# SOLVENT EXTRACTION MIXER-SETTLER DESIGN

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*Abstract* – The paper briefly addresses key aspects of the design of SX mix boxes, impellers, settlers, piping, materials and other features for conventional units. Designs such as Krebs, Outokumpu and reverse flow mixer-settlers, as well as alternative contactors, are not included.

## Introduction

Mixer-settlers were first utilised in the nuclear industry because of their low headroom, which minimised 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. Since then, the use of mixer-settlers has spread to a wide range of applications, and they continue to enjoy favour in the mining and metallurgical industry due to their simplicity, ease of operation, stability under a wide range of flows, accessibility for clean-out and reliable scale-up. Their versatility is demonstrated by their application to small multi-stage installations, such as for rare earths, through to very large scale plants for copper recovery. Consistent effort has been made to improve efficiency and reduce capital and operating costs of the basic design. This has led to the development of new designs, some of which have been commercialised. This paper focuses only on the conventional design. Space necessarily limits the amount of detail presented. References with more detailed information are given.

## Basic Design Concepts

In its simplest form, a mixer-settler consists of an agitated tank (mixer or mix box) in which the aqueous and organic solutions are contacted, followed by a shallow gravity settling basin (settler) where the solutions disengage into individual layers for separate discharge. Multiple mix boxes may be used of either cylindrical or rectangular shape, depending on the desired retention time, capacity, materials of construction and site layout. The settler may also be cylindrical or rectangular, though rectangular is most commonly used in order to provide a more compact layout, and to minimise interstage piping runs.

A typical arrangement is shown in Figure 1, which consists of two cylindrical mix boxes and a rectangular settler. The mix boxes are configured in-line, though an "L" shaped arrangement is also often used. The number of mix boxes usually lies in the range of one to three. One is suitable for small plants using extractants with rapid kinetics. Two or three stages are more applicable to larger plants and longer mixing times. In this particular design, the mix boxes are separate vessels joined by a launder. In other arrangements, especially for large operations, the mix boxes may be formed by subdividing a single rectangular construction, which eliminates the connecting launder. In some cases, they have been made part of the settler. The first mix box is shown with a pump-mix type of impeller, which provides head for interstage pumping of the solutions as well as mixing the two phases. External interstage pumps have generally been avoided because of the risk of creating permanent emulsions leading to high residual entrainment levels leaving the settlers. The second mix box is fitted with a mixing impeller designed for maximum mixing efficiency with minimum shear. The agitators are commonly equipped with variable speed drives to allow the optimum speeds to be determined during commissioning and subsequent operation. The settler is equipped with a full width distributor to spread the flow evenly across the width. This is followed by a picket fence, which serves to dampen solution movement and act as a supplementary distributor. Some designers eliminate the distributor and rely solely on a picket fence. Others add a second or even third fence for some applications. The authors consider a well designed distributor to be highly advantageous. Full width organic and aqueous weirs are shown to minimise the discharge velocities. The aqueous discharge weir box is fitted with a secondary (advance) weir to facilitate the separation of a portion of the aqueous flow for recycle to the mix box. This may not be required in some cases, and in others it may be necessary to provide an advance weir in the organic weir box, or even in both boxes. It is recognised that some designers use other recycle arrangements, but the authors have found this particular concept to be successful and easy to operate. By giving the recycle "first bite" of the solution, it provides a constant hydraulic head for the recycle stream, which can otherwise be difficult to control. The solution leaves the settler via the advance weir box, which provides limited surge capacity for flow variations. All of the discharge pipes are fitted with manual control valves. It is good design practice to install a simple vortex breaker at the inlet to each discharge pipe. Generally, the discharge pipes are connected to the bottom of the weir boxes to avoid air entrainment, which can lead to crud formation and increased entrainment losses.

**Mix Box Details**

The required overall retention time is set by testwork, the extractant supplier's recommendation and industry practice. Typically, it varies from 1 to 5 minutes. The mix boxes are designed to provide this under dynamic operating conditions. This means that the operating crest on each mix box and the volume in the downcomer (or upcomer in some designs) is included. Commonly the mix boxes are designed with the same external dimensions for ease of construction, though some designers prefer to use a smaller first box. The height of each box is generally minimised to reduce construction costs, though this may not be important for smaller plants. Care must be taken in setting the active solution height to avoid vortexing and air entrainment. Typically, a minimum aspect ratio (active height to vessel diameter) of about 0.6 is employed. Adequate freeboard must be allowed in each mix box to account for the crest heights, which depend on the mix box dimensions and the pressure drop through the system.

In Figure 2, the first box is fitted with a false bottom to which the organic and aqueous feed and recycle pipes are connected. The aqueous and organic must be kept separate by installing dividers in the false bottom, otherwise the organic flow will be hindered due to its lower density. If the recycle line is designed for dual use (ie aqueous or organic), it must have its own separate compartment in the false bottom. Some designers use a "boot" protruding below the base of the mix box, instead of a false bottom. This may be an extension of an internal draft tube, which is used in some installations. In another variation, especially where the piping is of very large diameter, the false bottom is extended up the sides of the mix box in order to provide sufficient area for the pipe connections. Following conventional mixing design practice, vertical sidewall baffles are used to promote proper mixing patterns. Each box is fitted with a horizontal baffle at the top overflow port to reduce short-circuiting. Sometimes anti-vortex baffles are installed near the top of the first mix box, especially when the pump-mix impeller is mounted higher up the vessel in conjunction with a draft tube. The dispersion formed in the first mix box enters the second stage via a downcomer to avoid short-circuiting. In some designs, the downcomer is mounted in the first mix box. In comparing various designs, it should be recognised that the design features are often influenced by the preferences of the designer, as well as by plant layout and materials of construction issues.

A variety of pump-mix impeller designs have been used over the years. As plants initially grew larger, especially for copper SX, the applications lay outside of the experience of the equipment suppliers, and the impellers were generally specified by engineering firms and consultants. The most common design was the single shrouded type with six radial straight blades mounted over a cylindrical hole at the bottom of the mix box (which became known as the General Mills impeller). The other common type was the double shrouded type with eight radial swept-back curved blades, usually elevated to about one third of the liquid depth and fed by a draft tube (Davy BB impeller). Key issues are to provide adequate pumping head and mixing power, while minimising the formation of fine droplets, which can lead to entrainment losses. For auxiliary impellers for the second (or third) stage, standard up pumping low shear mixing types have generally been specified. In recent years the equipment supplier Lightnin has undertaken extensive hydraulic test and modelling work to compare different impeller types, out of which they have developed new pump-mix and auxiliary impeller designs, which have since been widely used. A significant outcome is their ability to select the recommended optimum design for each particular application, including the feed hole diameter and clearance between the impeller and the bottom of the mix box in the case of pump-mixers. A vital part of mix box design is the minimisation of the head required to be developed by the pump-mix impeller. Although it has the great advantage of operating as a self-regulating device over a wide range of flowrates, the pump-mixer has a low head capability. Thus, the design head must be carefully estimated and specified to the impeller supplier before finalisation of the mix box design, in case adjustments are required.

**Settler Details**

The design settling area is generally specified from industry experience supplemented by testwork as appropriate. Specific settling area can typically vary from 2 to 6 $m^3/h/m^2$ over a temperature range of 10 to $40^0$C, and is affected by factors such as the type of extractant, extractant concentration, O/A ratio and the phase continuity. An important issue is the minimum operating temperature, as the phase disengagement rate is highly sensitive to temperature, particularly below $20^0$C. At the other extreme, the maximum temperature is determined by organic degradation considerations, and is typically around 40-$45^0$C. The shape of the settler is determined by specifying a width based on an organic velocity within the range of 3-6 cm/sec, derived from industry experience. Above this range, there is a risk of excessive turbulence at the weirs, while lower velocities can result in uneven flow patterns across the settler. Designers vary in their practice but, from a cost point of view, it is usually advantageous to adopt a narrower settler to reduce the cost of the distributor, picket fence, weir boxes, interstage piping and roof. The authors have had consistent success at the upper end of the velocity range. Of course, the velocity is also dependent on the depth of the organic layer. This is usually set as low as possible to minimise the volume of the organic inventory, which is frequently a high cost item. It is commonly within the range of 150-300 mm, and can be varied by adjusting the height of the aqueous weir. The organic weir is normally fixed, and sets the overall static depth of liquid. The settler sidewall height is normally about 1m, which allows for a freeboard of around 200 mm, plus adequate depth for the dispersion band, aqueous layer, and a clearance under the aqueous weir in the range of 100-200 mm. Some designers have opted for a slope down under the aqueous weir box in order to reduce the depth in the main portion of the settler. In some cases, the available site area can have an overriding effect on the shape of the settlers.

Figure 2 shows an inlet distributor consisting of a full width launder fitted with a series of holes in the bottom. The authors have found this to be effective for "killing" the velocity of the incoming dispersion, and achieving a good distribution across the settler width. It may be advantageous to cover the centre portion of the launder to avoid splashing of solutions over the top into the settler and the environment above. A variation of this concept is the use of a HDPE pipe in lieu of the launder, which is particularly advantageous if the settler is lined with the same material. It is recognised that many other designs have been used. The distributor is followed by a conventional picket fence, consisting of two rows of slats mounted offset to force the liquids to go through several $90^0$ direction changes on the way through, as illustrated in Figure 4. Because of the effective operation of the distributor, the fence can be of the low head type. As mentioned above, some designers opt for no distributor; in which case the picket fence must be designed for a higher pressure drop in order to achieve effective distribution. This type of fence is sometimes designed as a chevron, which provides more stilling area immediately in front of the feed from the mix box. Typically, the inlet portion of the settler, with the distributor and picket fence, is regarded as part of the active settler area.

In the design shown in Figure 3, the separated aqueous passes under the organic weir box on its way to the aqueous weir box. However, when a plastic lined construction is used for the settler, it may be preferable to use a "drop-in" one-piece weir box assembly, supported from the settler walls or from external members without compromising the integrity of the lining. In such an arrangement, the organic and aqueous weir boxes are constructed back to back, and the aqueous passes underneath both boxes then flows up and over the aqueous weir in the reverse direction, as shown in Figure 5. The length of each weir box is generally specified to accommodate the connection of the discharge piping. In the case of the "drop in" design, the weir boxes may be extended beyond the settler side walls to enable the bottom connection of the discharge piping without penetrating the plastic lining of the settler. Various designs have been utilised for the adjustable aqueous weir mechanism. A key issue is to eliminate leakages through any joints, which can lead to the undesirable migration of liquids when the flows are stopped. The range of adjustment is set to produce the desired variation in organic layer depth. The discharge weir boxes are not considered to be part of the active area of the settler. It is recognised that other liquid discharge arrangements have been used, including taking the organic or aqueous recycle stream from the main body of the settler, thus significantly reducing the length of the recycle piping. This could be adequate, for example, for small or intermittent recycle flows.

**Piping Design**

A key consideration is the pressure drop through the interstage piping, which must be minimised to keep the pumping head to be developed by the pump-mixers within acceptable limits. This normally requires low pipe design velocities, in the order of 1 m/sec, which can result in large pipe diameters, especially for high capacity installations. Other important issues include the reduction of pipe lengths, minimisation of bends, and careful arrangement of pipe runs and valves for ease of operation and maintenance. This should involve evaluation of various layouts for the entire SX circuit and associated tankage in relationship to associated plant areas, looking at all major pipe runs and connections to the mix boxes and weir boxes. Recycle pipes usually need particular attention, and may require the construction of trenches or pipe way tunnels in some instances. Drainage/refill and crud removal piping for the mixer-settlers also need careful planning, especially if gravity drainage is to be used. Time spent at this stage is paramount in obtaining a well layed out, cost effective overall plant design. Standard piping design criteria can normally be applied to pumped lines. One very important consideration is the accessibility of the manually actuated valves on the interstage and recycle pipes from the upper level walkways near the settler discharge weirs without having to descend to ground level. These valves are frequently used to maintain consistently high levels in the weir boxes under varying flow conditions, to avoid air entrainment. They may also have to be closed on plant shutdown. This facility may require the fitting of long stem valve actuators.

**Other Design Considerations**

A vital aspect of mixer-settler design is the elevation and support of the settlers, which have major implications for overall plant layout, piping design, capital cost and access for operation and maintenance. Three alternative concepts are illustrated in Figure 6. In the first, the settlers are at ground level, and the interstage piping is located in trenches covered by grating or concrete slabs, while the valve actuators are at operator level to provide ready access. This is a particularly convenient arrangement for operators; however it is most suitable when the site topography allows the associated tanks and pumps to be located at a lower level to accommodate gravity flow from the mixer-settlers. Good examples include large copper SX plants located in mountainous terrain the Western USA. For a flat site, this arrangement will involve significant excavation, which can be prohibitive. The other two concepts involve the elevation of the settlers on fill or concrete, steel or wooden supports, and are more applicable to flat sites. Generally the determining factor is the capital cost, which is affected by ground conditions and the price of local materials. With the fill option, tunnels through the fill or interstage trenches are required for some of the recycle pipes. The various options should be carefully evaluated early in the design phase.

The provision of walkways is particularly important, and should be developed with experienced operating input. Key areas include the top of the mix boxes, and the settler picket fences and discharge weir boxes. For indoor installations, mixer-settlers are normally covered to avoid organic evaporation losses and to protect against dust, insects and wind turbulence. Suitably located sampling and inspection hatches must then be installed. It is common practice to provide open area or large hatches above and immediately in front of weir boxes to facilitate manual crud removal and adjustment of the aqueous weir.

The materials of construction can have a significant impact on the mixer-settler design, and therefore must also be addressed early. For example, the selection of HDPE lined concrete can lead to the adoption of a “drop-in” weir box design. HDPE has been selected as a cost effective material for large-scale copper SX facilities, especially when the presence of chloride renders 316 SS unsuitable. For smaller plants, self-supporting FRP has been widely used, and has the advantage of allowing shop fabrication and shipment to site, whole or in segments. Other materials commercially applied over the years include concrete lined with thin gauge stainless, FRP or epoxy-sand mix, steel lined with PVC or epoxy, FRP–balsa sandwich and even wood.

Fire protection measures vary from plant to plant depending on the requirements of the insurance underwriters. The best fire protection measure is the use of a high flashpoint diluent for the organic, which results in a relatively low fire risk, and allows some installations to be equipped with very simple water based fire fighting systems. Others have adopted manually operated or automatic foam based systems. If foam is to be used, it should be AFFF (Aqueous Film Forming Foam) which, unlike some other foams, does not permanently damage the expensive organic liquid. Other design features include gaps between adjoining mixer-settlers (which can be used for walkways) and, in extreme cases, firewalls separating groups of mixer-settlers. Surrounding pad areas and trenches should drain to a safe location, and sumps should overflow into the same drainage system.

## Conclusions

The design of conventional mixer-settlers for the separation and extraction of metals is now well established and proven over a very wide range of capacities. However, details vary according to the particular application, the materials of construction and the preference of individual designers. Overall plant layout and piping design are affected by site characteristics, materials of construction and local cost factors. Fire protection measures are generally driven by the requirements of the insurance underwriters.

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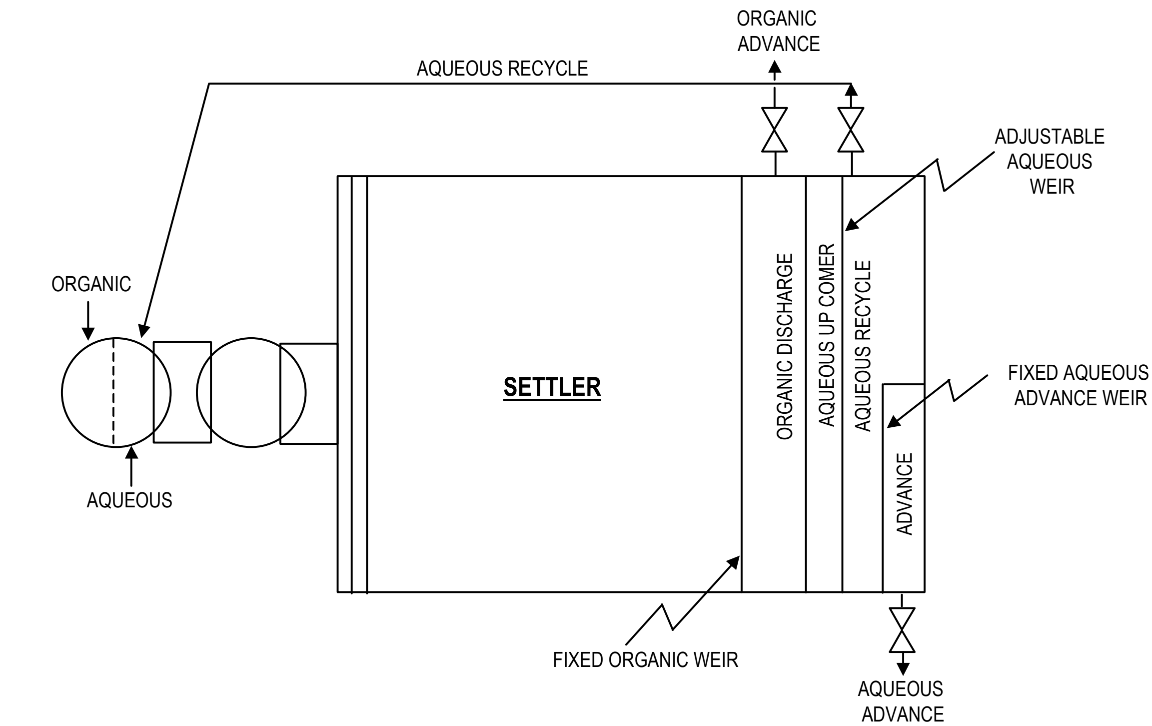
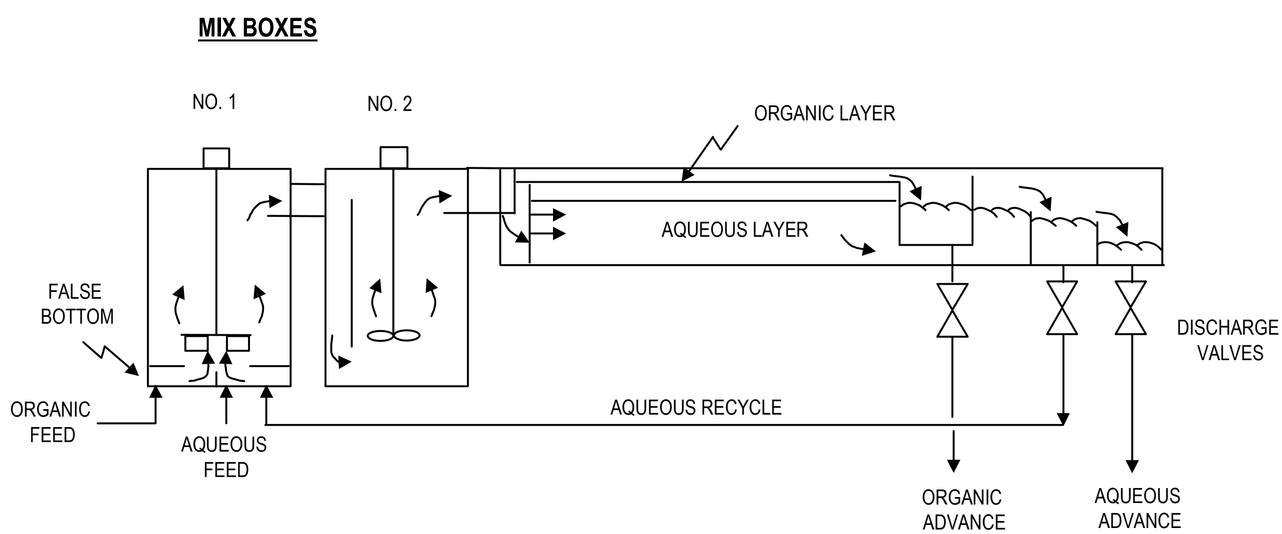
# FIGURE 1

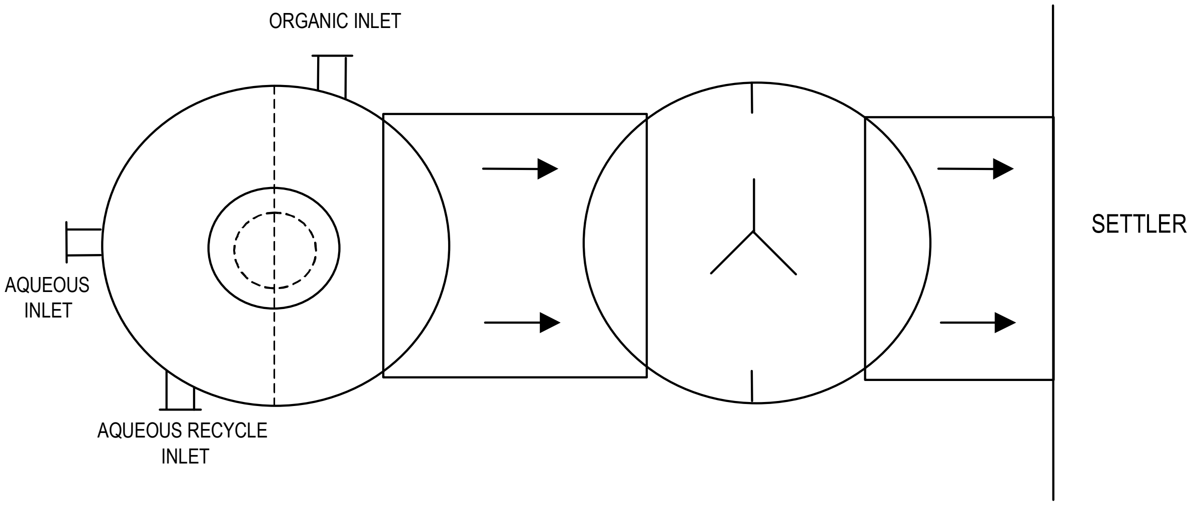
# BASIC DESIGN CONCEPTS

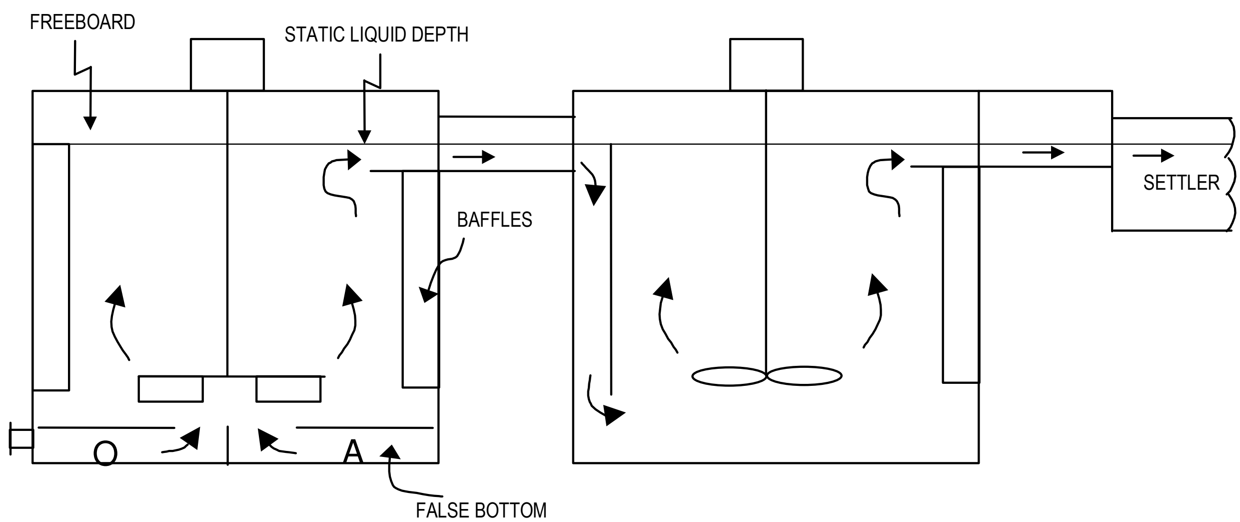


# FIGURE 2

# MIX BOX DETAILS



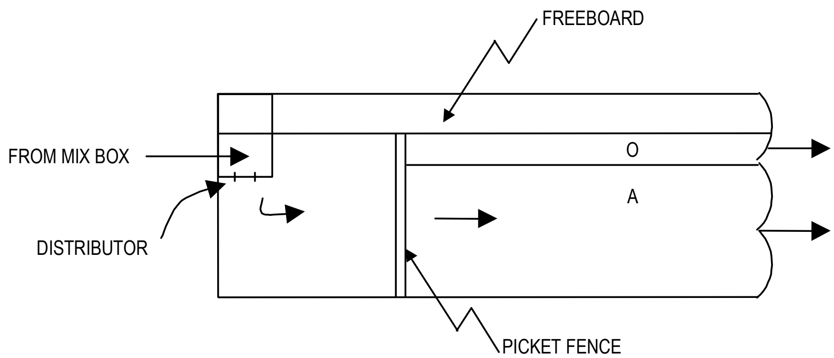

**NO. 1 MIX BOX**

**NO. 2 MIX BOX**

NOTE: False bottom divided into organic and aqueous compartments. Orientation of divider varies with piping layout, including aqueous recycle.

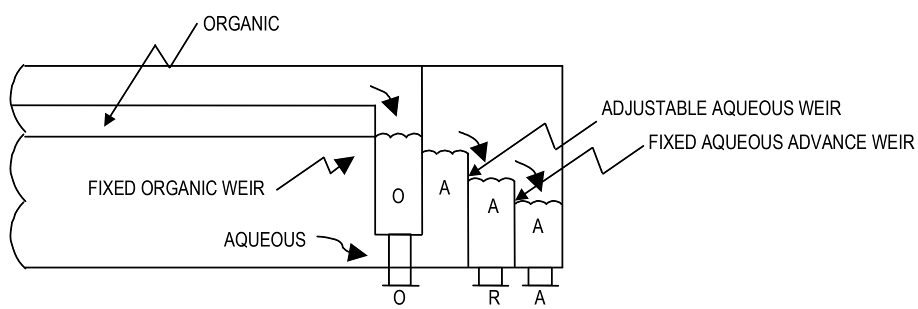
# FIGURE 3

# SETTLER DETAILS



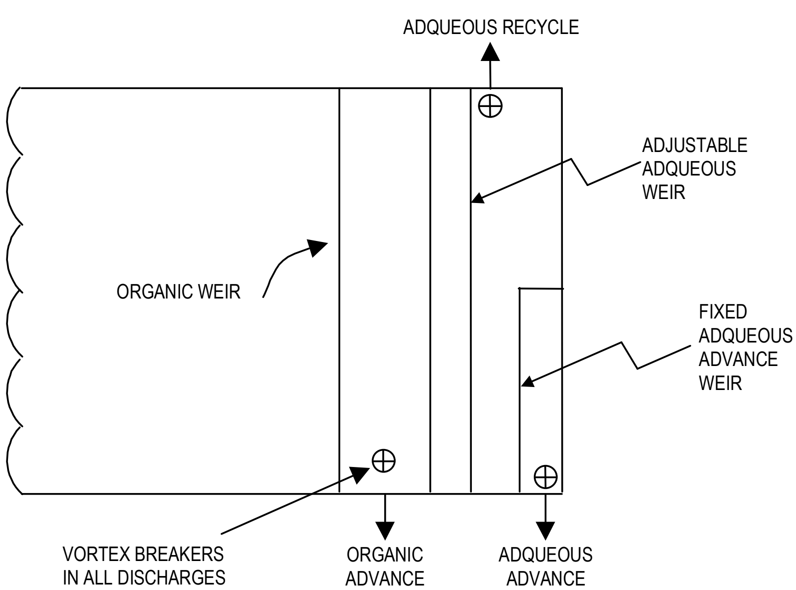

**FEED END**

**ELEVATIONS**

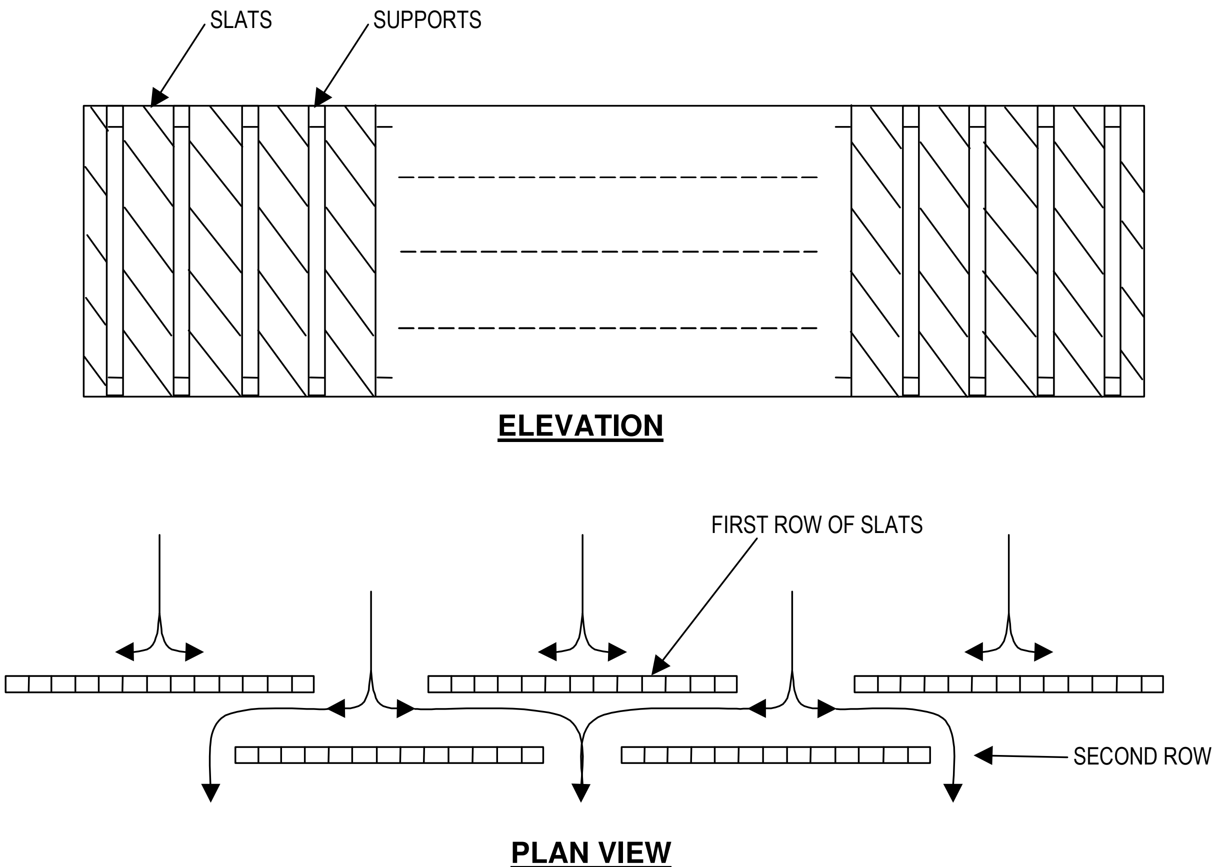



**DISCHARGE END**

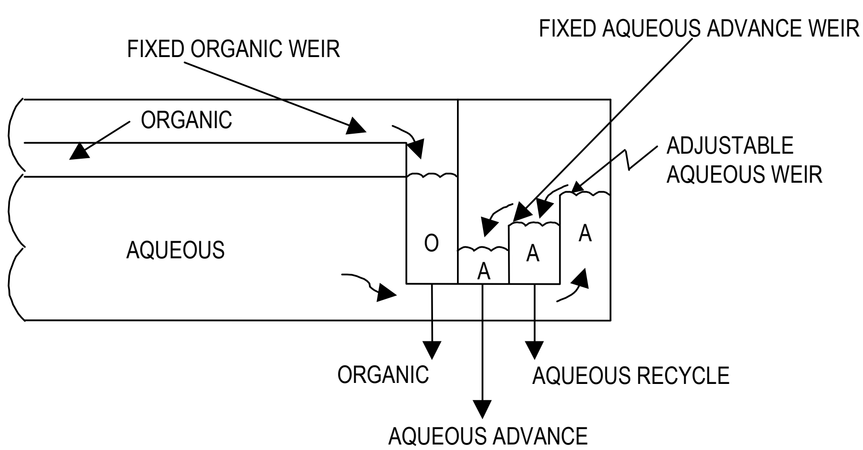
**PLAN VIEW OF DISCHARGE END**



# FIGURE 4
# PICKET FENCE CONCEPT

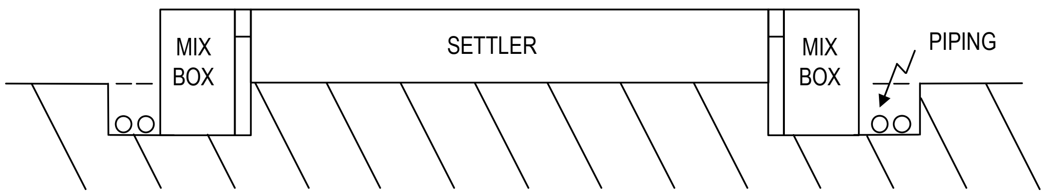



# FIGURE 5
# DROP-IN WEIR BOX CONCEPT

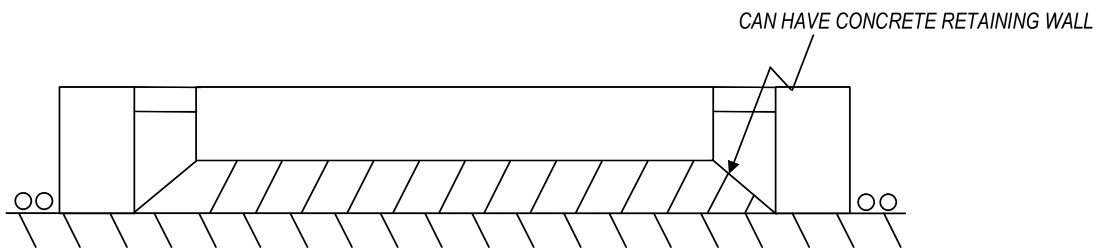


# FIGURE 6

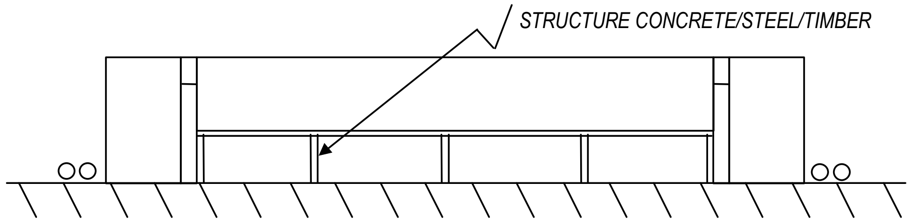
# VARIOUS MIXER-SETTLER ARRANGEMENTS




**GROUND LEVEL**




**ELEVATED ON FILL**




**ELEVATED ON STRUCTURE**