented Circular Mixer-Settler

4.2 ELECTROSTATIC MIXER-SETTLER

Developed by CE Natco in the nineteen seventies for copper SX. In the mixing step, an emulsion is deliberately created which improves mass transfer. The settler involves the combination of electrostatic and centrifugal forces in an electrically charged hydrocyclone. The resulting cyclone underflow contains aqueous droplets of in excess of 1 cm diameter. The coalescence rate is said to be 10 times faster than with a conventional mixer-settler. The raffinate and strong electrolyte streams are passed through CE Natco OSX multi-media coalescers to obtain very low organic entrainments levels. A skid mounted portable pilot plant was tested at Ranchers and Cities Service SX plants in Arizona. Each contactor stage comprised a throttled centrifugal pump for mixing and pumping, a retention column allowing 1 minute reaction time and an electrostatic separator column. Average extraction efficiency was 95% and the settler loading rate was 25 gpm/ft^2. Commercial quotes were submitted for various projects but the cost advantage over conventional mixer-settlers was not considered to be sufficient.

Advantages

- High mixing efficiency.
- Smaller footprint and lower organic inventory.
- Reduces organic vapor loss.
- Allows lighter diluents to be used.
- Reduces SX contamination by airborne materials.
- Reduces interfave sludge build-up.
- Improved safety.
- Reduced fire hazard.
- High specific settling rate of 25 gpm/ft^2.

Disadvantages

- Relies on coalescers to achieve low organic entrainment levels.
- Insufficient cost advantage compared with conventional units.

5. COLUMN CONTACTORS

Column contactors have so far found limited use for uranium and nickel-cobalt SX and have not yet been commercially applied for copper. However, in recent years there has been increasing interest in the use of pulsed columns in particular.

5.1. PULSED COLUMNS

Two commercial pulsed column installations were adopted for uranium operations in France in 1979 and 1981. Prior to this, pulsed columns were used in the nuclear industry since the nineteen fifties.

More recently, two Bateman pulsed columns were installed in the uranium extraction circuit at Olympic Dam, South Australia, in 1996 to operate in parallel with the then existing Krebs mixer-settlers to increase production. Ten more were added in the 1997 expansion program. Eventually, a total of 14 units were installed (13 operating + 1 spare), to treat the entire solution flow about 3,000 m^3/h, operating in parallel.

The pulsed column consists of a vertical cylindrical contacting section with settlers at the top and bottom. The contacting section is fitted with either sieve plates or "disc and doughnut" plates. The latter have been generally used for uranium extraction, for example in the Bateman units at Olympic Dam.

An organic or aqueous dispersion is formed by applying energy in the form of a pulse. The pulse can be provided mechanically or pneumatically. The pneumatic option is more suitable for large columns.

The organic phase enters via a disperser at the bottom of the column and the aqueous via a disperser at the top. The system can be operated either organic or aqueous continuous. The organic overflows via a weir at the top, and the aqueous leaves from the bottom under level control which maintains the organic/aqueous interface in the bottom settler for organic continuous and in the top settler for aqueous continuous.

The material of construction for the plates is selected to avoid coalescence of the dispersed phase. Thus for aqueous continuous metal plates would be favoured, while for organic continuous a plastic such as FRP would be suitable.

The amplitude x frequency of the pulse determines the energy input, which is typically varied using a three way valve on the air supply. As the energy increases, the droplet size becomes smaller, which gives higher extraction efficiency but higher entrainment.

Figure 11 shows the Bateman design arranged for organic continuous cinditions. It includes discs and doughnuts, and utilizes a pneumatic pulsation leg.

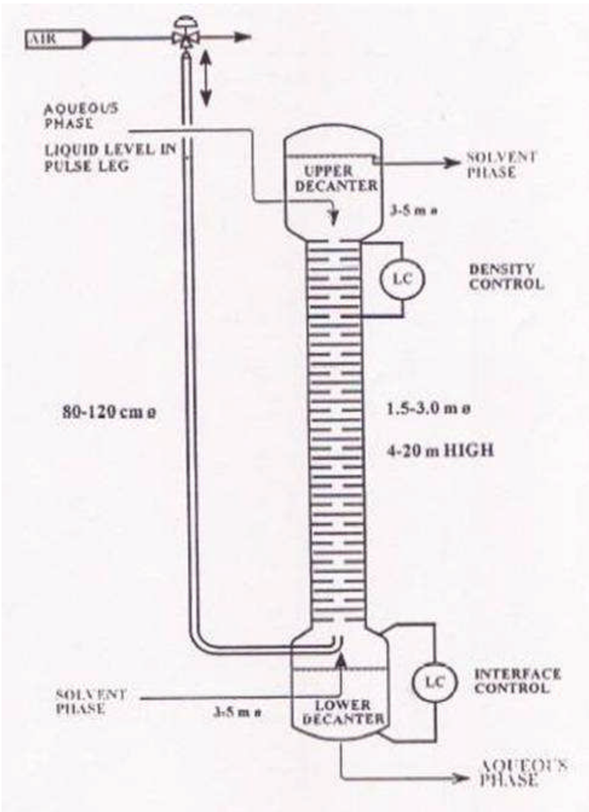

Fig. 11: Elevation View of Bateman Pulsed Column system

Advantages include:

- Potentially lower organic inventory than conventional mixer-settlers.
- Capex advantage increases with number of required stages.
- Small foot print area.
- Ability to operate with the solution with the smaller flow as the continuous phase.
- No phase recycle needed.
- Can incorporate a large number of stages in one column.
- Totally enclosed system, excludes dust, minimizes evaporative losses, improves fire protection, and excludes air.

- Has greater tolerance for suspended solids.
- No internal moving parts; low shear; low entrainment; low maintenance.
- Ability to vary droplet size.
- Opportunity to use inexpensive FRP for construction.

Disadvantages:

- Capex advantage is reduced with fewer stages.
- Height of column not suitable for indoor location.
- Les flexible for large feed flow variations than conventional mixer-settlers.
- Pilot scale testwork needed to develop scale-up data.
- Less accessible for clean-out.
- Visual monitoring of process difficult.
- Power requirement for pulse generation.

5.2. KARR RECIPROCATING PLATE COLUMN

Now available from Koch Process Industries, NJ, USA. It has been used commercially in the chemical, petrochemical and pharmaceutical industries.

It was tested by Falconbridge, Canada, for a proposed new nickel refinery in the nineteen seventies. It was preferred over mixer-settlers as being more suitable for the urea formaldehyde reinforced plastic construction preferred for the chloride conditions, and by the desire to eliminate interstage piping.

More recently, it has been tested for nickel/cobalt separation from laterite leach solution.

It consists of a series of perforated plates with large diameter holes and high free cross sectional area mounted on a reciprocated central shaft. Reciprocating motion imparts energy to the liquids thus creating droplets. Periodic baffle plates are included to suppress axial mixing. The drive unit is equipped with a variable speed motor to allow optimization of the column performance.

Reciprocating plate motion produces uniform shear mixing across the entire column cross section, making the column particularly suitable for systems which tend to form stable emulsions.

The column shell can be constructed of carbon steel, stainless steel or higher alloys, Teflon, glass-lined steel, or FRP. The internal plate stack can be constructed of stainless steel, higher alloys, Teflon, or FRP.

It can handle some suspended solids in the feed solution, and can be considered as alternative to the pulse column.

Figure 12 shows a schematic of the Karr column concept.

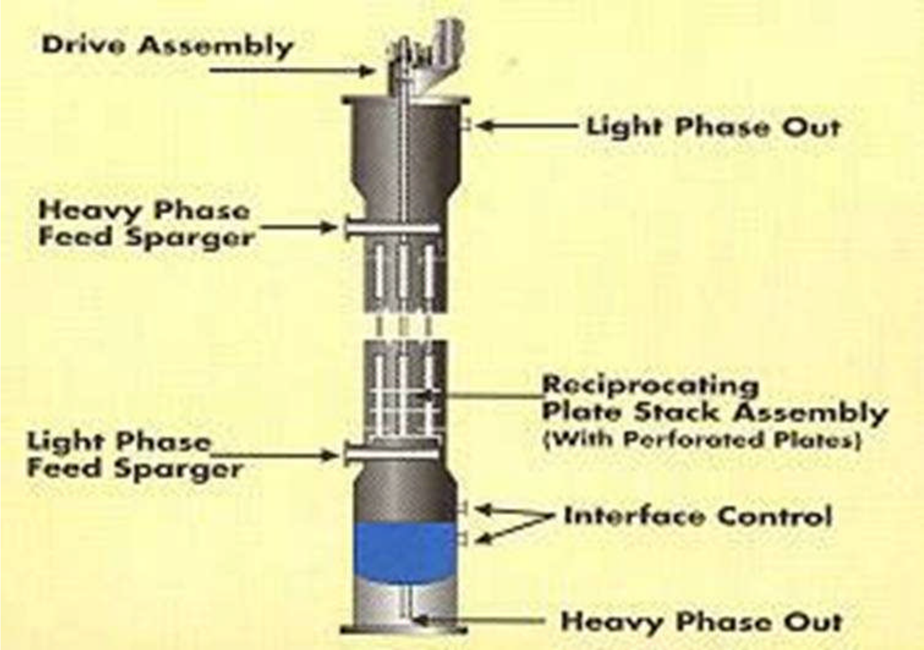

Fig.12: Schematic elevation of Karr Column

5.3. OLDSHUE-RUSHTON (MIXCO) COLUMN

Supplied by Lightnin (now SPX Process equipment. It has been widely used in chemical, petrochemical and pharmaceutical industries.

There have been a limited number of metallurgical applications including nickel/cobalt separation by Inco, Ontario, Canada, and zirconium/hafnium separation by Eldorado Nuclear, Ontario, Canada.

Units have been built up to about 3 m diameter.

Agitation is provided by 6-bladed paddle type mixers mounted equidistant on a central shaft. “Doughnut” type plates are fitted equidistant from the mixers. The column contains vertical baffles

Figure 13 shows the column concept.

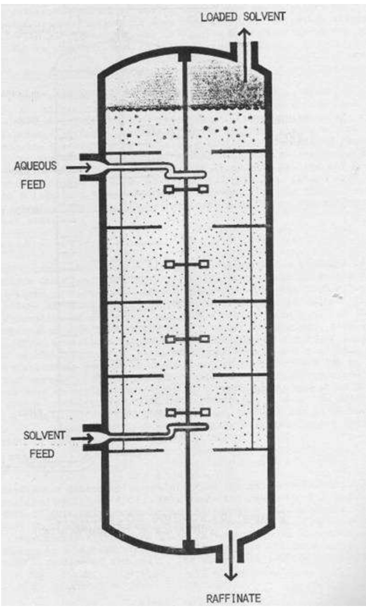

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Fig. 13: Elevation View of Oldshue-Rushton (Mixco) Column Concept

Comparison with pulsed column:

- about 30% lower capacity for the same diameter due to greater back mixing.
- can also handle suspended solids – Eldorado Nuclear have operated up to 5-6% solids.
- less flexible with regard to phase continuity.
- it is designed for either aqueous or organic continuous, which have different design of impeller.
- narrow operating rpm range between insufficient agitation and emulsion formation.

6. CENTRIFUGAL CONTACTORS

The Podbieliak contactor is supplied by Baker Perkins (now B & P Process Equipment), Michigan, USA. It was used commercially at Texas-Zinc Minerals Corp. uranium plant in Utah in the nineteen fifties.

It has also used in the nuclear industry where short organic-aqueous contact times are required, and Denison Mines, Canada, for the recovery of rare earths after uranium IX.

It is a horizontal continuous differential counter-current type centrifugal contactor with up to 10 theoretical stages per unit.

Internals consist of a series of concentric sieve plates; thus it acts like an accelerated sieve plate column. Aqueous moves from the centre outwards, while organic moves inwards. It Includes clarification zones for organic and aqueous before discharge. Organic discharges under pressure so that a pump is normally not needed. The aqueous solution needs to be pumped.

Other differential centrifugal contactor designs include Quadronic, Alfa-Laval, Robatel and Luwesta.

Figure 14 presents a cut-away schematic of a Podbielniak unit, while Figure 15 shows an SX circuit with Posbielniaks on extraction and stripping duties.

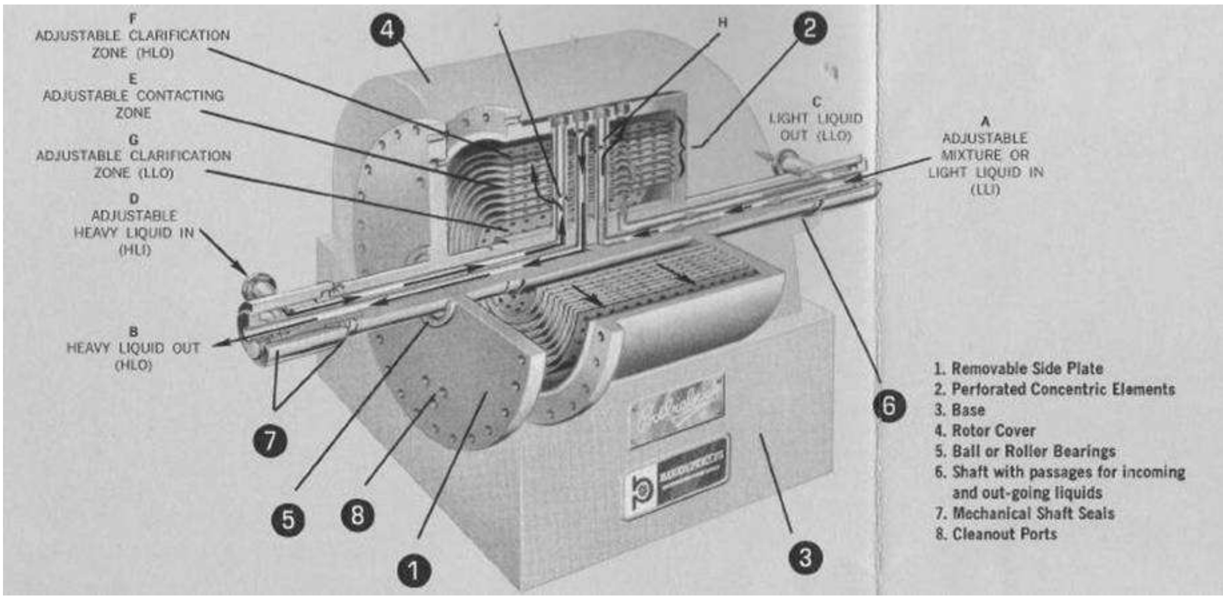

Figure 14: Cut-Away Schematic of a Podbielniak Centrifugal Contactor

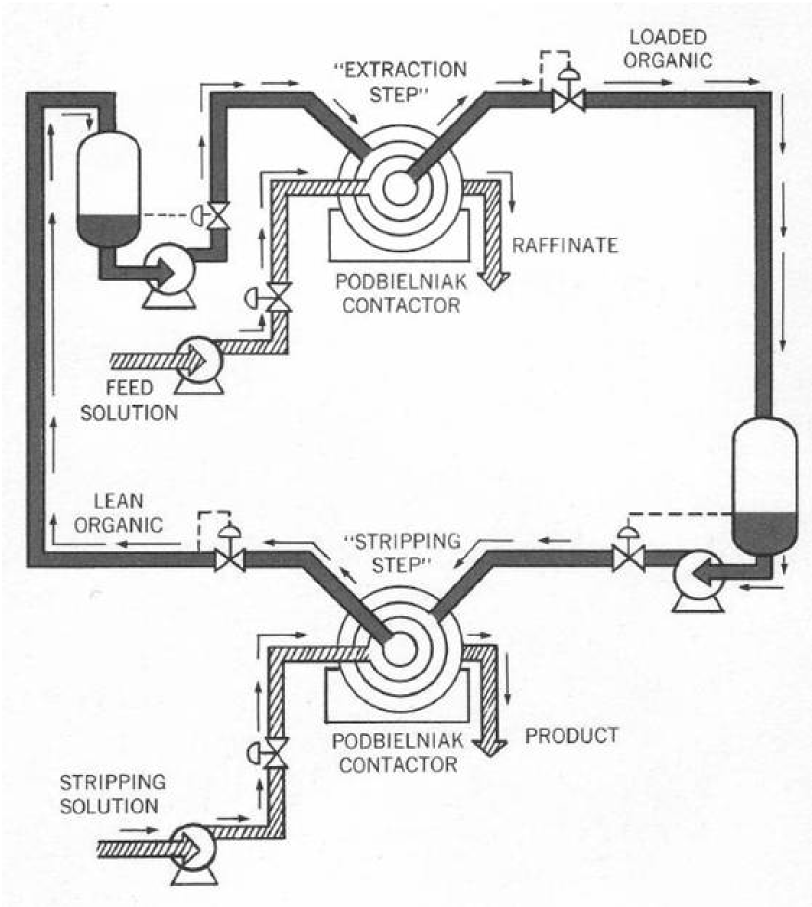

Figure 15: SX Circuit with Podbielniaks on Extraction and Stripping Duties.

Advantages include:

- Can operate with small droplets promoting rapid kinetics.
- Less back mixing than columns.
- Can operate with liquids with small density differences.
- Because of the very short contact time, it can handle relatively high flow rates, up to 140 m3/h of feed solution. Capacity is proportional to speed of rotation.
- Can operate with either phase continuous over a wide range of phase ratios.
- Has a very low organic inventory – typically about a factor of 25 times less than an equivalent mixer-settler circuit.
- Very small footprint area and is totally enclosed (has balanced mechanical seals).
- Flexibility can be provided through changing feed location, seal arrangement and internal elements.

Disadvantages include:

- No access or viewing of process while in operation. (Access is provided for inspection and cleaning).
- Tend to be expensive, but this is offset by low organic inventory, low footprint area, and less structures.
- Limited tolerance to suspended solids.
- Power requirement.
- More sophisticated operation and maintenance than mixer-settlers.

7. CONCLUSIONS

The conventional mixer-settler has historically been the workhorse of the copper industry, and there has been intesive ongoing development work to obtain cost and performance improvements. In addition, there has been increasing interest in recent years in the development of alternative designs aimed at obtaining improvements in key areas such as capital cost, organic entrainment, footprint area, organic inventory, layout, controlability, operating convenience, ability to handle solids, and reduction of crud exclusion of dust and air. To date, this has resulted in a number of Krebs installations and, more recently, a growing number of large scale applications of the reverse flow and VSF designs.

A variety of alternative mixer-setttler designs have also been commercialized over the years for other SX applications. Some others have been piloted for copper but did not progress to commercial scale. Some of these could possibly be re-visited.

Likewise, a limited number of pulsed columns, other column designs and centrifugal contactors have been used for other SX application, and there may be situations in which they could become attractive for copper.

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