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EVOLUTION OF MIXER-SETTLER DESIGN FOR USX

By

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ABSTRACT

The early USX mixer-settler designs in the late 1950s and 1960s were adopted from the nuclear industry. Inter-stage transfer was by gravity, airlifts or pumps. During the 1960s, pump-mix type mixer-settlers of various designs were increasingly favoured. The advent of copper SX in the late 1960s led to the development of what became known as the conventional mixer-settler which was designed to minimize entrainment losses of the more expensive organic extractant and to keep organic out of the associated copper EW facility. A number of new designs were developed and applied for USX. Objectives included reduction in footprint, especially for indoor operations, and reduction in capital cost, organic inventory and entrainment losses. The USX designs included the use of trays or baffles in the settlers, a launder for primary phase disengagement, and static in-line mixers. Relative few USX plants have been built since the uranium price decline beginning in the early 1980s and continuing through to fairly recent times, and only the Krebs and conventional mixer-settlers have continued to be applied along with pulsed columns which have found increasing favour. In the meantime, there have been further developments in copper SX mixer-settler design which are available for application for USX. These include reverse flow settlers, Outotec VSF mixer-settlers, MMS side-feed mixer-settlers and MC process mixer-settlers which features a new mix box and pump-mixer design. Possible future developments could involve improvements to current designs, revisiting earlier commercial designs, further development of previously piloted designs, and new innovations. The main objectives are opex related - to reduce entrainment losses and power consumption, and capex related - to reduce footprint, settler area and organic inventory.

INTRODUCTION

The first hydrometallurgical applications of mixer-settlers were in the nuclear industry in the 1940s and 1950s for specialized applications including purification of uranium, reprocessing of fuels and separation of fission products. Reasons for their use included low head room requirement, simplicity and low maintenance. This paper follows the subsequent development of mixer-settler design from the early uranium solvent extraction (USX) plants in the early 1960s, through the introduction of pump-mixers then the advent of copper solvent extraction (CuSX) plants and development of the conventional mixer-settler in the early 1970s and up to the present time. More recent designs are reviewed and possible future developments are identified.

EARLY USX MIXER-SETTLERS

The Kerr-McGee plant at Shiprock, New Mexico, became the first uranium ore processing plant to adopt solvent extraction when it replaced the existing ion exchange (IX) circuit with a Dapex SX facility as part of an expansion in 1956(1). The extraction section comprised four circular mixer-settlers arranged in a cluster. The extraction mixer-settlers shown in Figure 1 differed in elevation by 12 inches, so that the aqueous phase flowed between stages by gravity, while organic was transferred "uphill" using air lifts. The extraction settlers were cylindrical wood stave tanks with a stainless steel mix boxes placed on legs against the wall inside each settler with interconnecting piping through the settler walls. Standard flat blade turbines were used for mixing(2). The carbonate stripping circuit comprised two carbon steel mixer-settlers. In this case the mixers were outside the settlers, the solvent flowing by gravity and the aqueous advanced via with air lifts. These settlers were cone bottomed because of the presence of small amounts of precipitates which were formed during stripping.

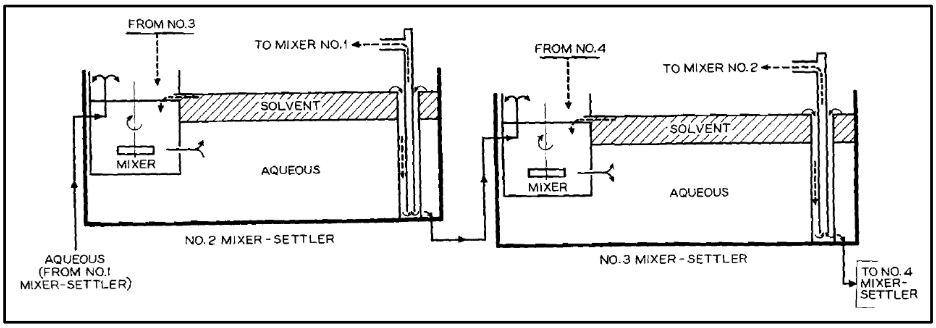

Figure 1: Kerr-McGee Shiprock Extraction Mixer-settler Design(1)

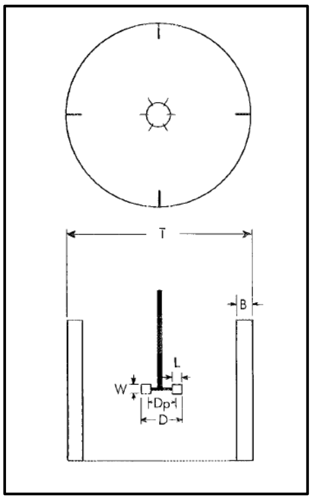

Figure 2: Typical Dapex Mixing Tank and Turbine(2)

Climax Uranium also established a Dapex SX plant in the same year at Grand Junction, Colorado. Wood stave external mix boxes were used for both extraction and stripping. The mixer-settlers were located at grade and the organic flowed by gravity between stages while the aqueous advanced via air-lifts as shown in Figure 3. The success of the Climax and Shiprock USX plants was largely due to the extensive development work carried out at Oak Ridge.

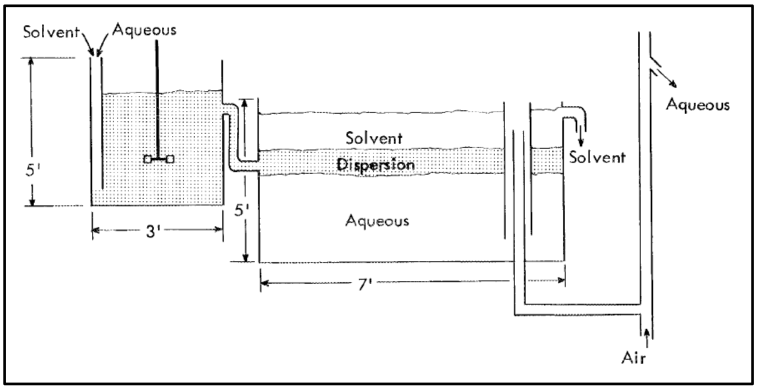

Figure 3: Climax Grand Junction Extraction Mixer-settler Design[2]

Similar design concepts were used for subsequent Dapex operations and continued when Dapex began to be replaced by the more selective Amex Process from the late 1950s. Cylindrical settlers were favoured by the ready availability of wood stave tanks in the USA, which were resistant to both acid and organic and were relatively inexpensive compared with stainless steel or lined steel. Also, it was considered that the cylindrical settler design with an internal mix box located at the centre and a peripheral organic discharge launder resulted in low settler velocity and overflow weir velocity which maximized phase disengagement and minimized entrainment.

As an example, Figure 4 shows the mixer-settler design installed at the Kerr-McGee Amex operation at Grants, New Mexico in 1958.

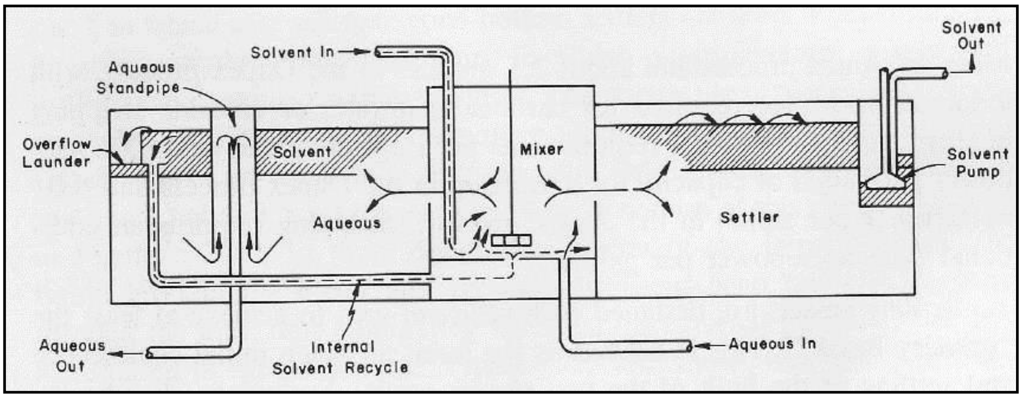

Figure 4: Kermac Mixer-Settler Design

In extraction, the 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 peripheral launder with a recycle pipe provided back to the mix box. The settlers were wood stave and the mix boxes stainless steel. The strip mixer-settlers were similar but smaller.

The El Sherana project at South Alligator River valley, Northern Territory, Australia, in 1959, became a milestone in mixer design. The Amex SX testwork at the Australian Mineral Development Laboratories (AMDEL) in Adelaide, South Australia, reported by A. E. Bellingham in 1961[3], found that to avoid visible entrainment the N^3D^2 value should not exceed 20 (where N is the mixing impeller speed in revolutions per second and d is the impeller diameter in feet). This became the standard rule of thumb for future mixer design and operation for many years. It is only in recent years that more sophisticated modelling parameters have been used. The El Sherana extraction mixer-settler design is shown in Figure 5. It was a modified version of the design developed at the Winchester Raw Materials Laboratory, National Lead Company, Massachusetts.

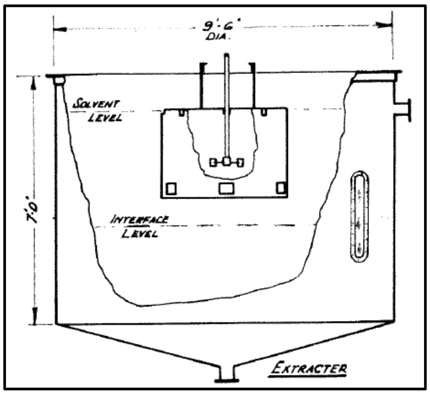

Figure 5: El Sherana Extraction Mixer-Settler Design[3]

It consisted of a cylindrical FRP lined settler with a centrally positioned internal PVC mix box equipped with a stainless steel flat blade turbine. Inter-stage transfer of both phases was via pumps. The stripping units were a smaller version of the same design.

ENTER THE PUMP-MIXER

The development of the pump-mix mixer-settler for the nuclear industry, reported in 1954 by Coplin et al of the Knolls Atomic Power Laboratory (KAPL) in Schenectady, New York, USA[4], was another significant milestone in the mixer-settler story. The KAPL design, shown in Figure 6, was of the "partitioned box" configuration which eliminated inter-stage piping. The impeller was double shrouded with four straight vanes, akin to a centrifugal pump, and provided hydraulic head for inter-stage pumping of the aqueous phase, for mixing and for interface control. Organic overflowed by gravity from the previous box into the mix box.

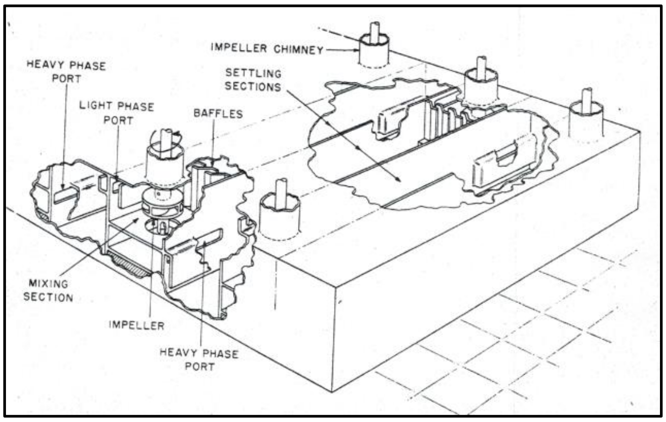

Figure 6: KAPL Pump-Mix Mixer-Settler[4]

During the 1960s, pump-mix type mixer-settlers of various designs were increasingly favoured for USX operations. Perceived advantages included elimination of inter-stage pumps or air lifts, elimination of individual phase interface sensing and control, operating flexibility, and the ability to stop and re-start the feed flow without upsetting the system hydraulics. Settlers were both cylindrical and rectangular, though the trend was towards rectangular. Likewise, there was a trend towards external rather than internal mix boxes.

THE ADVENT OF COPPER SX AND THE DEVELOPMENT OF THE CONVENTIONAL MIXER-SETTLER

Copper solvent extraction emerged in the late 1960s based on selective extractants developed by General Mills Chemicals in the USA. Because of the relatively high cost of the extractants compared with the amines used in USX, and the need to keep organic out of the associated electrowinning facility, greater attention was given to minimizing organic entrainment when designing mixer-settlers for CuSX. The first plant, which was installed by Bechtel at Ranchers

Bluebird in Arizona, utilized inter-stage pumping, but pump-mixers were used at all subsequent plants and settler picket fences were introduced. The early CuSX plants which followed Ranchers Bluebird were designed by Holmes and Narver in association with General Mills Chemicals, in the USA, and Power Gas, part of the Davy Group in the UK. Both groups selected an external mix box with a pump-mix impeller, and a distributor and/or picket fence to promote even flow velocity across the width of the settler and quell turbulence at the settler inlet. The organic discharged over a fixed full width weir at the end of the settler which determined the liquid level and the aqueous flowed under the organic weir and discharged via an adjustable full width weir which was used to set the elevation of the phase interface and thickness of the organic layer in the settler. The mixer-settlers were arranged “head to tail” with the mix boxes at alternate ends to minimize the length of the inter-stage piping and hydraulic head to be developed by the pump-mixers. Apart from the pump-mixers, the overall design concept was similar and became known as the **conventional mixer-settler**. Although primarily designed for CuSX, it soon became increasingly favoured for USX applications. The mixer-settler concept recommended by General Mills in 1972 shown in Figure 7 reflects the typical features of the conventional mixer-settler(5). Apart from the use of two or more mix boxes and differences in the design and number of picket fences, the concept has not significantly changed over the subsequent 40+ years!

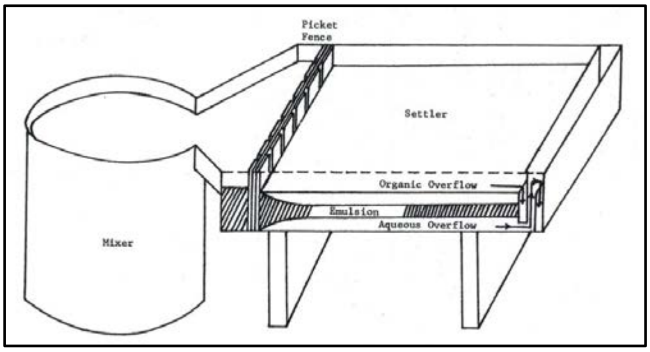

Figure 7: Conventional Mixer-Settler Concept Recommended by General Mills(5)

Holmes and Narver/General Mills Pump-Mixer

Early CuSX pilot plants were operated at Duval and Bagdad in Arizona in the mid 1960s with the assistance of General Mills. They used Denver Equipment package mixer-settlers equipped with single shrouded straight vane pump-mix impellers. Similar pump-mix impellers were adopted for the second commercial copper SX plant, at Bagdad, Arizona, designed by the engineering firm Holmes and Narver in association with General Mills The pump-mix impeller became known as the General Mills mixer and was used for numerous subsequent projects. It consisted of a single shrouded turbine with 6 straight blades attached at right angles to the lower surface located close to the base of the baffled mix box. As shown in Figure 8, the aqueous and organic enters a cut away opening in the lower side of the turbine via an opening in the base of the mix box(5). The Bagdad mixer-settlers were of stainless steel construction.

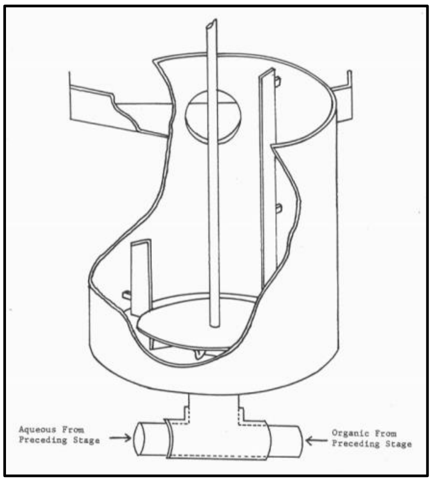

Figure 8: General Mills Pump-Mixer(5)

General Mills found that the following criteria should be followed to avoid high organic entrainment due to excessive shear[5]:

- N^3D^2 ≤20 (as recommended by Bellingham[3]).
- Maximum tip speed 800ft/min (4 m/sec).
- Vanes attached to the bottom of the impeller only.
- Vanes not extended beyond the edge of the impeller.

Later designs included a false bottom with a dividing plate to separate the incoming organic and aqueous to avoid the problem of the heavier aqueous hindering the flow of organic, and the straight vane impellers were superseded by high efficiency swept back curved vane units introduced by Lightnin Mixers in the mid 1990s[6].

Power Gas/Davy Pump-Mixer

In the early 1970s, Power Gas tested a variety of pump-mixer designs and mix box configurations and selected a double shrouded impeller with 8 swept back curved vanes on the basis of high pumping and mixing efficiencies and low shear to minimize entrainment. The impeller was elevated above the base of the mix box and the organic and aqueous was introduced via a draft tube connected to a false bottom fitted with a dividing plate to separate the incoming organic and aqueous. Perceived advantages of the elevated impeller included ease of starting organic continuous, reduced head requirement, and reduction of the effect of the mix box base on circulation patterns. The design was first applied at the third commercial copper SX plant at Nchanga, Zambia, in 1974. For the first USX application, which was at Bear Creek, Wyoming, in 1976, the bottom dividing plate was extended to the top of the draft tube which further reduced the pumping head for the impellers. The design became known as the Davy Pump-Mixer and is shown in Figure 9. The very large scale Nchanga mixer-settlers were constructed in concrete lined with thin gauge stainless steel to reduce costs and included rectangular mix boxes. The much smaller Bear Creek USX mixer-settlers were of FRP construction with cylindrical mix boxes.

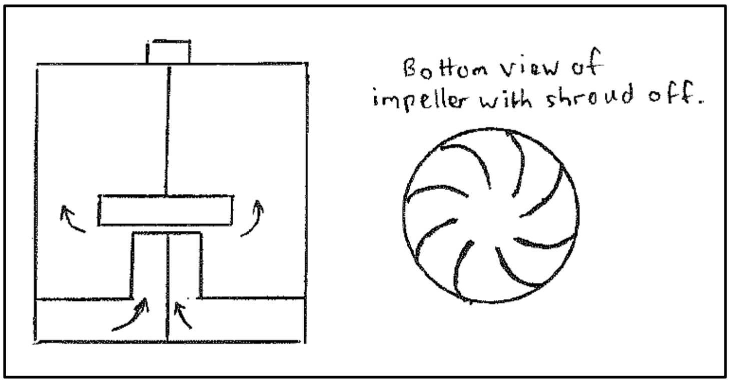

Figure 9: Power Gas/Davy Pump-Mixer[7]

DEVELOPMENT OF NEW USX MIXER-SETTLERS DESIGNS

While CuSX plants continued to adopt conventional mixer-settlers in the 1970s and 1980s, a number of new designs were developed and applied for USX. Objectives included reduction in footprint, especially for indoor operations, and reductions in capital cost, organic inventory and entrainment losses.

IMI Mixer-Settler

This design was developed by Israeli Mining Industries (IMI), Haifa, Israel, and applied at Western Deep Levels uranium plant in South Africa in 1971. 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, through a distributor, and flows radially outwards. The separated organic phase discharges via a top peripheral launder, while the aqueous exits via a bottom channel fitted around most of periphery. Baffles are fitted in the settler to reduce turbulence and promote coalescence. Perceived advantages include low velocity in the settler and at the discharge weirs to improve phase separation and reduce entrainment losses, 50% reduction in settler area and 30% lower capex[8]. The IMI design is illustrated in Figure 10.

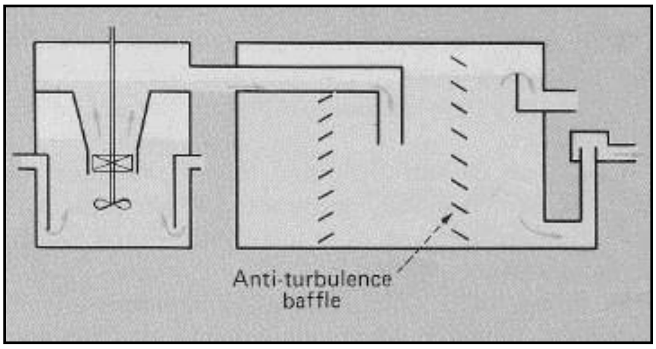

Figure 10: IMI Mixer-Settler

Lurgi Multi Tray Settler

Was developed by Lurgi, Germany, and applied at 3 commercial uranium plants in South Africa in the early 1970s[9]. It consists of a multi-tray settler receiving feed from a mixer which can be of various designs. The settler is fitted with multiple trays (5-20) fed by a distributor. Coalescence and separation occur on each tray. Trays in the light phase are open at top, while trays in heavy phase are open at bottom. There is an overflow weir at the end of each tray for one phase. Perceived advantages include reduced footprint area at 15-40% of conventional design, and lower capex depending on the materials used. However, the organic entrainment is higher than for conventional units, requiring a coalescer for organic recovery. Figure 11 shows the President Brand plant, one of the South African installations.

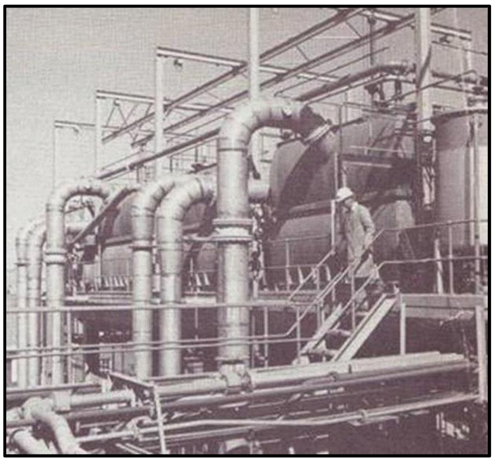

Figure 11: Lurgi Multi-Tray Settlers for USX at President Brand, South Africa

Krebs Mixer-Settler

Was developed by Krebs in France in the 1970s, and first applied for USX at Mounana, Gabon, in 1997. It was subsequently installed at numerous uranium plants, indoor operations in particular. The agitator is fitted with a low head, high volume 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. Typically the primary separation of the organic and aqueous phases is up to 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. Perceived advantages over the conventional units include 50% smaller footprint area, smaller building for indoor plants, all piping located at one end, shorter inter-stage and recycle piping and lower capex and organic inventory. Disadvantages include reduced operator visibility, more difficult access for crud removal and settler cleanout, speed of auxillary impeller is governed by the conical pump speed and additional power for conical pump. Also, some operations have reported higher than predicted organic entrainment, said to be due to the action of the conical pump.

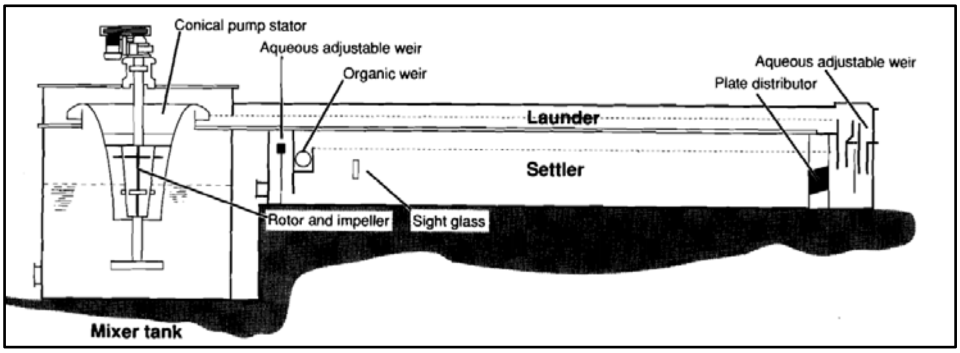

Figure 12: Krebs Mixer-Settler[10].

CRA Baffled Settler

Was developed by CRA (Conzinc Rio Tinto Australia) Research, Boolaroo, NSW, Australia, and first applied as a retrofit at Rossing Uranium in Namibia to the first and last extraction stages in 1978. It was subsequently installed at two other USX plants and several CuSX plants[11]. The settler is divided into two zones. In the first zone horizontal baffles accelerate coalescence by reducing the draining distances of the phase to the plate surface which directs the phases up or down. In the second zone staggered vertical plate baffles minimize flow at the phase interface promoting de-entrainment. As with the Lurgi settler, it can be coupled with a mixer of various designs. Reported benefits include[12]:

- Organic and aqueous entrainments from an existing conventional settler can be reduced to <10 ppm for the same flows.
- Flows to an existing settler can be increased by up to 100% with acceptable entrainments.
- Settler area can be reduced by up to 50% while maintaining similar entrainments to conventional units.

The baffled settler concept is illustrated in Figure 13.

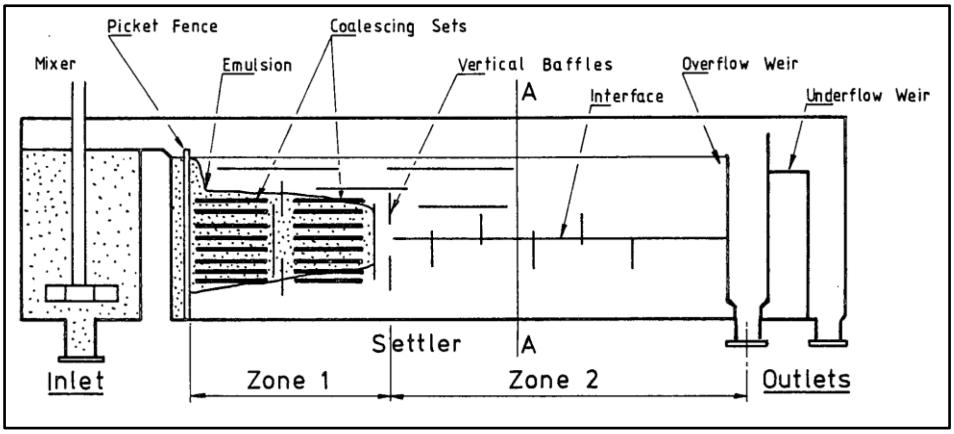

Figure 13: CRA Baffled Settler[11]

Kenics Mixer-Settler

This design was developed in the late 1970s by the Kenics Corp, Massachusetts. A pilot plant was operated at the Kerr-McGee uranium ore processing operation at Grants, New Mexico, in 1978, and a single stage extraction unit was installed at the Conoco Conquista Mill, Texas, for uranium recovery from CCD tails[7]. It was adopted for the Earth Sciences' uranium from phosphoric acid operation at Calgary, Canada, in 1980. It consists of a Kenics in-line 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 taken 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. "Windows" are fitted into the settler wall for level control purposes. Perceived advantages include plug flow in the mixer with no back mixing, narrow droplet size distribution due to the static mixer which leads to rapid phase disengagement in settler, lower footprint and smaller organic inventory than the conventional design, low organic entrainment at around 10 ppm, lower capex, and is a totally enclosed system which excludes dust, minimizes evaporative losses, improves fire protection and excludes air. Disadvantages include use of inter-stage organic pumps, more challenging Interface level control, turndown in feed flow limited to about 30% after which efficiency falls away, and limited access for crud removal. The system is shown in Figure 14.

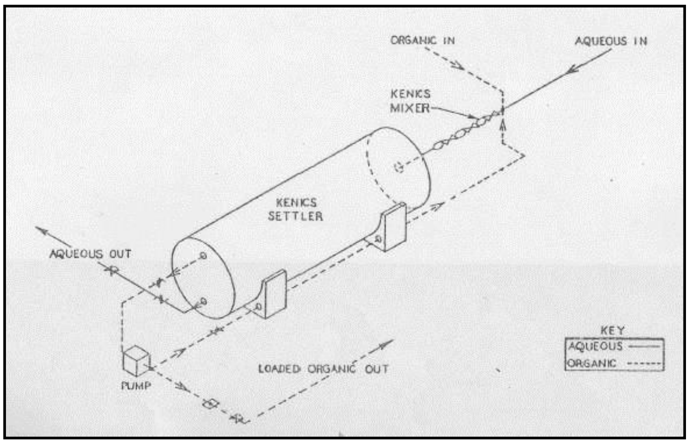

Figure 14: Kenics Mixer-Settler

Davy Combined Mixer-Settler (CMS)

Was developed by Davy Mckee in the UK in the late 1970s and installed at two commercial uranium plants for JCI at Western Areas and Randfontein in South Africa which came on stream in the early 1980s. Mixing and phase separation are carried out in one vessel. During operation there are 3 zones: an upper zone comprising the separated organic phase; a lower zone comprising the separated aqueous phase; and a 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 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 with separate mix boxes and settlers. This means that the area required for phase disengagement is reduced. CMS units were only used in the extraction circuits at the two commercial plants as the economic benefit was significantly 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 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 higher than for conventional mixer-settlers - in the range of 200-400 ppm versus 200 - and organic recovery equipment is normally used such as flotation or filtration systems. Perceived advantages include: much smaller footprint area, lower capex, smaller building for indoor plants, simplified plant layout, can be totally enclosed, short inter-stage piping; no recycle piping; no pipe trenches, pump-mix agitators are lower head and lower speed, reduced instrumentation and electric cabling runs, can handle unclarified feed solution, self-regulating crud layer, not sensitive to changes in feed solution flow rates and can cope with intermittent very high solids in the feed solution. The CMS concept is illustrated in Figure 15.

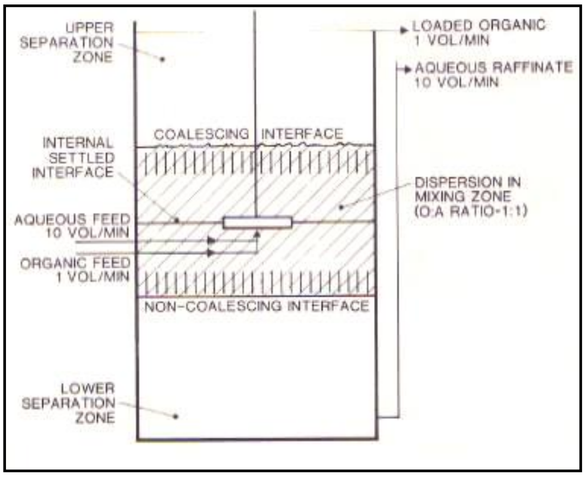

Figure 15: Davy Combined Mixer-Settler[13]

FURTHER DEVELOPMENTS IN CuSX MIXER-SETTLER DESIGN

Relative few USX plants have been built since the uranium price decline beginning in the early 1980s and continuing through to fairly recent times, and only the Krebs and conventional mixer-settlers have continued to be applied along with pulsed columns which have found increasing favour. In the meantime, there have been further developments in CuSX mixer-settler design which are available for application in USX.

Reverse Flow Mixer-Settler

Has been increasingly used in large scale copper, nickel/cobalt and zinc SX operations since the mid 1990s, and is now available through a number of engineering firms. The main difference from conventional the mixer-settler is the addition 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 box and settler designs are essentially the same as conventional units. Settler discharge weirs, piping and valves are all at one end, thus gaining similar advantages to the Krebs design. However, the reverse flow has a larger footprint, larger organic inventory and longer inter-stage piping than Krebs. It has similar access and operator viewing advantages as the conventional design and offers some capex advantage due to having all the mix boxes at one end[14]. The reverse flow concept is shown in Figure 16.

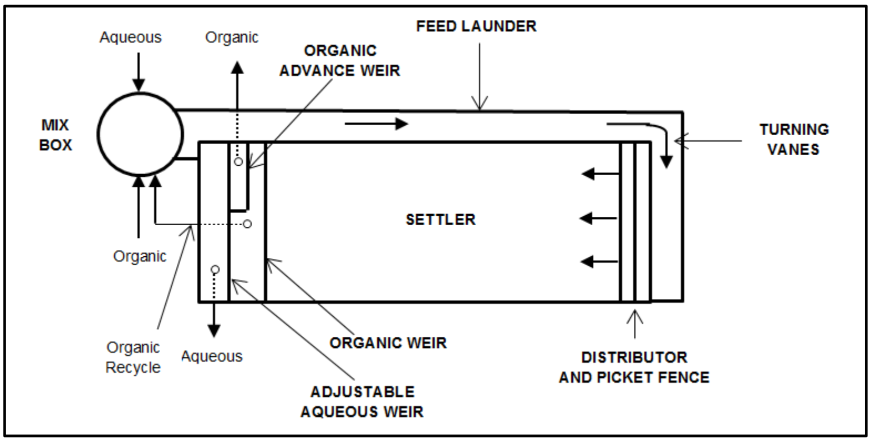

Figure 16: Reverse Flow Mixer-Settler

Outotec Vertical Smooth Flow (VSF) Mixer-Settler

This is a proprietary mixer-settler design developed by Outokumpu in Finland 1990-1993 and has been adopted for a growing number of large scale CuSX projects since 1995[15]. It was installed at the Talvivaara heap leaching operation for by-product uranium recovery in 2012. Inter-stage pumping and mixing functions are split between a DOP (Dispersion Overflow Pumping) unit with a pumping impeller, and a double helix SPIROK mixer which is designed for low shear agitation. An additional SPIROK mix box can be included for large flows. 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[7]. 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. Outotec have continued with further developments in the design of the mix box, mixers and settler, and have introduced modular designs. Advantages claimed versus conventional mixer-settlers include reduced entrainment due to low shear, uniform drop size, and the deep settler discharge end; reduced crud formation due to gentler mixing; and high stage efficiency. The concept is shown in Figures 17a and 17b.

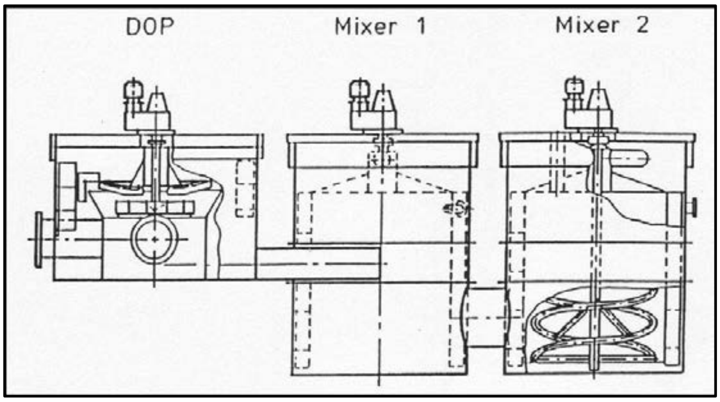

Figure 17a: VSF DOP Unit and SPIROK Mixers[15]

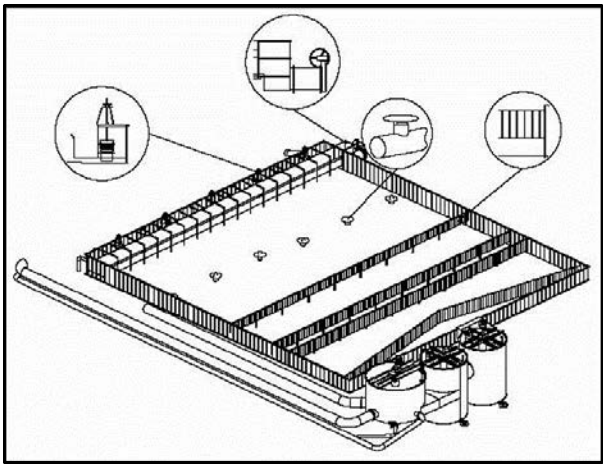

Figure 17b: VSF Mixer-Settler[14]

Miller Metallurgical Services (MMS) Side-Feed™ Mixer-settler

Was developed by Miller Metallurgical Services in Brisbane in 2004 and subsequently installed at numerous copper SX operations. In 2008 it was applied for USX at the Uranium One ISL operation at Honeymoon, Australia. The mixer and settler are realigned so that the feed stream is directed into the side of the settler behind the first angled picket fence. Side feeding is not new having been installed at Cyprus Miami and Kennecott copper operations in USA Arizona in 1970s and 80s; however the concept has been refined by MMS with the settler and mixer orientation now allowing all the piping to be installed on one side of the plant as shown in Figure 18. The side feed arrangement also introduces the dispersion into the settler at the full depth thus eliminating the major feed slot eddy. The feed is split along the width of the settler using staggered and carefully spaced straight distribution vanes. The straight vanes eliminate the swirling flow associated with the curved vanes that are required to turn the flow through ninety degrees in the reverse flow arrangement. This method of distribution has improved the settler operation with flow now shown to be across the full cross section of the settler[16].

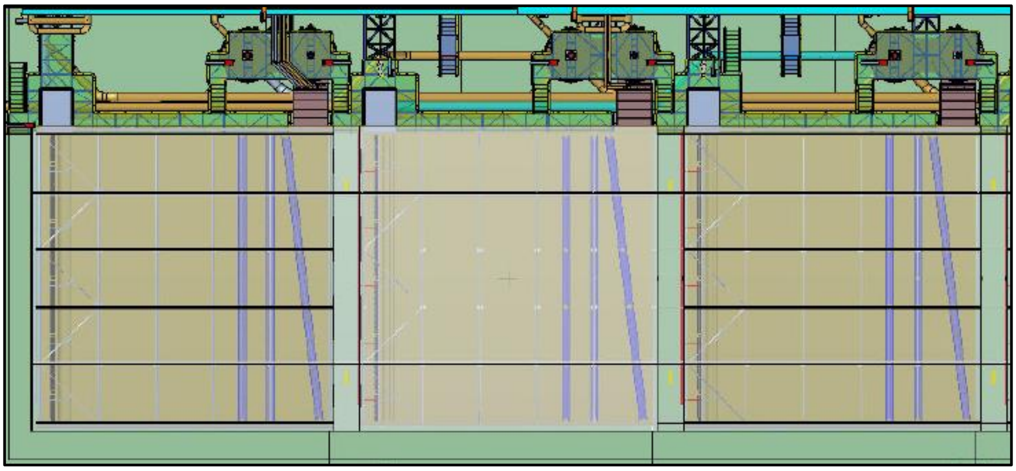

Figure: 18 MMS Side-Feed Mixer-Settler[17]

MC Process Mixer-Settler

Was developed by MC Process in South African and installed in USX plants at Ezulwini, First Uranium Corp in 2009, and Mine Waste Solutions, Simmer and Jack, in 2010, both in South Africa. It is targeted particularly at mid-tier plants. Through use of their innovative new Constant-Q Impeller, the need for a false bottom in the pumper-mixer tank has been eliminated. Instead, due to the geometry of the Constant-Q Impeller, a slight conical section is included in the base of the tank, and the impeller then provides both the requisite pumping and mixing necessary for the USX plants at a tip speed of below 215 m/min. The impeller presents 23.9° discharge angle to the fluid (said to be lower than other designs), and hence causes reduced shear and emulsion formation. There is a distributor attached to the bottom of the pump-mixer tanks, into which up to four inlets may be connected (accounting for one organic feed, one aqueous feed, one recycle line and one other). These streams are all drawn upward, with the cylindrical portion of the four-way distributor acting as the orifice in a conventional false-bottom configuration, as shown in Figure 19. Other features include an expanding distribution channel between mix box and settler to minimize turbulence at settler inlet, height and level adjustability of the aqueous weirs and visual adjustment of recycle percentages in both aqueous and organic weirs to facilitate for mix box O/A control, profiled organic weirs to reduce organic losses due to misting reduce air entrainment in the organic. Vacuum-infused pure fibreglass-reinforced polyester (FRP) is the sole material of construction of SX settlers[18].

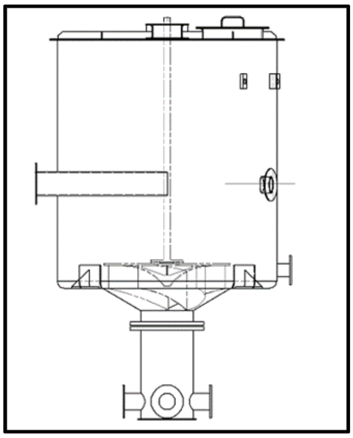

Figure 19: MC Process Mix Box and Constant-Q Pump-Mixer

THE FUTURE?

Possible future developments in mixer-settler design can be considered in four categories: improvements to current designs, revisiting earlier commercial designs, further development of previously piloted designs, and new innovations. The main objectives are opex related - to reduce entrainment losses and power consumption, and capex related - to reduce footprint, settler area and organic inventory.

Improvements to Current Designs

Current approaches include:

- Utilization of CFD modelling of the flow through the settler to identify areas of possible improvement[17][19].
- New impeller and mix box designs[18][20] to reduce power consumption, Improve stage, efficiency, improve phase disengagement and reduce entrainment losses.
- Modification to settler flow distributors, picket fences and discharge weir design to improve settler flow patterns and reduce entrainment.
- Modular design to reduce capex and construction schedule[21].

Revisiting Earlier Commercial USX Designs

Some designs which may be worth revisiting include:

- The use of trays in the settler as used in the Lurgi design in order to reduce settler area, organic inventory and capex.
- The Davy CMS design is particularly applicable to USX extraction duty and offers significant settler area, organic inventory and capex reductions. Its ability to handle to handle up to 300 ppm suspended solids and solids flow surges means that it could treat CCD overflow directly without the need for a clarifier and polishing filters, akin to the fluidized bed IX systems.
- The Kenics design has very desirable mixing characteristics including plug flow in the mix box, low shear, and narrow droplet size range resulting in rapid phase disengagement in the settler and potentially low entrainment losses. Today's improved instrumentation and control systems may make the original settler design easier to operate. Alternatively, consideration could be given to utilize one of the current settler designs. It was reported that a Lightnin static mixer with adjustable vanes coupled with a conventional settler fitted with 2 picket fences was successfully piloted at a uranium plant in Australia in 1999[22].
- The CRA baffles appear to deserve revisiting as a way to either reduce entrainment losses or settler area and organic inventory.

Further Development of Previously Piloted Designs

Some possibilities include:

- The Davy Mckee Segmented Circular Mixer-Settler developed in 1974 which 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, USA) to accelerate coalescence. Periodic cleaning of the pads is necessary to remove accumulated solids and crud if present. Pilot plant tests were carried out on CuSX in Zambia, Zaire and Chile, and demonstration tests were carried out at S.E.C. Corporation in Texas[23]. Cost comparisons with conventional mixer-settlers indicated an installed cost saving of 30-35% and a solvent inventory saving of 30-40%. The main problem was of plugging of the packing although the unit is designed to facilitate removal for cleaning. Interest waned and the concept went into abeyance. Given the potential savings it could be worth considering for further development.
- Vertical stacking of conventional mixer-settlers as a means of reducing footprint and utilizing gravity flow for one of the phases has been piloted and may be of interest for locations with limited flat site area.

New Innovations

Some areas of possible interest include:

- Use of electrostatic or ultrasound techniques which have been investigated in the past but may warrant further investigation.
- Designing the reverse flow mixer-settler feed launder to achieve most to the primary phase break as in the Krebs unit to reduce settler area and organic inventory.

CONCLUSIONS

The early USX mixer-settler designs in the late 1950s and early 1960s and were adopted from the nuclear industry. Inter-stage transfer of aqueous and organic was typically achieved by gravity and/or airlifts or pumps. Settlers were either rectangular divided boxes, generally for smaller operations, or cylindrical for larger plants. Mix boxes were located both external to the settler or within the settler.

The pump-mixer was then introduced and during the 1960s various designs were increasingly favoured for USX operations. Perceived advantages included elimination of inter-stage pumps or air lifts, elimination of individual phase interface sensing and control, operating flexibility, and the ability stop and re-start the feed flow without upsetting the system hydraulics. Settlers continued to be both cylindrical and rectangular though the trend was towards rectangular. Likewise, there was a trend towards external rather than internal mix boxes. Mixing impellers were generally standard flat blade turbines

CuSX emerged in the early 1970s, and because of the relatively high cost of the extractants compared with the amines used in USX, and the need to keep organic out of the associated electrowinning facility, greater attention was given to minimizing organic entrainment, and pump-mixers rather than inter-stage pumps or airlifts became standard practice. The designers of the early pump-mix plants, Holmes and Narver/General Mills and Davy, selected an external mix box and a distributor and/or picket fence to promote even flow velocity across the width of the settler and quell turbulence at the settler inlet. The pump-mixers were either single shrouded with straight vanes or double shrouded with curved swept back vanes. Curved vane single shrouded pump-mixers were later introduced and eventually became standard practice. Apart from the pump-mixers, the overall design concept was similar and became known as the conventional mixer-settler. Besides the use of two or more mix boxes and differences in the design and number of picket fences, the concept has not significantly changed over the subsequent 40+ years!

While copper SX plants continued to adopt conventional mixer-settlers in the 1970s and 1980s, a number of new designs were developed and applied for USX. Objectives included reduction in footprint, especially for indoor operations, and reduction in capex, organic inventory and entrainment losses. The designs included the use of trays or baffles in the settlers, a launder for primary phase disengagement, and static in-line mixers.

Relative few USX plants have been built since the uranium price decline beginning in the early 1980s and continuing through to fairly recent times, and only the Krebs and conventional mixer-settlers have continued to be applied along with pulsed columns which have found increasing favour. In the meantime, there have been further developments in CuSX mixer-settler design which are available for application for USX. These include the reverse flow settler, Outotec VSF mixer-settler, MMS side-feed mixer-settler and the MC process mixer-settler with new mix box and pump-mix design.

Possible future developments could involve improvements to current designs, revisiting earlier commercial designs, further development of previously piloted designs, and new innovations. The main objectives are opex related - to reduce entrainment losses and power consumption, and capex related - to reduce footprint, settler area and organic inventory.

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