KSB Know-how

Submersible Mixers:

Planning Information

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Preface

This know-how brochure gives an overview of how KSB submersible mixers of the small blade (Amamix) and large blade (Amaprop) variety have been utilized in the past and which applications are possible.

The possibilities of application for submersible mixers are too complex to be fully treated by this document; therefore, it does not aim for completeness.

For the planning and selection of submersible mixers it is important to consider the criteria identified within this document. Ignoring these criteria may result in failures of the mixers, installation accessories and ultimately the overall process.

Should you have any further questions regarding applications that have not been dealt with here, feel free to contact KSB, Inc. for support (sales@ksbusa.com, 804-222-1818).

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The terms used in conjunction with mixing and flow technology are defined as follows:

Aeration

Gas (typically air) is introduced to the fluid in order to trigger oxygen transfer and/or mixing.

For example: Surface aerators, bottom diffusers and nozzles / ejectors are used for the generation of bubbles and oxygen transfer.

Thickening

Process of moisture removal to concentrate a substance or fluid.

For example: condensed milk, the mixing in of fillers, or the raising of viscosity, e.g. through polymerization.

Emulsification

This refers to the mixing of two or more liquids, which are immiscible (un-blendable). Mixtures which after the mixing process do not separate are termed “stable emulsions”.

For example: diluted soluble oil, long-life milk

Homogenization

The process of evenly distributing concentrations or differences in temperature within one or more combined soluble fluids. The mixer has the task of shortening the time taken to achieve even distribution and maintaining or establishing a homogeneous state.

For example: Neutralization, pH level adjustment, prevention of layer formation.

Flow generation

The generation of fluid flows required in process technology.

For example: Horizontal flows in the elimination of phosphate and nitrogen in sewage treatment.

Rheology

The study of the deformation and flow of matter.

For example: Wastewater sludge as found in anaerobic digester has special non-Newtonian properties that must be studied.

Suspension

Mixing with the aim of generating a uniform concentration of solids throughout the fluid. The breaking apart and prevention of sedimentation and floating layers.

For example: Lime milk, sewage sludge, liquid manure. About 95% of fluids which are agitated by mixing machinery are suspensions.

Improvement of heat transfer

Through mixer-generated flows heat transfer between warm and cool surfaces is facilitated and a permanent, uniform temperature can be established.

For example: all endo- and exothermal mixing processes.

Thinning

Agitation to change concentration/viscosity.

For example: Stirring of paints prior to application.

Activated Sludge

Wastewater with biological floc responsible for treatment, which are kept in suspension and aerated. For the purposes of this document it shall have a sludge volume index (SVI) value of 100 ml/g and 80% of the total solids (TS) shall be volatile solids. Sludge with varying properties will not be completely mixed due to abundance of inorganics.

For example: Wastewater found within typical oxidation ditch or sequencing batch reactor (SBR).

As a leading manufacturer of submersible mixers, KSB delivers complete solutions for mixing applications. Not only have the submersible mixers themselves been developed, but equally the application and system technology as well as the know-how for selecting the mixing equipment.

This know-how is based on mixing history, extensive research, experience gained from thousands of field installations, and a thorough knowledge of current mixing technology.

In general process engineering mixing refers to a process achieved through the use of agitating or mixing machinery

Mixing Basics

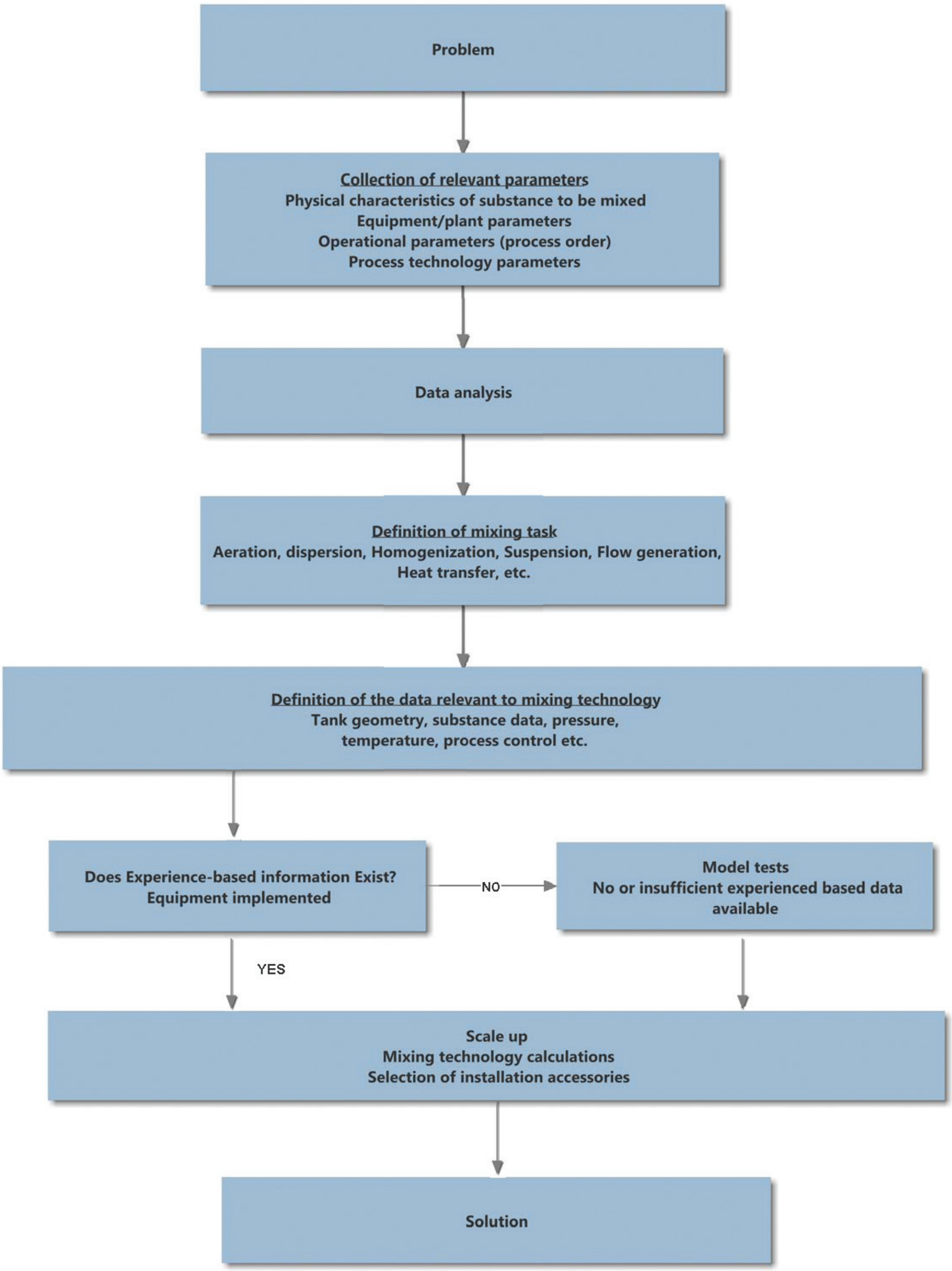
Movement within fluids (defined here as "flowing media"), is initiated by flow generation machinery. The flows include both directed and undirected laminar/turbulent motion which is utilized to tackle specific tasks in associated processes.

In order to be able to realize the importance of mixing, one must first be aware that there are very few products that do not require mixing during production or subsequent refinement. The simplest form of mixing can be something as rudimentary as stirring with a stick or using a cooking spoon for preparation of food in the kitchen. It shall be noted that for given applications this is still "state-of-the-art technology". However, if a greater volume of material needs to be mixed, then appropriate mixing machinery should be utilized. The appropriate machine can vary from a blender used to make a milk shake to large concrete mixer trucks used to supply a job site. This document focuses on submersible mixer technology and the applications for which it is appropriate.

Fig. #1 - Typical WWTP Process Tank (Henderson, NV)

For the optimization of a mixing process, the complete picture including all of the parameters affecting the process must be known. For example, note the above photograph (fig. #1) which depicts a typical activated sludge tank in operation. By just looking at the surface it is unclear if this is an anoxic, anaerobic, or possibly even a SBR tank; furthermore there could be significant flow obstructions sitting just below the water surface. Therefore it is easy to see that when only surface level information is provided, the process success is always at risk. However with the complete picture, economically advantageous solutions ensuring good process results can be achieved.

The following sketched action plan has proved itself reliable in the development of new mixing processes.



Mixer Selection Basics:

For effective analysis and answers to questions it is necessary to work with a qualified mixer manufacturer. The use of all resources achieves necessary integration of the end user into a trusting, well-informed working relationship.

To carry out the mixing task an economical and technically suitable mixer should be selected, i.e. the mixer with the best life cycle cost is preferred for installation. In order to assess the life cycle costs of similarly suitable mixers; the capital cost of the machinery, the maintenance, cost of construction (i.e. walkways, access platforms), and energy costs must all be monitored for a given period of time.

In the field of sewage treatment, submersible mixers are predominantly used for the task of suspension. Visualization of suspension is shown in figure #2, which demonstrates a typical settled sludge blanket being mixed into full suspension. Homogenization and emulsification are seldom required, however when required they can be dealt with alongside suspension. To accomplish suspension, differing strengths of turbulence are required based on the medium to be mixed.

Fig. #2 - Suspension of Activated Sludge

To accomplish suspension with a submersible mixer, a turbulent flow (jet stream) can be generated which incorporates the entire contents of the tank. However a description of turbulent flows is in no case simple, and can never be comprehensive. Turbulent flows have an irregular pattern with complicated time dependence and special variations in speed, such that a single measurement will never lead to a reproducible result. Instead it is a random result.
In general, turbulent flows show the following characteristics:

- Turbulent flows are swirling flows.
- Turbulent flows are three dimensional flows.
- Turbulent flows are temporary flows.

The above information means that an ideal homogeneity (ordered mixture) like figure #3 is impossible in a suspension, only a stochastic homogeneity (random mixture) can be achieved, as shown in figure #4. As you can imagine because this mixture is random a localized velocity measurement is not very useful.

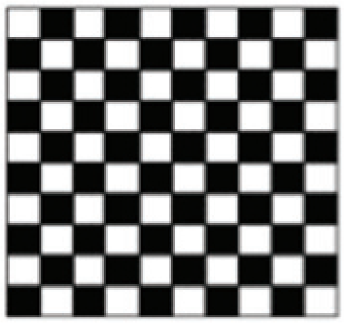


Fig. #3 - Homogenous (ordered Mixture

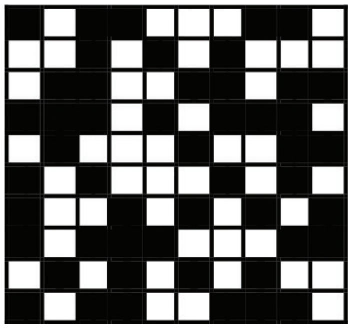


Fig. #4 - Stochastic (Random) Mixture

Therefore the degree of suspension is more reliably determined by evaluating the distribution of the of solids concentration.

Trouble Shooting
If mixing is not being sufficiently carried out; some questions can be asked in order to evaluate the situation:

- How have the mixers been installed?
- How have the mixers been positioned?
- Has a sampling been carried out? If yes, what were the results?
- Has only a visual inspection been carried out to judge the actual condition?
- Are there any problems with the equipment installed upstream (i.e. screens, clarifiers, etc.)?
- Which kind of dry substance content is not being mixed or is available in excess?
- etc.

If clarification through these questions is not possible, then an appointment and on-site inspection by equipment manufacturer is necessary.

Information Required for Mixer Selection
As previously mentioned, the knowledge of all relevant parameters to the mixing system is an absolute must for the selection.

As a rule, even marginal conditions must be equally taken into account. The questionnaire provided at the end of this handbook will help guide you to provide all relevant information.

As a general rule one could say that the more data available, the better the selection of the mixing equipment will be.

Rheological Properties:
Rheology is a relatively young discipline which was founded together with the American Society for Rheology in 1929 where Professor Bingham gave the discipline its name. The discipline centers on the measurement, description of, and explanation behind flowing liquids under the effects of outside forces and deformations.

Rheological investigation is an integral part of both research and quality/production control. Its use in various branches of industry such as chemistry, biology, pharmacy, and the food and beverage industries underlines rheology's growing significance. Even in the field of sewage treatment, rheology can be utilized for the explanation of different flow behaviors. For example in wastewater treatment the behavior varies greatly between statically (fig. #5) or polymer thickened (fig. #6) sludge. In the pictures you can visually see the differences between moistness and pourability (note beaker angle of incline) of the two sludge samples with similar solids content.

Fig. #5 - Statically Thickened Sludge (~5% TSS)

Fig. #6 - Polymer Thickened Sludge (~5% TSS)

Rheology differentiates between three basic properties: viscosity, elasticity and plasticity. In addition, viscoelastic materials exist possessing a unique combination of viscous as well as elastic characteristics.

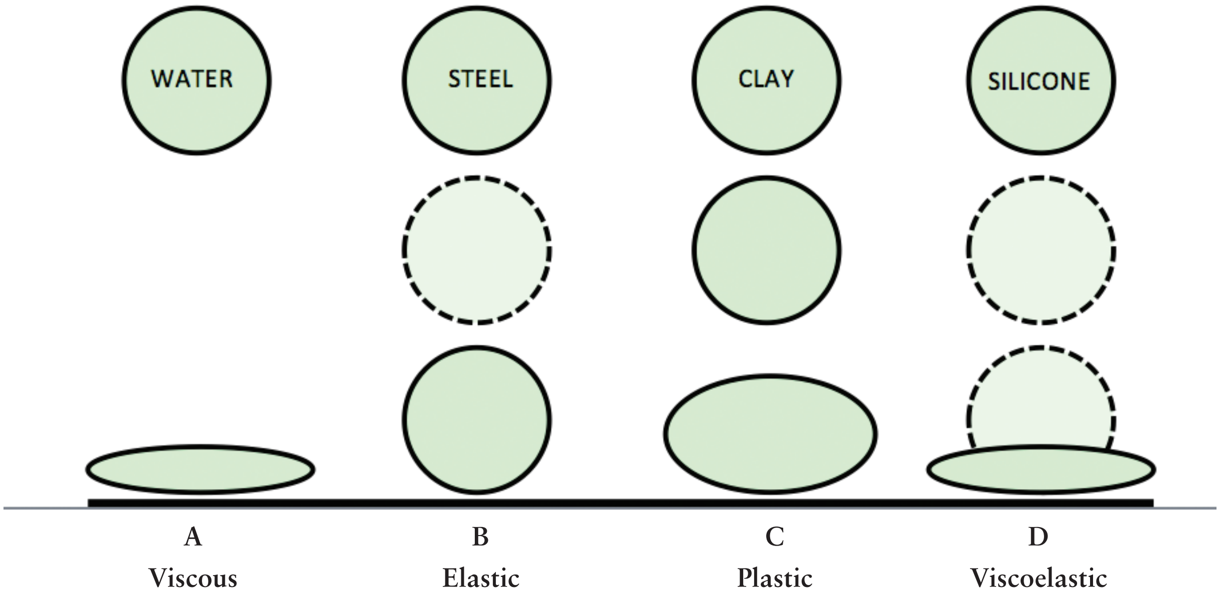


Fig. #7 - Rheological Properties Demonstration

Rheological behavior can be demonstrated if a water droplet, steel sphere, ball of clay and silicone rubber sphere are dropped onto a clean steel plate from a moderate height. Figure #7 and the below descriptions provide the results of such a demonstration.

(A) **Viscous behavior**: after impact the water droplet flows outward until it forms a thin film.
(B) **Elastic behavior:** the steel sphere bounces and eventually comes to rest undistorted.
(C) **Plastic behavior:** the clay sphere becomes deformed due to its malleability and remains in this distorted form.
(D) **Viscoelastic behavior:** the silicone rubber sphere bounces several times like an elastic body, but if left for a period of time, begins to flow outwards like a viscous body.

Viscosity:

In most mixing applications the working media will be a liquid. The resistance to flow in a liquid can be characterized in terms of the viscosity of the fluid if the flow is not turbulent. In the case of a moving plate in a liquid, it is found that there is a layer which moves with the plate and another layer which is essentially stationary (if it is next to a stationary plate). There is a velocity gradient as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed (fig. #8).

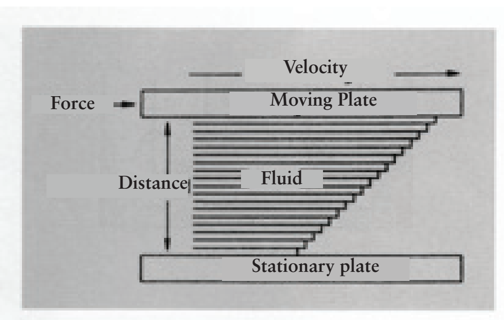


Fig. #8 - Viscosities in Newtonian Fluids

The force acting upon each layer is referred to as the shear stress (τ), and the change of velocity per layer with regard to the distance between the plates as the shear rate (γ). Isaac Newton found a linear relationship between shear stress and shear rate

$$\frac{Force}{Surface} = \eta \frac{\Delta Velocity}{Distance}$$

In the case of a Newtonian fluid, viscosity is a material constant being dependent only upon pressure and temperature. If the behavior of all fluid material could be explained in Newtonian terms, then rheology would swiftly become boring. Moreover, many important phenomena which we all experience in daily life would cease to exist.

Non-Newtonian behavior becomes apparent when a linear relationship between shear stress and shear rate does not exist, i.e. a 50% increase in shear stress does not result in a 50% increase in shear rate. Furthermore, the viscosity value is no longer a material constant but it is rather dependent on the shear rate. Typical shear rate-dependent flow behavior is shown in figure #9.

(A) **Plasticity:** These materials have a yield point, i.e. theyonly begin to flow when a certain shear stress has been reached.
(B) **Shear-Thinning:** Also known as pseudo-plasticity or intrinsic viscosity. If the shear rate is increased, these materials exhibit a large decrease in viscosity.
(C) **Shear-Thickening:** Also known as dilatant exhibits opposite characteristics to shear-thinning. An increase in shear rate precipitates the relativelyrare phenomenon of an increase in viscosity.

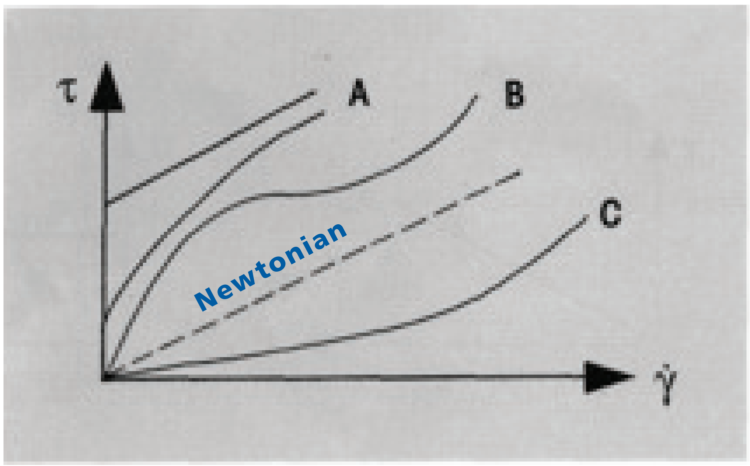
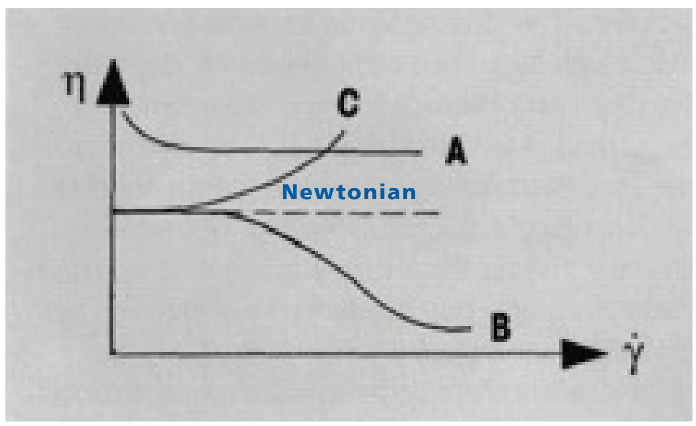


Fig. #9 - Non-Newtonian, shear rate-dependent flow behavior (dotted line = Newtonian)



Applied Rehology:

A typical example of shear-thinning behavior is displayed by ketchup or whipped cream in a can: if the bottle is shaken with a reasonably constant motion, then the previously reluctant fluid will begin to flow. Once the bottle is placed on the table again, the contents return to a more solid state.

This is all very relevant because the majority of municipal and industrial waste sludge exhibit shear-thinning behavior, and therefore possesses intrinsic viscosity. Such example is shown below in the following figures #10 & #11, which show the affect that mixing has on such sludges.

Fig. #10 - Anaerobic Digester Sludge - No Mixing

Fig. #11 - Anaerobic Digester Sludge - After Mixing

Main fields of application:

- Municipal sewage treatment plants
- Industrial effluent treatment plants
- Agriculture
- Water Quality

Submersible mixers are an integral part of the equipment required in sewage and effluent treatment plants. The universal usage of submersible mixers since the 1960's has led to a broad spectrum of applications; hence, they are successfully used at many stages of water treatment such as:

Equalizer tank	Activated sludge tank	Nitrification (Aeration)
Thickener	Neutralization	Digestion tank (Anaerobic)
Denitrification (Anoxic)	Phosphate elimination (Anaerobic)	Selector tank
Oxidation ditches	Sand trap	Disinfection
Pump station	Buffer tank	Sludge holding tank
Reaction tank	Storm-water retention tank	Storage tank

Fig. #12 - Hartford County, MD WWTP utilizes > 100 submersible mixers for various applications

The essential submersible mixer tasks can be described as follows:

1. Sludge Agitation
Suspending or re-suspending viscous media

Sludges produced in process engineering are made for further use. For example Bentonite (drilling mud) is needed for sealing soils during drilling, or lime milk is used for conditioning sewage sludges. On the other hand sludges are often just waste products which must be disposed of.

For further sludge treatment, it is necessary to turn them into pumpable mixtures of homogenous consistency. If they are thickened for later transport it is important that the sludges that are fed to the dewatering equipment (e.g. centrifuge, belt filter or chamber filter press), be well mixed. A homogenous consistency is also required for municipal sludge used in agriculture land application.

2. Flow Generation
Maintaining certain flow conditions and/or pre-defined flow velocities. (Suspending solids and sludge flocculants in water)

Enhanced Nutrient Removals (ENR) of Phosphate and Nitrogen are ever important technologies in sewage or effluent treatment systems. Generating and maintaining the flow conditions required by the biological process is vital in the anoxic, anaerobic and aerobic treatment stages utilized for ENR. In sewage and effluent treatment plants, submersible motor mixers are preferably used to produce these flows.

Pratical Application:
The practical application of submersible mixers in the flow reactor (tank, reservoir, channels, ponds, aeration system, etc.) requires an exact knowledge of the effects of flow restrictions to be expected, both in terms of quantity and quality, as well as of the fluid mechanics. All of the three elements, the reactor, the mixer and the medium create one interactive system. A typical design goal is to effectively mix the system while utilizing minimum power. Assuming one parameter, the medium for instance, is constant then only the remaining parameters can be modified to increase efficiency. However more commonly both the medium and the reactor cannot be altered, therefore the mixing efficiency is driven solely by the mixer selection. In these situations the submersible mixer provides the most flexibility / options to optimize the system.

Mixer Sizing:

All processes that utilize mixers have a specific mixing result that needs to be achieved. Typically desired mixing results are complete suspension of activated sludge or a certain cross-sectional mean flow velocity. The energy density (power per tank volume) necessary to acquire such mixing result can serve as an extremely valuable evaluation criterion. This evaluation criteria is supported by the wastewater industry standard mixing document VDMA 24656 : 2010-03.

Energy Density = P_1 / V

P_1 = electrical power (W) from the electrical system at the operating point (wire to water power)
V = tank volume (ft^3)

However energy density varies greatly from tank to tank and among various mixer designs. Therefore it is valuable to know how to calculate the power of mixers and the parameters involved in the mixing process itself. The key to mixer performance is that with constant flow velocity (equilibrium) the forces involved in the mixing process are the determining factor. Therefore forces or thrusts, which are independent of power, are the necessary method for mixer sizing. For further details of the hydraulics required to reach equilibrium, see "Flow Build-Up" section 6.

Thrust $F_{req.} = F_1 + F_2 + F_3 + F_4 + ...$

$F_{req.}$ - required thrust (maintaining the balancing conditions for a defined velocity)
F_1 - internal friction in the fluid (turbulent movement in the fluid, jet stream vs. bulk flow)
F_2 - external friction on the wetted areas (floor, walls, obstructive installations)
F_3 - forces resulting from geometry losses (tank shapes, deflectors, obstructive installations etc.)
[fig #13]
F_4 - forces resulting from flow streams (inlets/outlets, air supply during aeration etc.)

Strictly speaking, the forces F_3 and F_4 belong to the internal and external frictions F_1 and F_2 as these losses mainly derive from flow separation and are caused by turbulent flows. Due to the interference effects, the total flow loss of the resistances in series is not equal to the sum of the individual resistances.

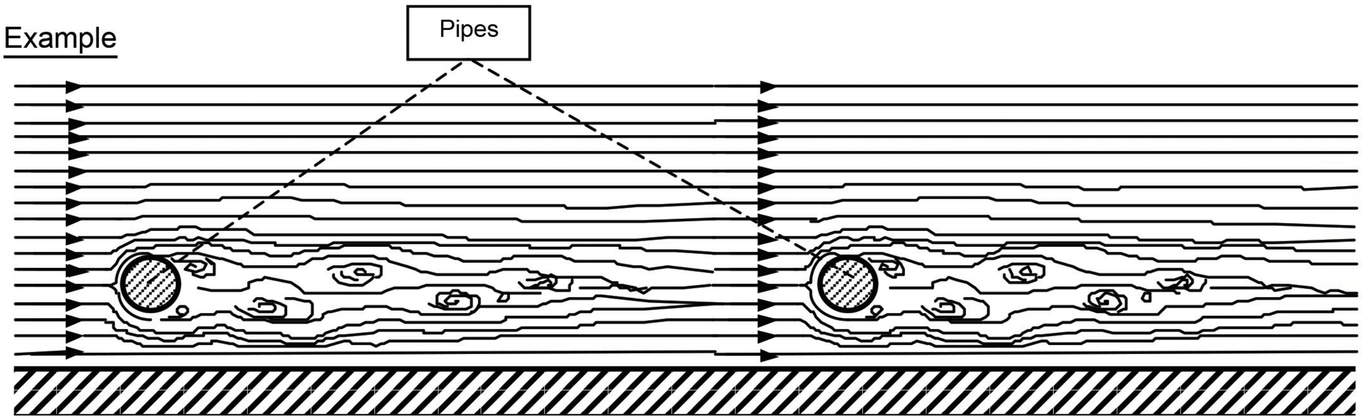


Fig. #13 - Example of turbulent flow from obstructive installations

The calculated required thrust is compared with the available thrust of the mixers and provides the required size and number of mixers to be used. Once the mixers are selected on a basis of thrust, then power requirement can be determined because the mixers' input power (P1) at the operating point (given thrust) is known via factory testing as shown in figure #14. This factory testing is done in accordance with the relatively new ISO 21630 standards released in 2007. **Note that there is no direct correlation or simple calculation to compare thrust to power; therefore it is not appropriate to size or compare mixers on a power basis!**

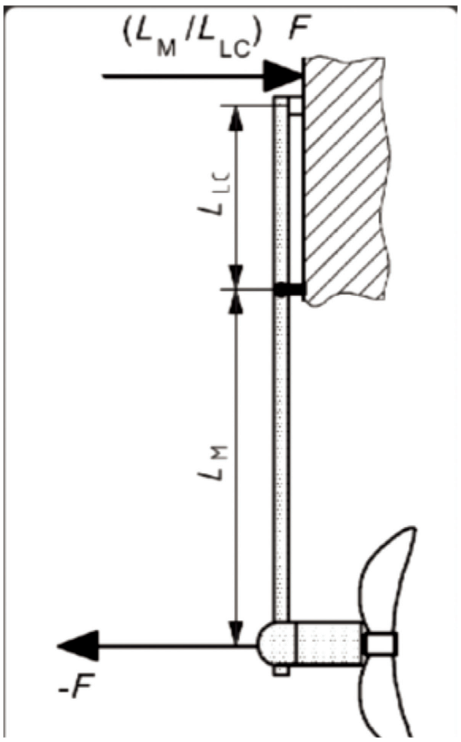


Fig. #14 - Thrust measurement apparatus for testing per ISO 21630

The last factor to be calculated is the energy density which can be used to compare different mixer makes, models, and technologies. Therefore energy density is a great tool for evaluating various solutions for a specific application, however be careful because the specification of a pre-determined energy density will not lead to correct results!

The energy density is influenced by the:

- tank geometry
- tank volume
- obstructions
- inlets / outlets
- aeration
- propeller diameter
- propeller speed
- propeller hydraulic design
- motor efficiency

The aim of KSB development efforts is to find favorable solutions in terms of energy consumption. Improving the propeller efficiency leads to a reduction of the energy density. If the energy density is specified, it will actually impede technically favorable developments! This also applies to the closely related average velocity gradient (G), which is discussed in the Metcalf & Eddy Wastewater Engineering Treatment and Reuse handbook.

Flow Build-up:

After the mixer has started-up and reached operating thrust, the flow will slowly build-up as illustrated below in figure #15 until it has reached the equilibrium conditions (average flow velocity).

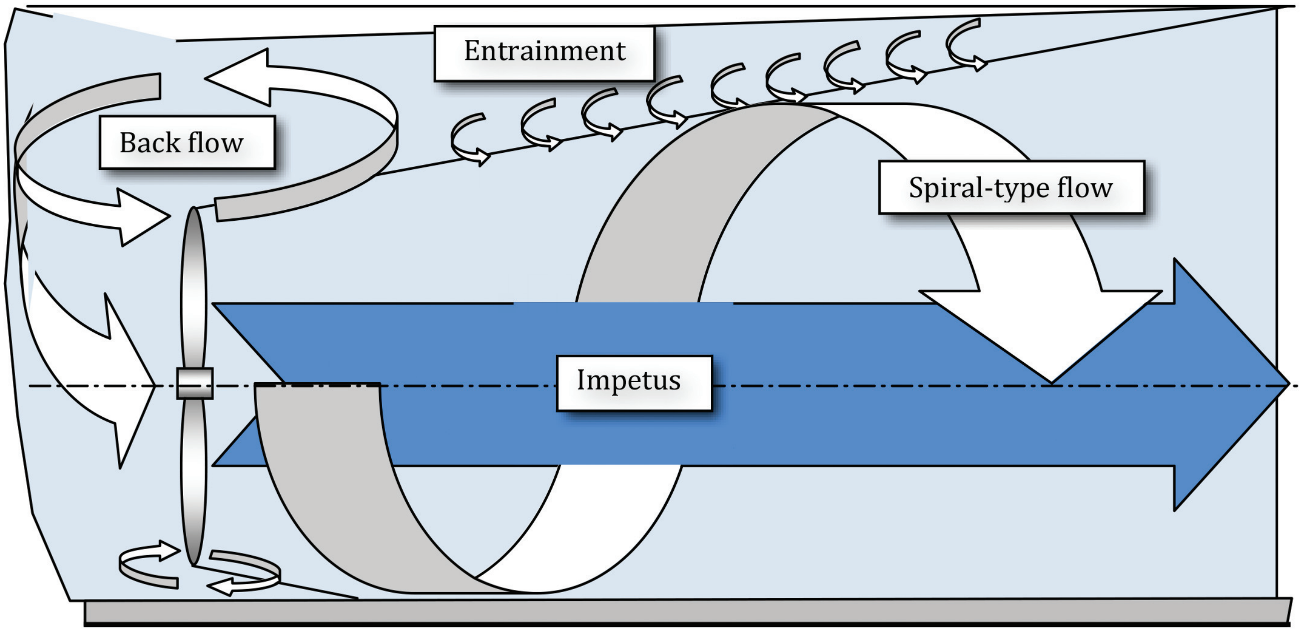


Fig. #15 - Flow Build-Up

The propeller's capacity depends on the propeller diameter, the speed and its hydraulic characteristics. The developing flow (jet stream) which comes in contact with the propeller's rotation becomes a far-reaching spiral-type jet stream as shown in below figure #16. A shearing stress takes place along this outer edge of the jet flow; which is the friction between jet stream flow and the slower moving liquid to be mixed outside of the jet stream.

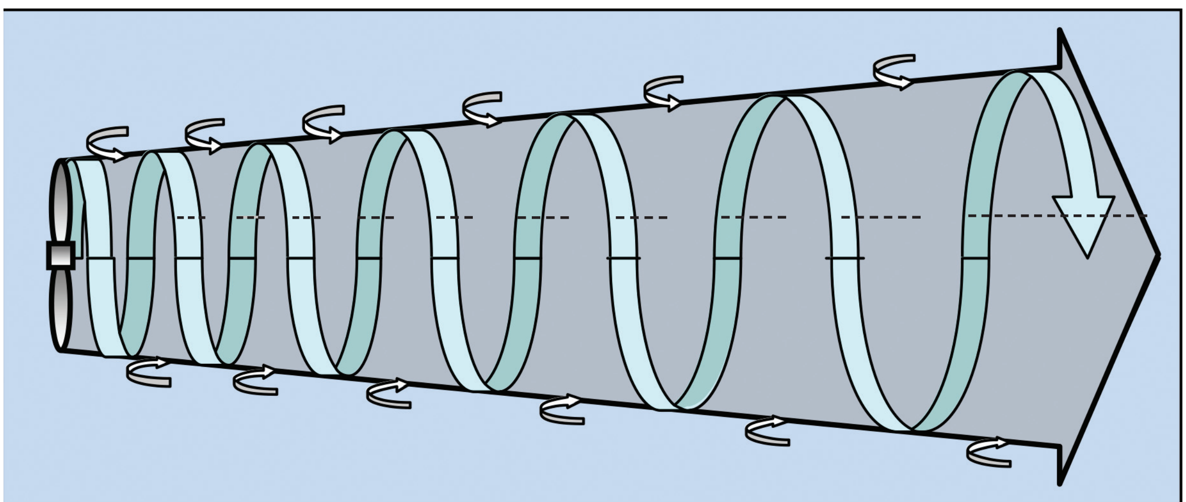


Fig. #16 - Jet Stream

Intensive mixing is achieved when the jet flow comprises the entire tank volume and induces a bulk flow (channel flow). The bulk flow is subjected to swirls induced by the propeller, but certain geometry dependent fluid dynamics (flow mechanics) will develop in every tank. Typical features are demonstrated below (fig. #17) in a “racetrack” type tank equipped with a partition.

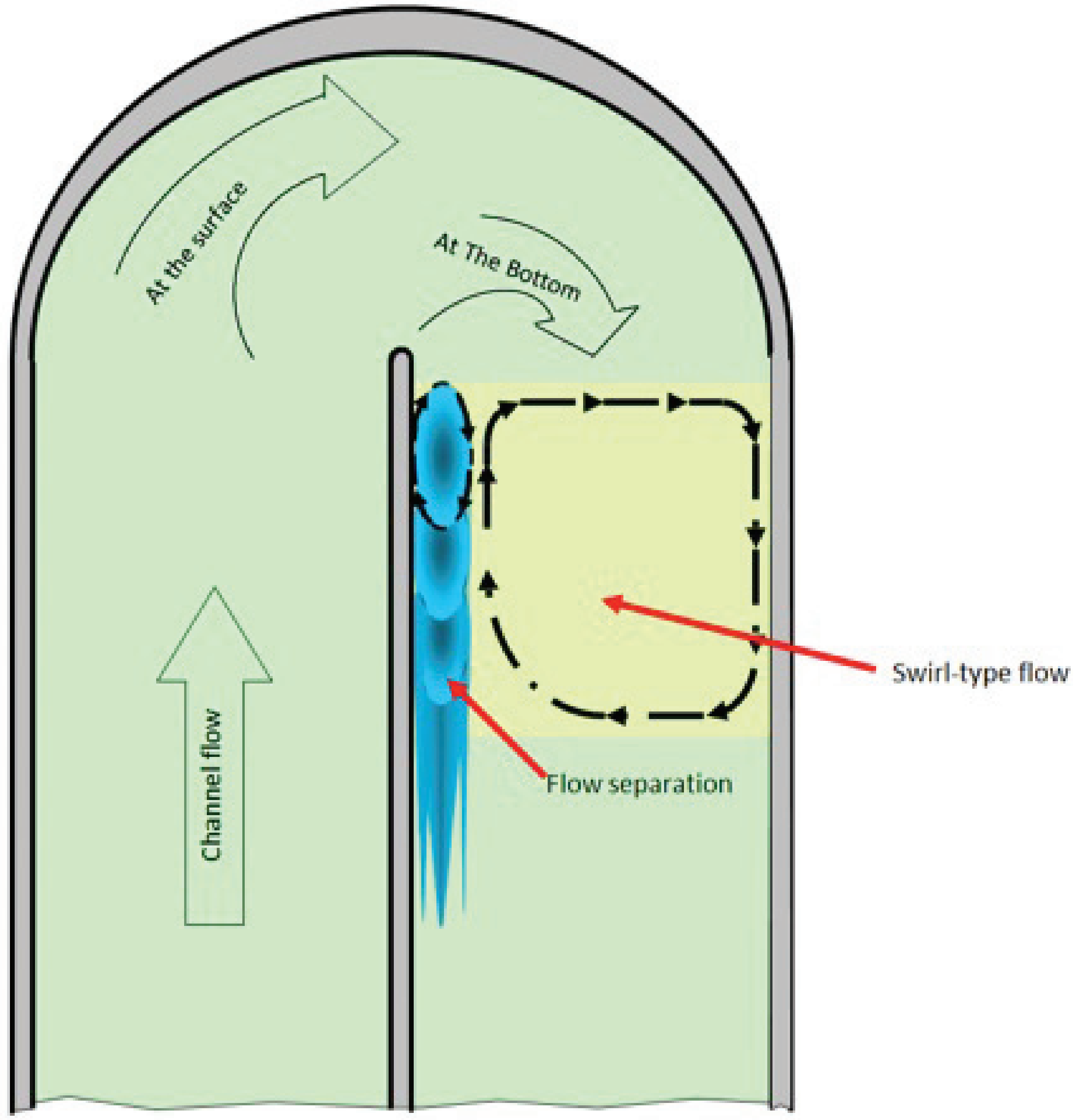


Fig. #17 - Flow deviations in a racetrack

The swirl-type flow interferes with the bulk flow (channel flow) in the cross-sectional area of the partition. The straight channel flow hits the tank wall in the curve, decelerates and is directed to the floor so that a curved spiral flow develops in the cross-section.

Furthermore a flow separation develops behind the partition and displays itself as a relatively stationary flow obstruction to the main flow. The reduced cross-section - due to this separation of flow - accounts for the majority of the losses with this particular geometry.

The build-up of the flow is terminated as soon as the equilibrium conditions have been reached (fig. #18). This is achieved when all forces impeding the build-up of flow are effective and there is no further increase of the bulk flow. It is this equilibrium condition that is most often desired in wastewater applications.

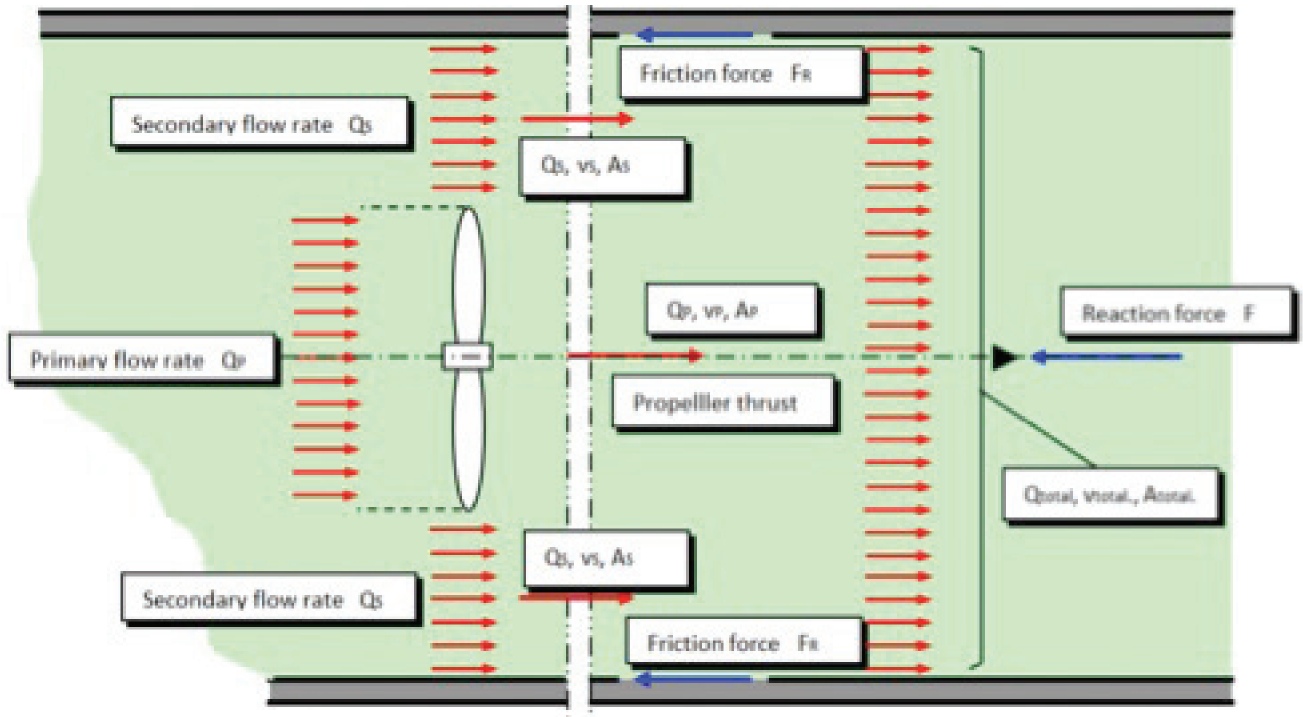


Fig. #18 - Equilibrium Flow Forces

Equilibrium conditions are:

Total propeller thrust = Total reaction thrust

Theoretical Circulation Time:
In many applications the circulation time is of interest to the designer. For example it is common to evaluate the circulation time in extended aeration oxidation ditches (fig. #19). The theoretical circulation time is the quotient of the tank volume and the mixer's flow rate. This value gives the theoretical time it takes for the mixer to circulate the complete contents of the tank one time.

$$t_{circulation} = \frac{V_{tank}}{Q_{mixer}}$$

$t_{circulation}$	(s)
V_{tank}	(ft^3)
Q_{mixer}	(ft^3/s)

One should not mistake the theoretical circulation time for the effective mixing time. The actually required mixing time depends on the medium to be mixed and its rheological characteristics.
As the rheological characteristics are usually not known, the circulation time is approximately taken as the mixing time.

Fig. #19 – Typical Oxidation Ditch (Malatya Turkey)

Furthermore proper mixer quantity and positioning is critical to ensure that total tank volume is actually circulated, such that flow paths are not short circuited. Not all fluid must directly move through the mixer in order to gain velocity. For more detailed information see further discussion in "Flow Guidance – Mixer Positioning" section 11.

Flow Velocities:

The number one question when designing is which velocity is correct?

Typically the horizontal flow shall be big enough to avoid sedimentation. The velocity to acquire sediment free operation depends on the substances in the liquid (sludge flocs, sludge, fibers, sand, etc.). Furthermore the size and abundance of these substances or particles depends on the type and quality of the upstream pre-treatment equipment.

From typical civil/ environmental engineering literature, we have specified **maximum** velocities to avoid erosion of channel contents (Table #1). These erosion velocities can be roughly applied to the necessary **minimum** velocity for horizontal transport of these same particles.

Channel Wall Material	Velocity (ft/s)
Sludge	0.33
Loose, not yet settled loam	0.50
Fine sane (0.4 mm)	0.50
Medium-fine or medium-corse sand (0.7 mm)	0.66
Coars sand (1.7 mm)	1.15
Fine gravel (2-5 mm)	2.00

Table #1 - Erosion Velocities

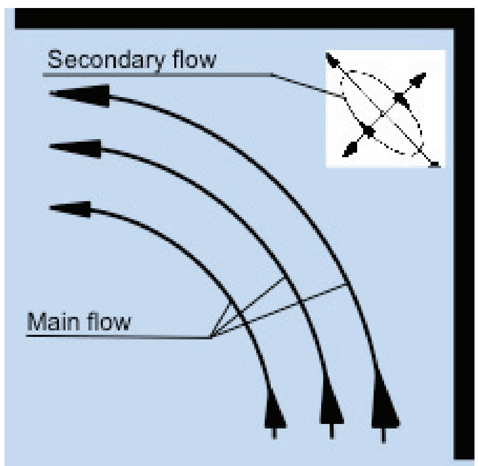


Fig. #20 - Corner Low Flow Area

Past investigations have revealed that the required horizontal flow for the transport of a sludge floc can actually be smaller than 0.33 ft/s. However, the usual requirements for flow velocities that are currently used in project specifications have a range between 0.66 to 1 ft/s. One of the few published guidelines is from the Metcalf & Eddy Wastewater Engineering Treatment and Reuse handbook, which notes typical oxidation ditch channel velocities of 0.8 to 1.0 ft/s.

Flow Distribution:

Just as important as the velocity value itself is the way in which it is defined. It is common for specifications to require a certain velocity (e. g. ≥ 1 ft/s) at each point of the tank, but in practice this is not feasible. As mentioned previously, every tank shape has areas of low-flow; plus regardless of tank shape the velocities at all walls, floors, and changes of direction will be zero. From a physical point of view, it is not possible to maintain a defined flow in these areas; however sedimentation is not expected to happen.

For example, in the corners of square and rectangular tanks one can observe a vertical swirl-type low flow zone (Fig. #20). Because this flow fluctuates and is stochastic there are no deposits, despite the lack of bulk flow velocity. Low-flow areas such as this can also be found behind obstructive installations and behind inlets and outlets.

Further complicating the situation is the fact that a simple calculation method capable of providing the velocity at a certain point in the tank does not exist. In fact, it requires a very time consuming and expensive computational fluid dynamics (CFD) model simulation to solve this problem. KSB provides such CFD models for very special tank geometries or as requested by the customer, but typically such detailed local velocities are not necessary to ensure adequate mixing for the process.

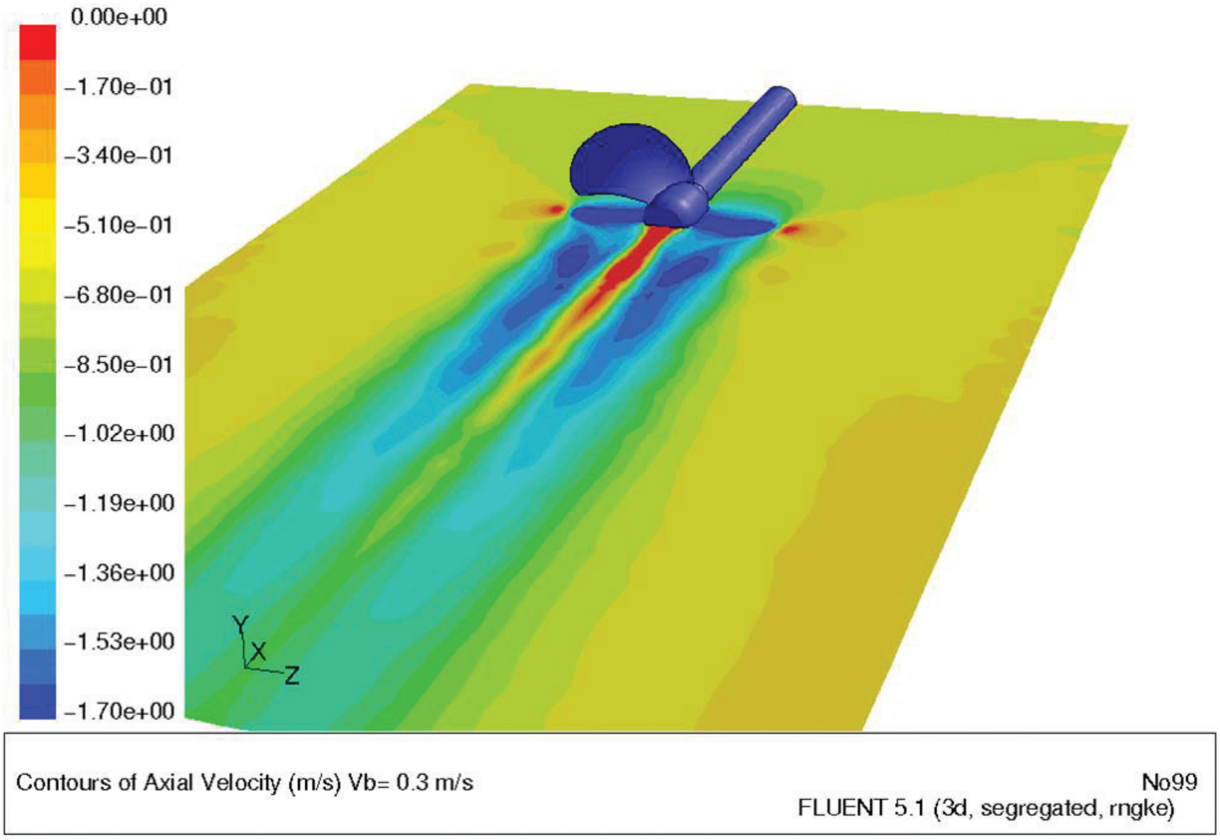


Fig. #21 - Localized CFD Flow Velocities

Therefore in practice a hydraulic calculation of the flow which only takes the tank friction losses into account is utilized. The limitation of this method is that it only provides a value for the **mean** flow velocity in the cross-sectional area. Thus only a mean velocity in the defined cross-section can be ensured. Due to the complex flow processes, another definition is not feasible.

Special Flow Loss Case - air supply (transverse flows):
In applications with air supply, transverse (vertical) flows with regard to the horizontal mixer flow occur which influence the flow distribution in the cross-sectional area. Therefore in addition to specifying the guaranteed mean velocity in aerated tanks, it is also necessary to indicate the square footage of aerated floor area and associated input air volume (SCFM). Since 100 % air supply is typically required only in the event of a malfunction or accident, it must be defined for which air supply conditions that the specified horizontal mean velocity is necessary.

For example it seems appropriate to specify a mean velocity of 1 ft/s without air supply. However, in the event of a maximum air supply (malfunction/ accident) a mean horizontal velocity of 0.5-0.66 ft/s should still be available.

The applicable velocities must again be determined by taking the expected solids into account. However when combined with aeration it is also important to consider typical operating procedure and how much if any mixing will be accomplished by the aeration.

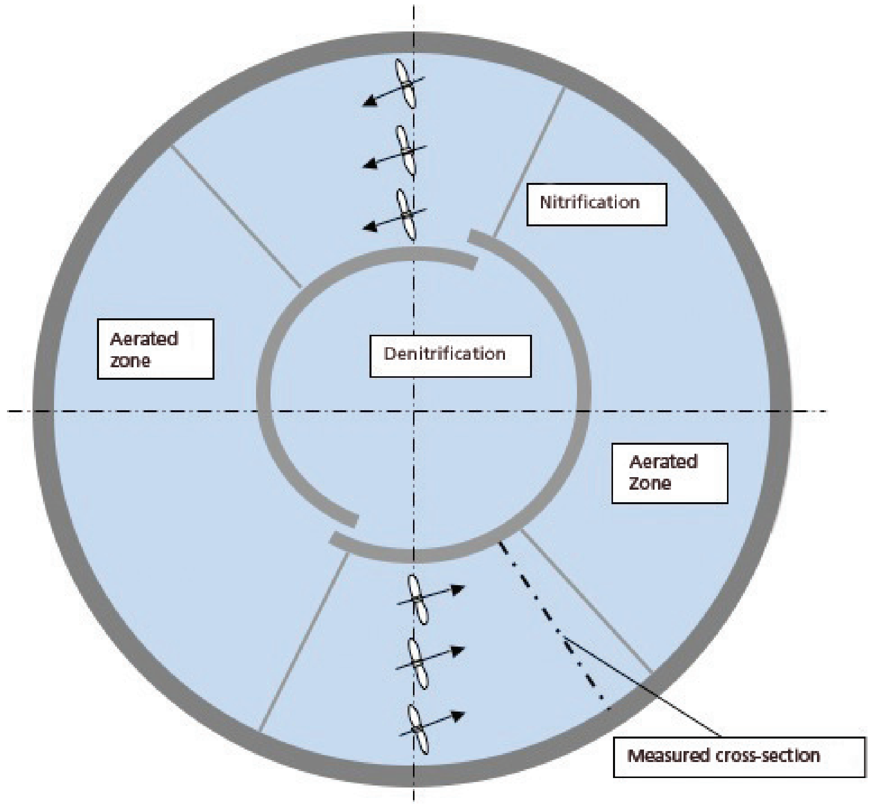


Fig. #22 - Schematic of Ring Shaped Test Reactor

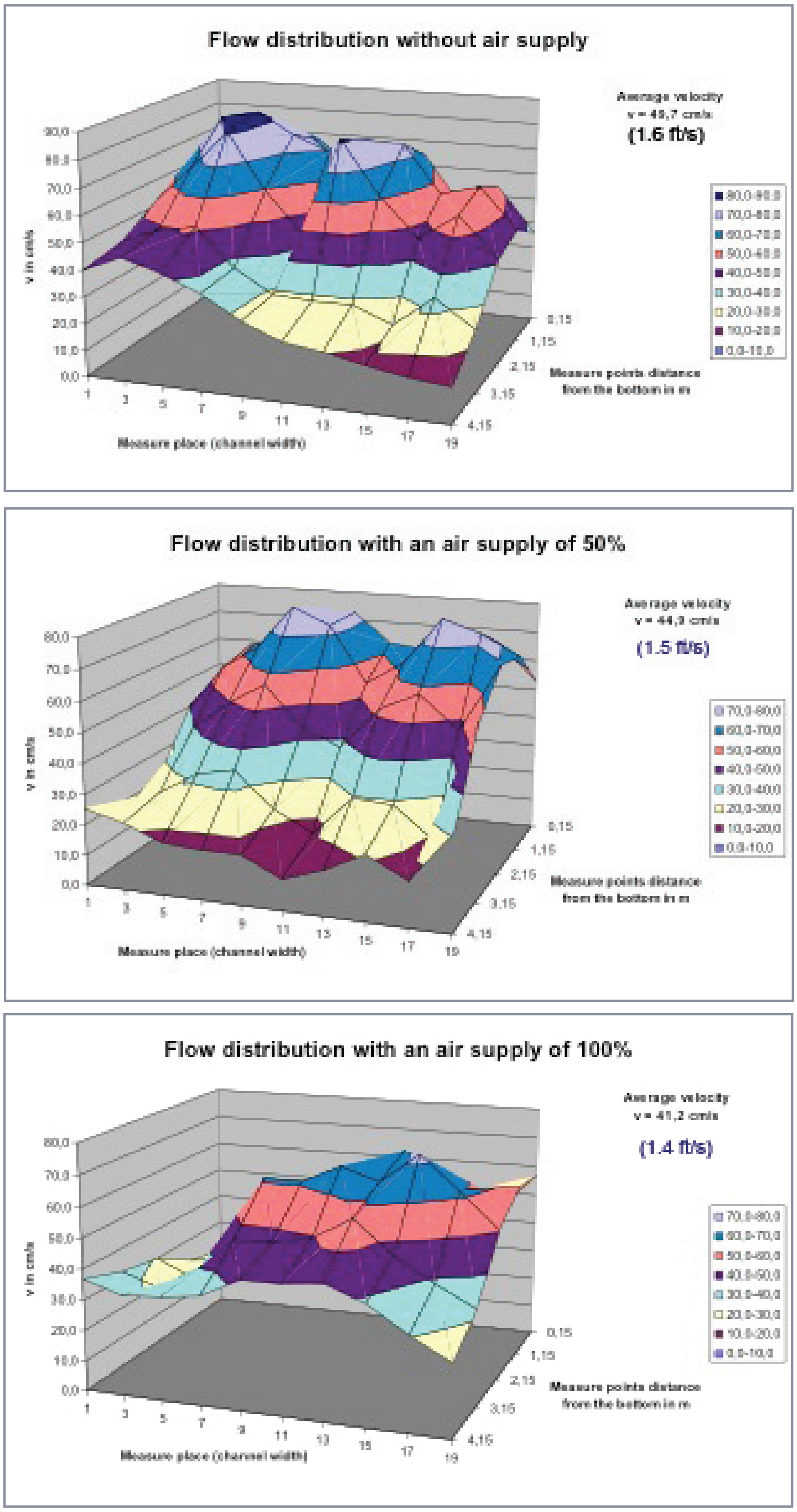
Example field test of mixing with aeration:

Ring shaped nitrification/aerobic tank (Fig.#22)

Quantity:	6 mixers
Tank Volume:	1.5 million gallons
Channel Depth:	16.5 ft
Max Air Supply:	7,770 SCFM
Propeller ∅:	8.2 ft
Power (P1):	4.7 hp
Energy Density:	0.10 W/ft3

The flow measurement was carried out at three different air supply rates (0, 50, & 100% of max air supply). The change of the flow distribution is displayed in the following diagrams (fig. #23). Note that as air supply increases the horizontal velocity becomes more constant across the tank depth, however the losses from transverse flow cause the average horizontal velocity to decrease.

Fig. #23 - Velocity Results (0%, 50%, & 100% air supply)



Mixing with Diffusers:

Previous section 8 touched on mixing combined with aeration as shown in adjacent figure #24. This topic will be focused in this section, since this is an increasingly common application, in activated sludge tanks (nitrification, SBR, etc.). In particular the correlation between horizontal flow generated by the submersible mixer and vertical flow induced by the supply of air shall be explained.

Physical fundamentals:

- Without the influence of external forces an air or gas bubble can only rise vertically in a liquid
- Without the influence of external forces a swarm of bubbles can only rise vertically in a liquid
- Depending on their direction, existing vertical flows (forces) have a positive or negative influence on the upward velocity of the gas bubbles (i. e. flow directed downwards towards the tank floor will reduce the velocity while the flow directed upwards towards the surface will increase the velocity).
- Existing horizontal flows (forces) do not have any influence on the upwards velocity of the gas bubbles
- Flows are vectors

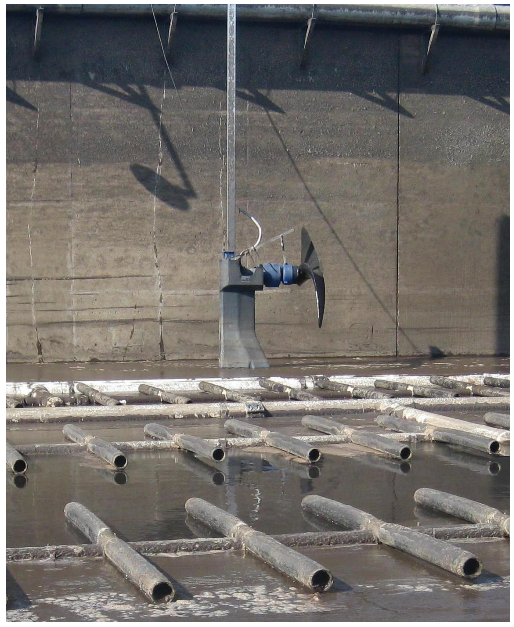


Fig. #24 - Combined Mixing & Aeration

Looking at individual bubbles reveals that a bubble corresponding to its expansion has a defined uplift and rises to the surface with the corresponding velocity.

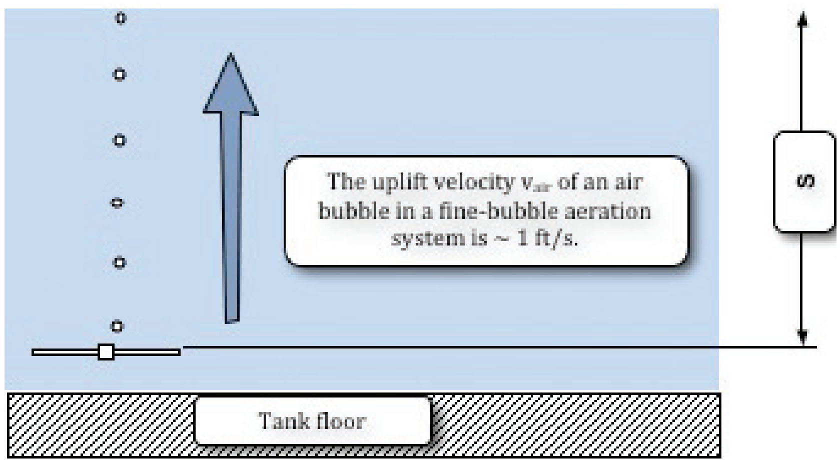


Fig. #25– Aeration without Horizontal Flow

The above figure #25 shows bubbles that are injected into the liquid at equal time intervals as they rise to the surface.

S => Path the air travels in ft
v_{air} => Uplift velocity in ft/s
t => Travel time in s

Bubble travel time
$$t = S / v_{air} \quad (s)$$

If a horizontal flow is present in the same system, the bubble travel time should not change according to the physical fundamentals. The following figure #26 shows a horizontal laminar flow with bubbles injected at equal time intervals as they rise to the surface. If the moving liquid is evaluated in volume segments per unit of time, it can easily be recognized that the bubbles in the corresponding segment rise vertically to the surface at the standard upward velocity (v_{air}).

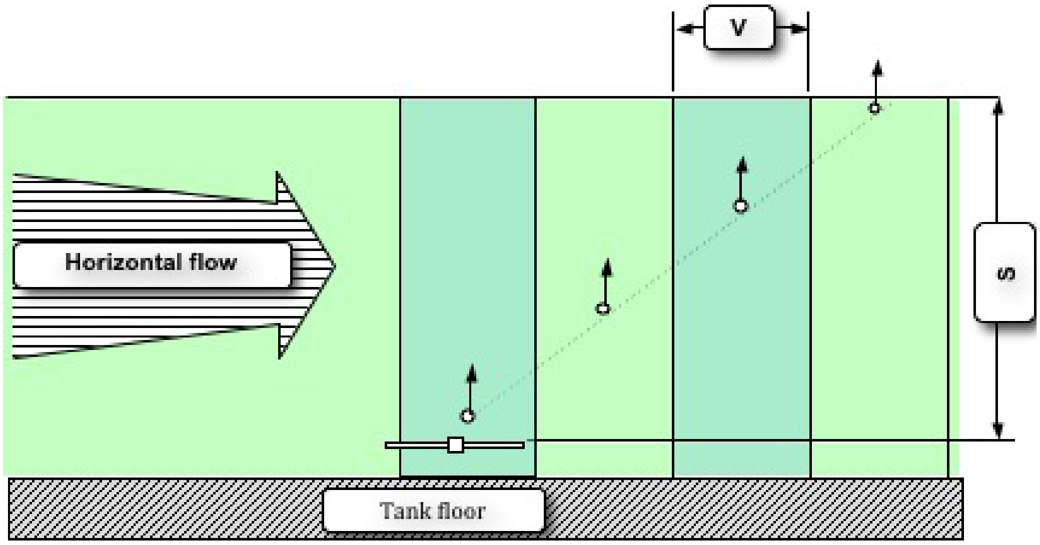


Fig. #26 – Aeration with Horizontal Flow

At the same time it can be see that the bubbles follow a diagonal movement along the resultant of upward bubble velocity and horizontal flow. However vertical path and thus time the bubble takes to rise to the surface is the same as in figure #25.

However in real world practical applications turbulent flows are present. Therefore the above consideration with a laminar flow is only a theoretical representation to show that the horizontal flow has no simple influence on the air/liquid contact time. Based on these finding the following question is raised:

Q: Is there any advantage from a process technology point of view by adding horizontal flows?

A1: Solids and sludge can be kept in suspension with the minimum process required air input.
A2: The bacteria are supplied with the new substrate.
A3: In practice the bubble travel time is actually longer.

Answers A1 and A2 are self-explanatory and shall not be further discussed. On the other hand answer A3 is in contradiction with the previous laminar flow based discussion; thus it must be further evaluated.

In practical applications, the individual bubble must be evaluated in conjunction with the turbulent swarm of bubbles and associated generation of water flow. This resulting turbulent water-air-mixture flow creates visual proof in the form of a swell at the water's surface as can be seen in the following figure #27. This liquid is moved to the surface along with the rising air and equivalent liquid flow is sucked up from the bottom of the tank. The following figure #28 shows how a swirl-type flow is present on all sides of the aeration, which makes the air rise to the surface faster. These swirl-type flows can double that of the individual bubbles upward velocity, reaching about 2 ft/s.

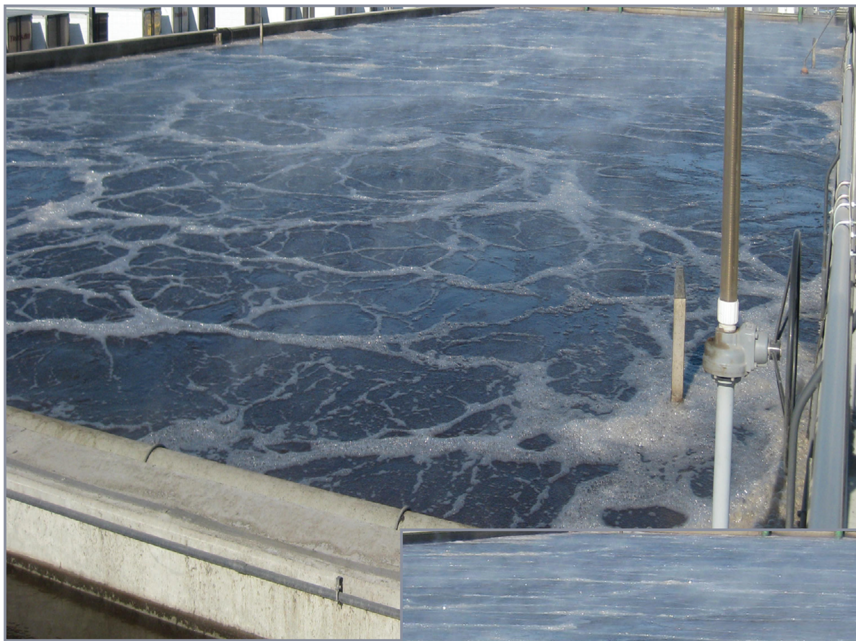


Fig. #27 - Aeration Swarming Affect

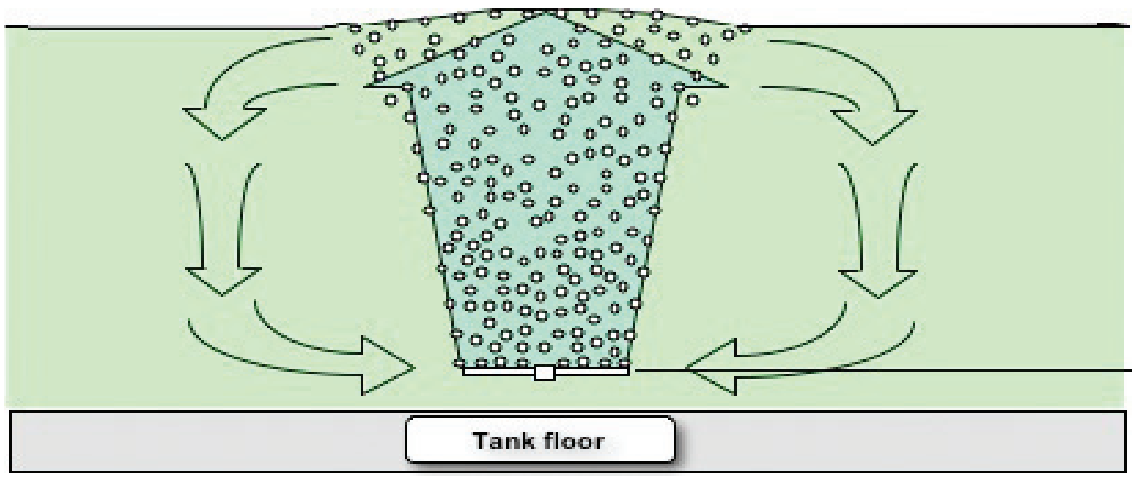


Fig. #28 - Aeration Swarming Affect

Aeration/Mixng Flows are vectors:
Therefore as depicted in below Fig. #29 the swirl flow has a postive influence and can be added to the air lift velocity.

	Uplift velocity of the air	*1*	*ft/s*
+	Flow velocity of the swarming swirl -type flow	*1*	*ft/s*
=	Total velocity	*2*	*ft/s*

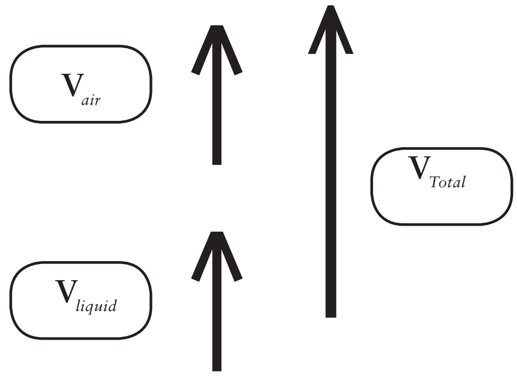


Fig. #29 – Combined swarming and uplift effect

The travel time of the bubbles is therefore significantly reduced by the swarming effect. This is a direct result of the inverse relationship between travel time and total upward velocity.
Now if a horizontal flow is added to these fluid mechanics (fig. #30), the shape of the swirl-type flow will change. Or in the ideal case, swirl type flow will be completely neutralized and fluid dynamic conditions will arise which are similar to those of laminar flows.

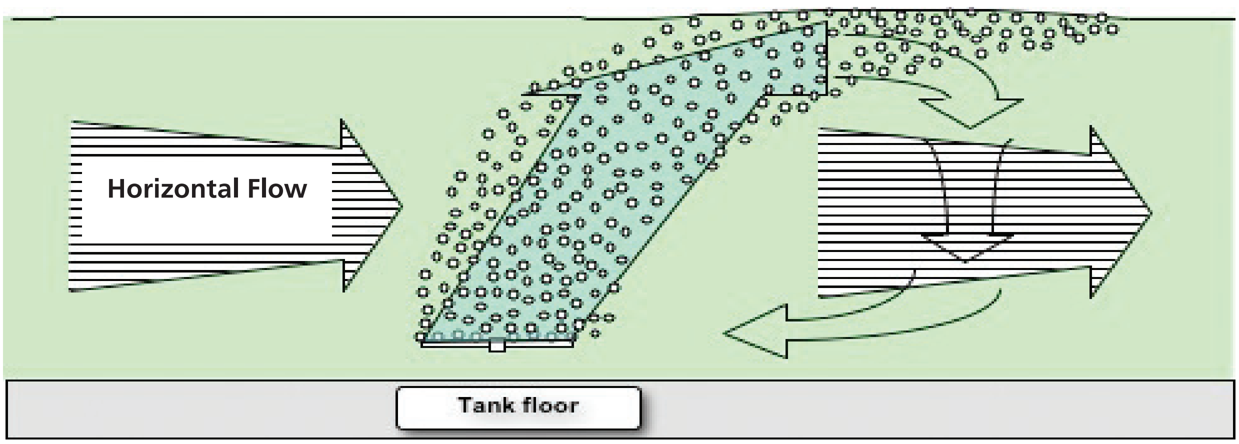


Fig. #30 – Addition of horizontal flow to aeration

The horizontal flow causes the turbulent bubble swarm to drift away with the flow. On the front, the swirl-type flow is neutralized or nearly neutralized. On the rear side, it is still there, however the horizontal bulk flow changes the shape and reduces the vertical velocity.

In summary the contact time of the bubbles is increased through the reduction of the vertical swirl flow! Because of this increased contact time, already efficient diffusers can provide even higher oxygen transfer rates to reduce operational costs. Furthermore because the mixing and aeration systems are completely independent, the energy intensive compressors can be turned down to provide only the aeration required for the biological process.

Solids Transport:
An extensive separation of solids is required to optimize sewage treatment plants. The quality of the equipment installed upstream of the tanks determines the type, shape, quality and particle size of the solids in the system. If a typical velocity of 1 ft/s is specified for the mixers, it means that not only sludge flocs but also non-volatile solids have to be moved. The medium flow through the different treatment stages must ensure that solids are transported to avoid the buildup of sedimentation. This may be accomplished by physical tank design to guide the flow through the tanks and mechanical agitation/guidance via submersible mixers.

Solids transportation cannot be defined solely by velocity; the guidance of the solids in the system is also highly important. Furthermore the velocity needed for a sediment-free operation (where possible) should be determined by the solids entering the tank and past experience were possible. By holding back/removing the solids at the headworks and optimizing the flow for biological purposes it is possible to reduce the velocity and, consequently, the required energy density of the mixing equipment. As can be seen by the table on page 23 the necessary velocity varies greatly depending on solids type.

As previously discussed, when there is no local turbulence sludge flocs can be mixed at a velocity of less than 0.33 ft/s. However for sizing the mixer the non-volatile solids are typically taken into account and a safe mean velocity of 1 ft/s in the cross-sectional flow area is assumed so that the power required to generate the flow can be calculated. The alignment of the submersible mixers which vary depending on the tank geometry, outlet and installations/structures in the tank is considerably responsible for the distribution of the flow in the cross-sectional area.

A strictly horizontal flow does not have any advantages for the distribution of the solids in the tank. The horizontal movement does begin suspension by putting the solids in horizontal motion; however specifically heavy particles move around close to the floor and specifically light particles are distributed in the entire cross-sectional area.

Simply put; in order for solids to leave the tank, they must reach the outlet. This means that the solids must be deliberately transported to the outlet. However keep in mind that heavier particles such as sand cannot be lifted with the typical mixer generated bulk flow velocities of around 1 ft/s. This should be no surprise if you consider that typical design guidelines for vertical sewage pipes require much greater velocities in the range of 6 to 8 ft/s.

Following are some examples of how to achieve such solids guidance.

Example: Flow through cascades arranged in series

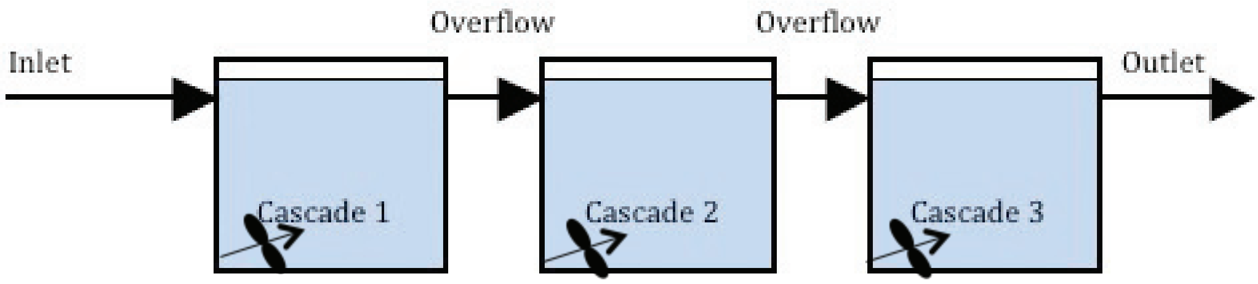


Fig. #31 – Cascades with overflow weir

Cascades which are designed such that the flow passes over an overflow structure, as illustrated in above figure #31, need flow guidance ensuring the solids are transported up to the overflow. Using a defined horizontal velocity, solids of a certain size, shape and density are moved, however, not lifted to the surface which means that in the long run a concentration of the specifically heavy solids takes place and sedimentation is to be expected. For further detail see following "Special Concerns" portion of this section.

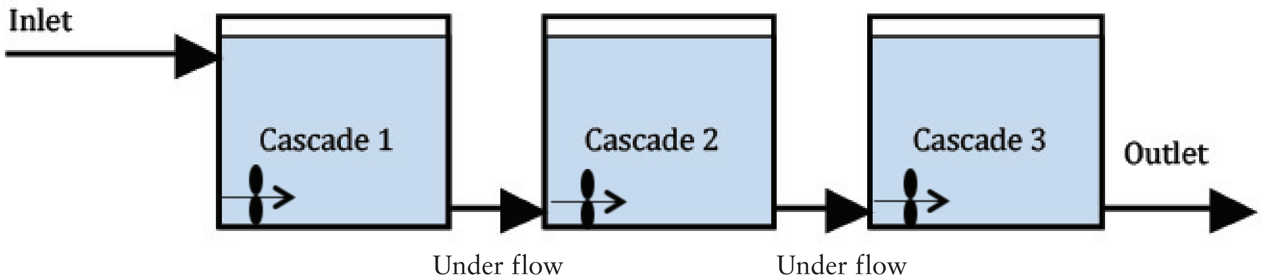


Fig. #32 – Cascades with underflow wier

Alternatively if the tank flow path is changed as shown in above figure #32 - underflow wier, then the solids are effectively transported by through flow.

Example: Flow in Round tank In order to remove solids it is possible to transport them to the middle of the tank through the use of submersible mixers creating a circular type flow (tea cup effect). In the case of a circular flow, the strongest flow takes effect around the outside of the tank, and weakens closer to the center, ceasing entirely at the center of the flow's rotation. Also the circulation in the tank is decelerated by the tank wall, resulting in the creation of a swirl-type flow which interferes with the circulatory movement. On the tank wall, this interfering flow is directed towards the floor and then to the center of the floor. In the tank center (axis of the circular flow), the velocity is zero and the swirl-type flow in an upwards direction is too low to lift the solids to the surface. These hydraulic phenomena are depicted in figure #33. Therefore tank drain/suction shall be placed at the center of the tank in order to remove solids.

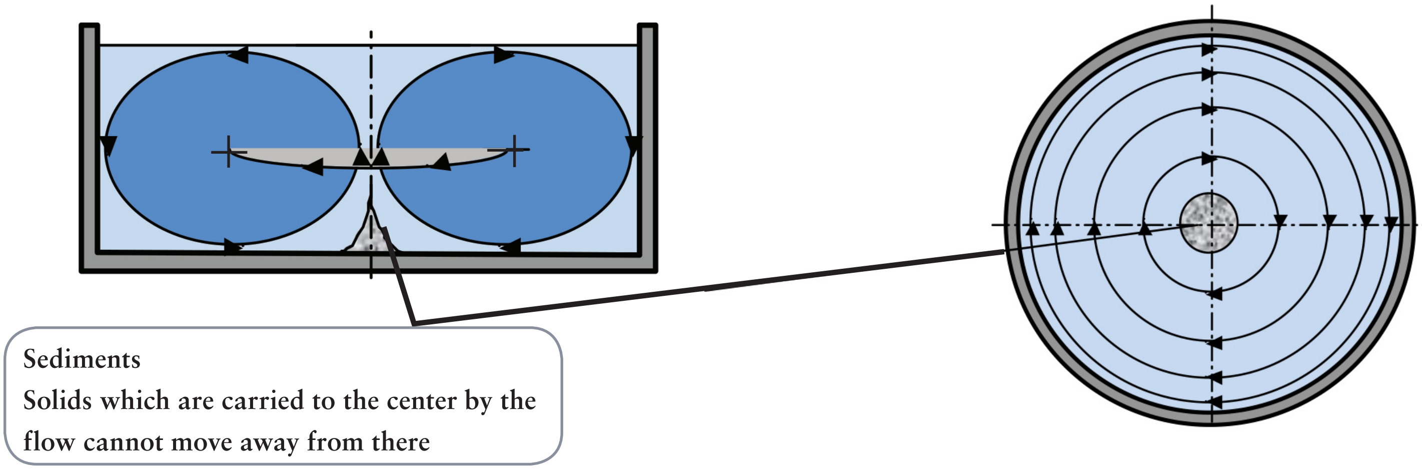


Fig. #33 – Hydraulics of round tank

Many times round tanks with center drain are routinely emptied or run at low water levels. In these cases submersible high speed mixers should be utilized to allow maximum run time during draw down. A recommended minimum water level will be provided by manufacturer, which gives minimum operating level for optimum mixing performance without vortex formation. However mixer operation (for propeller diameters < 24 in.) below this level is acceptable as long as the motor remains submerged.

Taking the tank geometry, the flow pattern and the solids transportation into account, a favorable tank drain can be designed to ensure the hydraulic transportation of solids out of the tank.

Special concerns regarding tanks with overflow weir outlet

When the outlet is arranged close to the surface (i.e. on overflows or outlet channels of pre-treatment tanks that have been retrofitted for de-nitrification), a vertical flow higher than the sinking velocity of the particles is absolutely necessary for the solids transportation (i.e. solids must be forced upwards). With special care this can be achieved with the use of submersible mixers (figure #34).

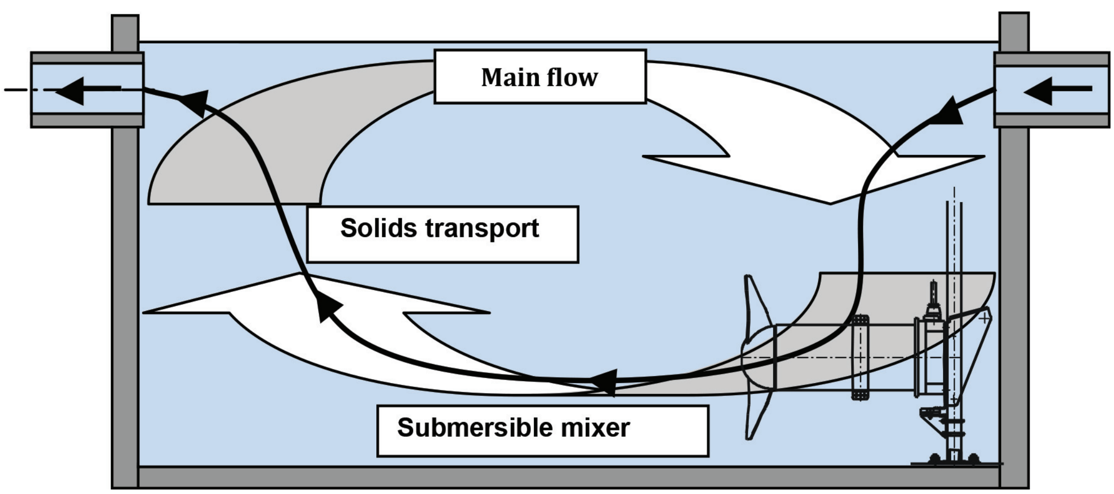


Fig. #34 – Solids guidance with overflow weir

It takes special care, because when the jet flow of the submersible motor mixer is not exactly directed to the overflow, the solids (i. e. more specifically the heavier solids) cannot be made to flow over the overflow structure. The result is a concentration of specifically heavier solids in the tank. This occurs because the solids are horizontally moved by the flow until a concentration has been reached for which the flow velocity (energy) is no longer sufficient.

The time it takes for sediments to form is directly dependent on the amount of specifically heavier particles reaching the tank. It may take one to two years or even longer for the deposits to develop in low-flow areas. Eventually tanks will need to be cleaned, which typically requires tank draining.

For optimum solutions it is highly recommended that there be design co-operation with a competent manufacturer of submersible motor mixers.

Propeller Hydraulics:

As discussed in section 6 the mixers capacity highly depends on the propeller diameter, the speed and its hydraulic characteristics. Please refer back to this previous section for basics regarding propeller hydraulics.

The running conditions of the mixer are also highly dependent on the hydraulic condition of the tank. The propeller capacity itself is constant and typically bigger than the inlet flow provided to the mixer. Since the fluid is not constrained near the mixer it will flow the way of least resistance; therefore as shown in figure #35 the propeller will draw in the local fluid and create a back flow (short circuit flow) to the propeller.

Tank shapes with higher loses will have an increasing amount of back flow. This is because the back flow is directly related to the losses imparted by the total hydraulic condition of the tank. Thus a reduction of the back flow is only possible by decreasing the flow losses encountered by the mixer. This can be accomplished by modifying tank obstruction and/or slowing the mixer speed to reduce internal friction forces.

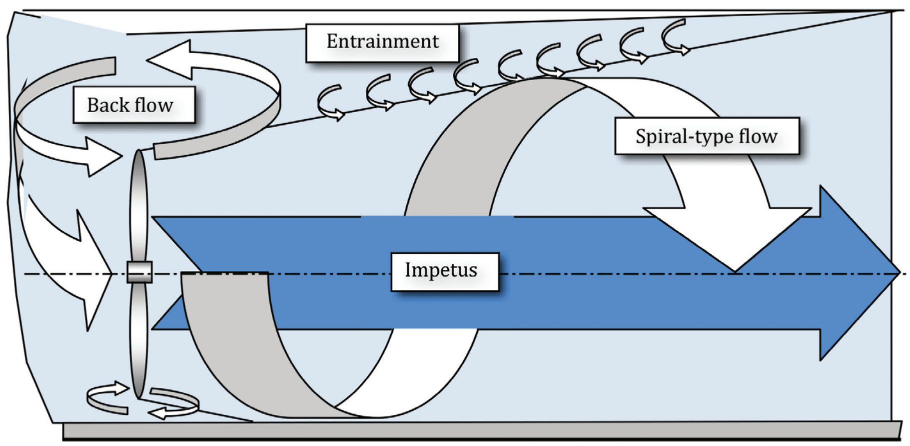


Fig. #35 – Propeller Hydraulics

General Positioning Considerations

Generally speaking, the flow jet stream (impetus) should start from a hydraulically optimal position (position varies according to tank geometry). Therefore with each KSB quote a mixer positioning sketch is provided to show the optimal position. Optimal positioning facilitates the smooth running of the mixer in order to prolong its service life. At the same time, the operational efficiency of the mixing system will increase via a low energy density.

KSB verifies all results and positioning guidelines via a combination of computational fluid dynamics modeling and field verifications. When positioning the mixer, negative effects on the propeller discharge and suction sides must be minimized. Sample interference can include:

On the suction side:	On the discharge side:
Flow stream from inlets and outlets	Disturbance of flow build-up
Turbulent flows resulting from obstructive installation	Obstructions directly in front of the propeller
Extra air in the area of the propeller	

In general negative influences on the suction side of the propeller impair its ability to run smoothly, and on the discharge side increase energy density.

General Tankage Considerations

For process success the tank design is as equally important as the mixer hydraulics and positioning. In particular the following data clearly shows that tank shape can highly affect thrust, creating over 350% variation. Since thrust is related to the required mixer power/size; tank selection will directly impact the capital and/or operational cost of the mechanical equipment.

Tank Shape	Volume Approx.	Needed Thrust	Dimensions Thrust Factor
Round	150,000 ft^3	170 lbf	1.00
Ring channel	150,000 ft^3	150 lbf	0.88
Rectangular	150,000 ft^3	220 lbf	1.29
Racetrack without guide bends	150,000 ft^3	530 lbf	3.12
Racetrack with short guide bends	150,000 ft^3	250 lbf	1.47
Racetrack with long guide bends	150,000 ft^3	220 lbf	1.29

*Standard activated sludge tank geometries of equal volume being mixed to achieve average blulk flow velocity of 1 ft/s.

Round Tanks

In relation to other shapes, round tanks are inexpensive to manufacture. However cost increase when multiple tanks are required because common wall construction cannot be utilized and there is a larger land space requirement. They also produce a low amount of tank geometry-related losses. This means that low energy density for mixing can be reached in these tanks given the same volumes. The flow distribution is problematic though, as incorrect positioning of the mixer can easily lead to the generation of unwanted flow patterns. The desired flow pattern must be defined based on the results required.

Possible results:

1. To remove solids from the tank (e. g. the cleaning of storm-water tanks)
2. To hold solids in movement (suspension) (e. g. activated sludge tank, sludge silos etc.)

1. Removing solids from the tank

In order to remove solids it is possible to transport them to the middle of the tank through the use of a circular jet flow (tea cup effect). If fluid is drained out of the tank from the middle, then the solids will be removed. This effect finds use in the cleaning of rainwater and sludge tanks, in which mixers establish and maintain a circular jet flow. This means that before the tank is emptied the solids have been removed, and if the level sinks low enough, the mixing machinery will surface.

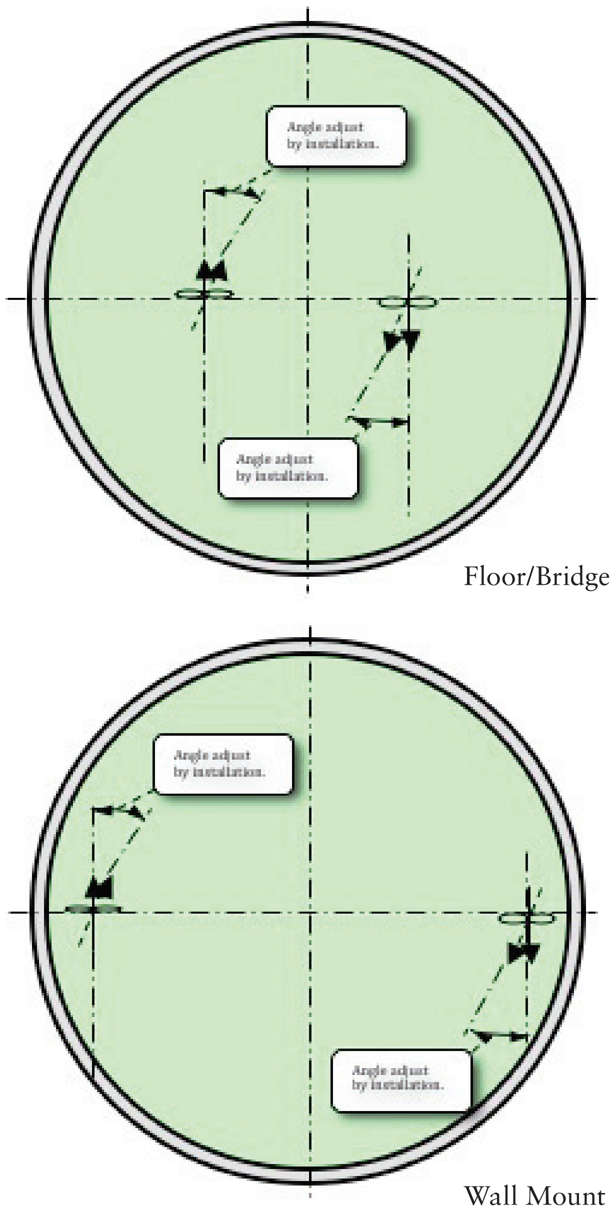
2. Holding solids in motion (suspension)

Solids should be moved by the jet flow and transported with the fluid. The difficulty of suspending solids increases with falling levels of viscosity in the fluid medium, and increasing solid densities (i.e. coarse sand laden water). This means that the sedimentation behaviors, or more precisely the fluid characteristics, are an important factor for the level of flow velocity required in order to keep the solids in suspension.

Circular (tea cup effect) flows like those mentioned above are not suitable and must be avoided.

This is made possible through following positioning guidelines:

The positioning of the submersible mixer in the tank
In order to avoid a circular flow (tea cup effect), the flow impetus is orientated towards the middle of the tank, thereby creating a stronger jet flow in this area which acts to prevent sedimentation in the center of the tank.



Floor/Bridge Mount

Wall Mount

Fig. #36 – Round Tank Positioning for Solids Suspension

This arrangement of the mixers is also dependent on its accessibility via bridges.

Installation of the mixer in relation to the tank wall

The operation of submersible motor mixers in immediate proximity to the tank wall is only possible with fast running (Amamix) mixers with a small propeller diameter.

Slow running (Amaprop) mixers with propeller diameters of 5 to 8 feet and propeller speeds of 15 to 60 rpm require a greater distance from the tank wall, as demonstrated in the adjacent sketches (Fig. #36); meaning bridges or other means of access are needed.

Ring Channel:

The fluid mechanics are the same as with a circular tank, but there are additional wall surfaces that depending on dimensions increase thrust requirements and associated energy density due to losses; or reduce thrust and associated energy density by helping to guide the flow. The sedimentation will be at the intersection of the floor and center wall structure if there is a low velocity (horizontal velocity < particle settle velocity) point behind the mixer. However when correctly sized and positioned the turbulence created by a submersible mixer is sufficient to keep all solids in suspension. Typically sedimentation in ring channels is because of insufficient number of mixers. See below figure #37 for examples.

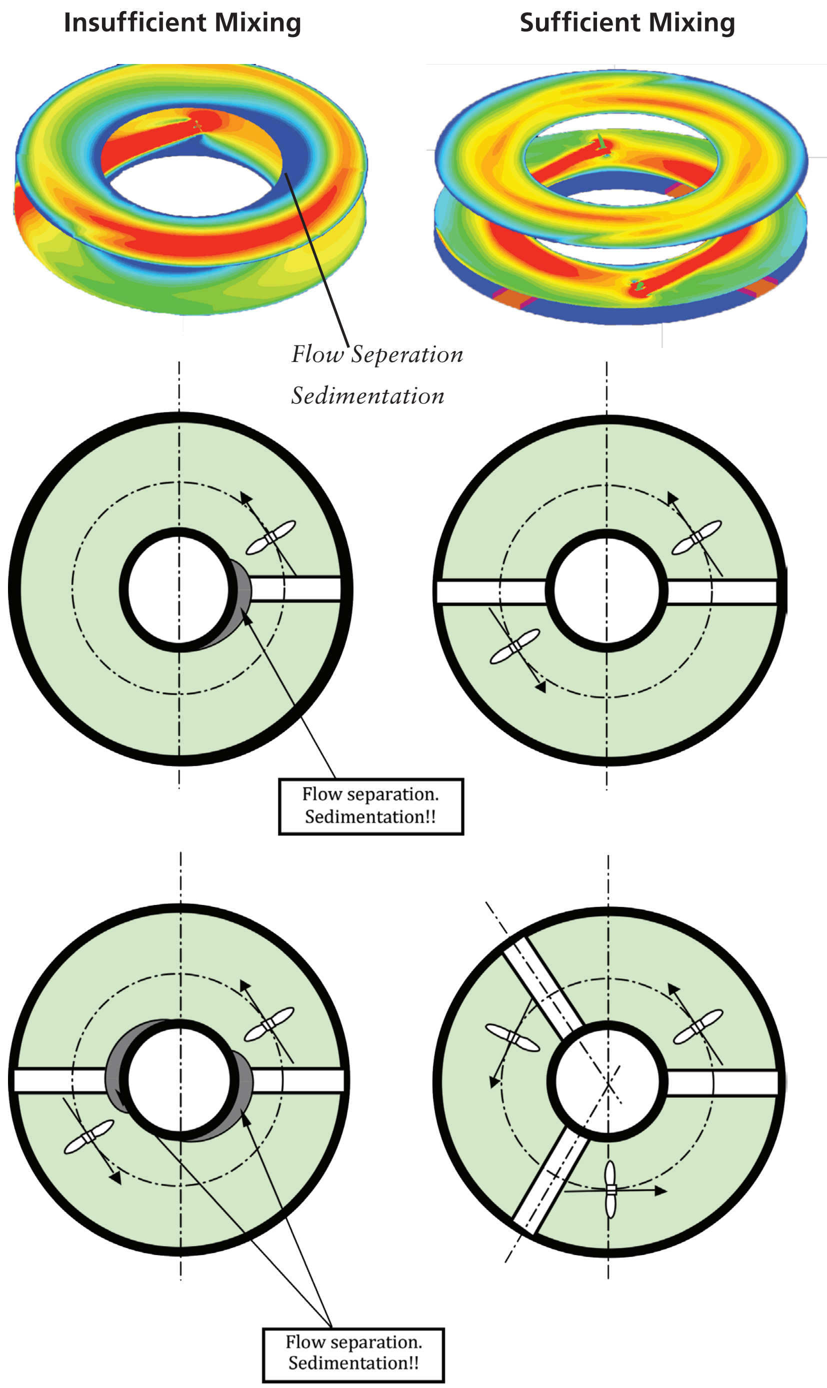


Fig. #37 - Ring Channel Sedimentation

Rectangular

In relation to other shapes, rectangular tanks can offer a large capital cost advantage when multiple tanks are required. This is typically because of shared wall and walkway design as well as reduction of land space requirements.

However as a result the rectangular tank design does sacrifice approximately 30% in mixing efficiency. The loss in mixing efficiency is primarily a result of corner vortices as can be seen in the adjacent figure #38.

It should be noted that even though these vortices act as a flow obstruction, there is random localized movement of the vortex that provides for deposit free operation. The complexity of the tank/mixer effects means that the designer must work with mixer manufacturer to evaluate the best overall solution on a case by case basis.

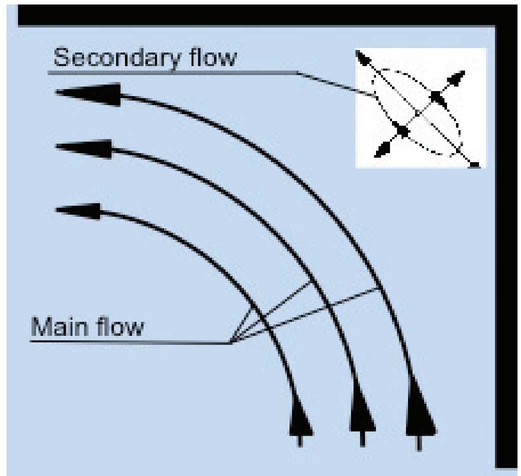


Fig. #38 – Retangular Tank Corner Vortices

Racetrack:

The channel flow of a racetrack provides the same effects at the floor and water surface as with the circular tanks and ring channels.

However largely in contrast to the circular tanks and ring channels, the flow behind the middle wall is obstructed by a flow separation (fig. #39). This flow separation is a quite large vortex resulting in a reduction of the flow area which creates additional flow losses. The additional losses can result in more than 3 times the mixing thrust as required for a round tank of similar volume.

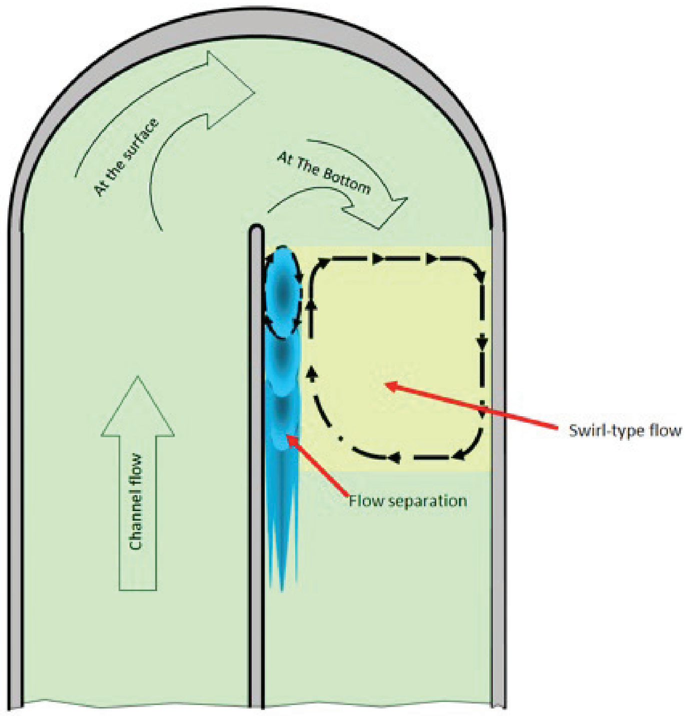
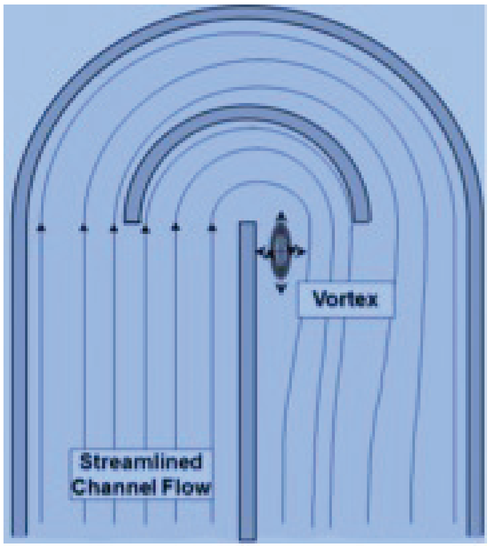


Fig. #39 – Racetrack Flow Separation

However the mixing energy density in racetrack tanks can be greatly improved by the addition of guide vanes. These guide vanes located at the bend help to direct flow around the tight turn and minimize the flow obstructing vortex. Long guide bends, which extend at least one channel width along the downstream side of the channel, can reduce the necessary mixer thrust by more than 50%. See below figure #40 for a schematic representation of "normal" guide bend on the left and CFD analysis vector results for a "long" guide bend on the right.



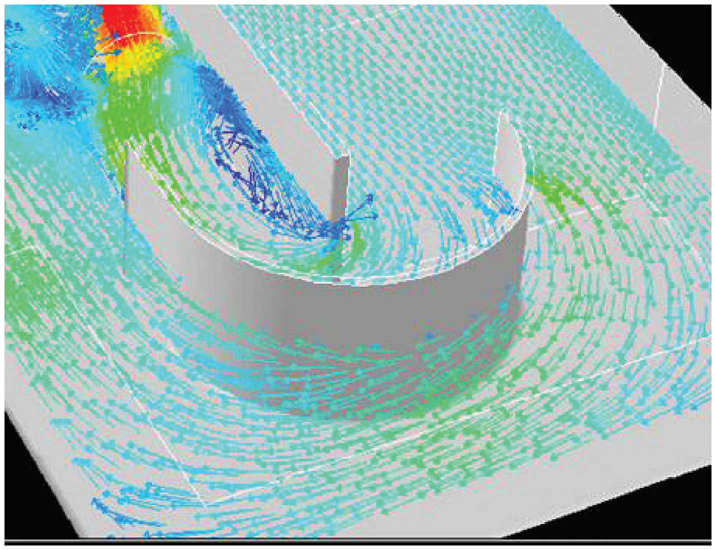


Fig. #40 – Racetrack's with Guide Bend

Special Case – Installation Limits for Long Tanks

Rectangular type tanks:
Fluid mechanic limitations for single mixer are illustrated in figure #41. Note that for tanks with length width ratio greater than 2.5 the bulk flow is short-circuited and a low flow area is created at the end of the tank. However by adding additional units the mixers work in series to create good bulk flow throughout the tank. This is illustrated in figure #42, which shows how the large green arrowed bulk flow is generated instead of the typical short circuited flow shown by the red arrows.

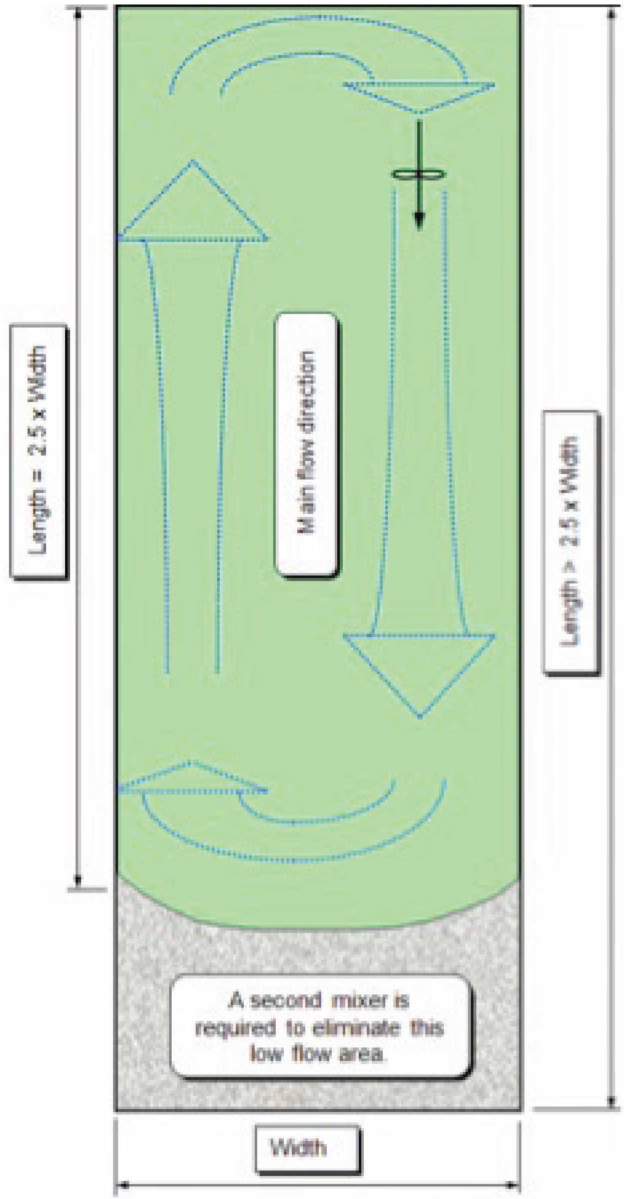


Fig. #41 - Long Tank Installation Limits

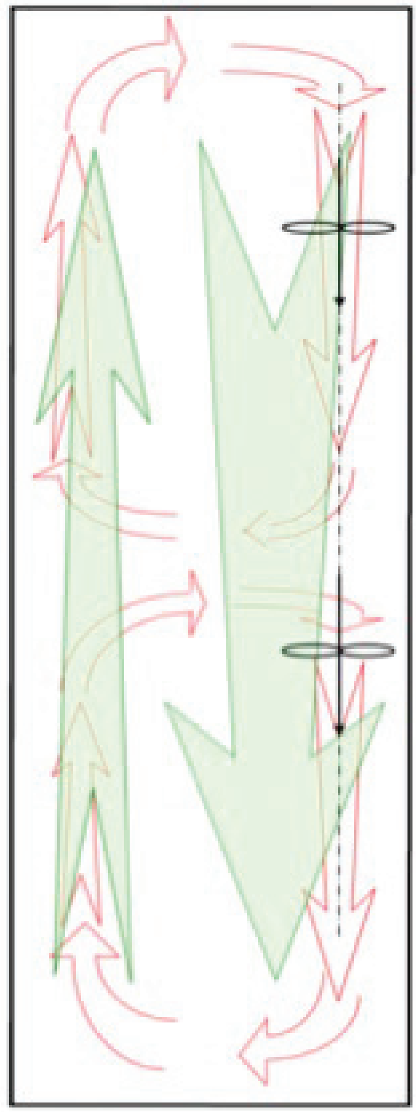


Fig. #42 - Long Tank Mixers in Series

Circular ring tanks or long curved rectangular tanks:

The fluid mechanics are the same in regard to the length-width ratio of rectangular tanks although the bend does have added negative effect. The flow impetus from the submersible mixer travels only in a straight direction, i. e. along the mixer‘s axis; therefore the flow will always hit the opposite wall when the tank is considerably curved. To a certain extent, this can be compensated for by positioning the mixer(s) such that it is directed towards the inside wall space. See following figures for example of poor mixing (fig. #43) created by insufficient number of mixers and the good mixing (fig. #44) created by the addition of another mixer.

Fig. #43 - Poor mixing in long tank

Fig. #44 - Good mixing in long tank

Aeration – Special Positioning Considerations:

Due to the added energy efficiency and flexibility, the addition of submersible mixers to aeration tanks is becoming increasingly common. However care should be taken in regards to mixer/aeration positioning.

If the bubble swarm engulfs the propeller, then air pockets will develop on the suction side of the propeller blades. These air pockets spread unevenly across the surface of the blades, in effect changing the hydraulic characteristics of the propeller. In turn this leads to alternating stress and associated vibrations causing movement of the mixer within its mounting; impairing both its smooth running and inversely affecting the service life of the machine.

To avoid this effect KSB provides the general positioning guidelines shown in below figure #45. Furthermore KSB recommends more specific separation from aeration details on a job by job basis.

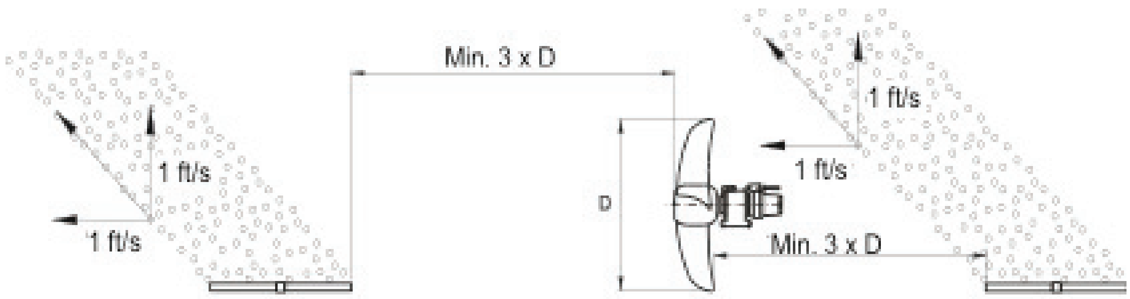


Fig. #45 – Recommend Aeration Free Zone
Applicable for air loads =< then 0.82 SCFM/ft²

Propeller design is equally as important because vibration effects are more prevalent in two-bladed propellers. Multi-blade propellers become less affected by the above-mentioned influences, so the higher the number of propeller blades the lower the negative effects. KSB recommends that if bubble-free flow to the propellers cannot be ensured; then 3 blade propellers with a reduced diameter should be utilized.

Sizing Information:

Throughout this document we have stressed the importance of working closely with a competent manufacturer to select the best mixer for a given application. The particular details and methods oriented with submersible selections are covered in the "Mixer Sizing" section 5 of this document. In that section it is also made clear that the energy density is not a good tool for mixer sizing. However with the better understanding provided by this document it is possible to use some "typical" energy density values for planning purposes. Therefore you will find below a table of typical energy densities for KSB submersible mixers. Please be sure to consider the associated notes when utilizing these values. Also be sure to note that the table clearly shows trends such as the inverse relationship between tank volume and energy density.

Typical Energy Density Requirements (w / ft^3)

upper value = small blade mixer lower value = large blade mixer

Size → (gal.) / Tank Type ↓	0 (0 ft^3)	50000 (6,691 ft^3)	100000 (13,368 ft^3)	150000 (20,052 ft^3)	200000 (26,736 ft^3)	250000 (33,420 ft^3)	300000 (40,104 ft^3)	350000 (46,788 ft^3)	400000 (53,472 ft^3)	450000 (60,156 ft^3)	500000 (66,840 ft^3)
Circular H = 0.5Ø	0.30 0.15	0.27 0.10	0.21 0.07	0.16 0.05	0.14 0.05	0.13 0.05	0.11 0.04	0.11 0.04	0.11 0.04	0.10 0.04	0.10 0.04
Race Track H = 12' L = 5W	0.42 0.18	0.37 0.13	0.24 0.09	0.23 0.08	0.18 0.06	0.15 0.06	0.15 0.05	0.13 0.05	0.12 0.05	0.12 0.04	0.12 0.04
Rectangular H = 15' L = 1.5W	0.40 0.15	0.33 0.10	0.24 0.09	0.24 0.07	0.21 0.06	0.18 0.05	0.16 0.05	0.16 0.05	0.16 0.05	0.15 0.04	0.15 0.04

Notes / Assumptions:

- Concrete tank walls
- No aeration considered. Typically aeration will increase energy density by at least 5%
- Typical activated sludge medium with TSS < 1%
- Design criteria is average velocity of 1 ft/s
- Race track (oxidation ditch) assumed to have long (extend downstream) guide bends

Amamix ® & Amaprop ®
Submersible Mixers

KSB

JSW07/11

MIXER SIZING INFORMATION

PROVIDE AS MUCH APPLICATION DATA AS POSSIBLE AND FORWARD TO:

KSB, Incorporated – Attention Application Engineering
4415 Sarellen Road
Richmond, VA 23231
FAX: (804) 226-6961; PHONE: (804) 222-1818

Project Name: ______________________ Location: ____________________________

1. APPLICATION DESCRIPTION

☐ Sludge Thickener ☐ Pump Sump ☐ Nitrification
☐ Sludge Dewatering ☐ Aeration Basin ☐ Denitrification
☐ Sludge Storage ☐ Sludge Storage ☐ Phosphate Removal
☐ Other (Define) ____

2. MIXED MEDIUM

☐ Activated Sludge ☐ Mixed Liquor Total Solids (mg/L or %) ______
☐ Raw Sewage pH Value ______
☐ Primary Sludge Temperature (^{0}F) ______
☐ Other (Define) *Aeration in tank (scfm) ______

*Define aeration type & operation in section 5 below (i.e. diffused aeration not in operation during mixing).

3. BASIN DIMENSIONS & DATA

Basin Walls: Concrete ☐ Steel ☐
Width (Feet) ______ or Diameter (Feet) ______ Filling Capacity: min: __________
Length (Feet) ______ max: __________
Dimension Notes ____
Fluid Depth (Ft) ______ Top is: Covered: ☐ Open: ☐

NOTE: Please enclose a sketch of the basin showing shape, inlets, outlets, bridges, aeration equipment, recirculation pumps, and any other features / obstructions which could affect mixer operation or location.

4. INSTALLATION ACCESSORIES

Mtg. Mast: ☐ 304 Stainless Hoist: ☐ Mast Mounted
☐ 316 Stainless ☐ Wall Mounted

5. OTHER: Please describe any other known basin or mixed fluid properties which may affect proper mixer selection: ____

____

____

____

References

1. International Organization for Standardization, Pumps – Testing – Submersible mixers for wastewater and similar applications, ISO 21630, 2007
2. Verband Deutscher Maschinen und Anlagenbau, Agitators in activated sludge tanks of wastewater treatment plants – Information on planning, project design and construction, VDMA 24656, 2010
3. Metcalf & Eddy, Inc., George Tchobanoglous, Franklin L Burton, H. David Stensel, Wastewater Engineering Treatment and Reuse 4th Edition, 2003
4. Fred Koch, KSB Fluid Mixing Manual, 2001

Photographs
All of the photographs for this booklet were taken by KSB or its representatives, unless otherwise noted.

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