CFD Analysis of Single Lagoon at Three Mile Oregon

April 2021

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Introduction

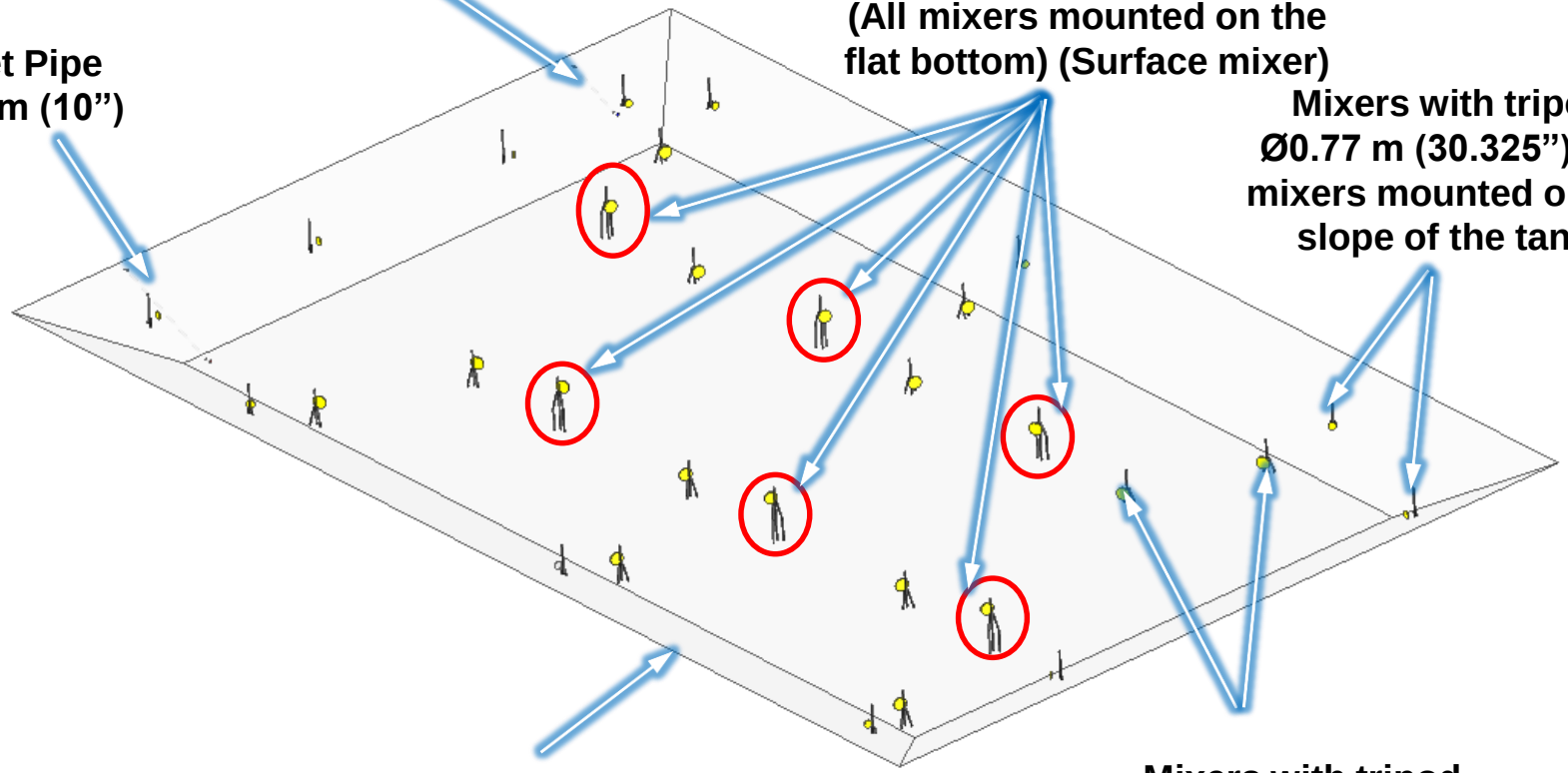
Objective

The purpose of the proposed CFD analysis is the investigation of bulk flow velocity and sedimentation risks for a single lagoon (Three Mile Oregon) equipped with 12x Flygt 4670.310 and 18x 4460.020 mixers.

Overview

- A total of one steady state analysis is performed.
- The tank is modelled as an open system with the flow rate of **900 GPM.**
- Only one liquid depth (**5.5 m**) is used for analysis.
- The whole geometry will include: tank geometry, 30 tripods, one inlet and one outlet pipes. No other extra internal details are considered.
- Agitation provided by **12xFlygt 4670.310** (with **3026 N** produced thrust) and **18xFlygt 4460.020** (with **3156 N** produced thrust) mixers with total produced thrust = **93120 N.**
- Fluid inside the tank will be modelled Non-Newtonian liquid with:
- Yield stress of **2.5 Pa**
- Apparent viscosity of **250 cP**
- All solid boundaries are treated as no-slip flat walls (hydraulically smooth).
- The top liquid surface is treated as a fixed plane with no-shear.
- Mixers will be modelled as a momentum source, which is a commonly used method for this application.

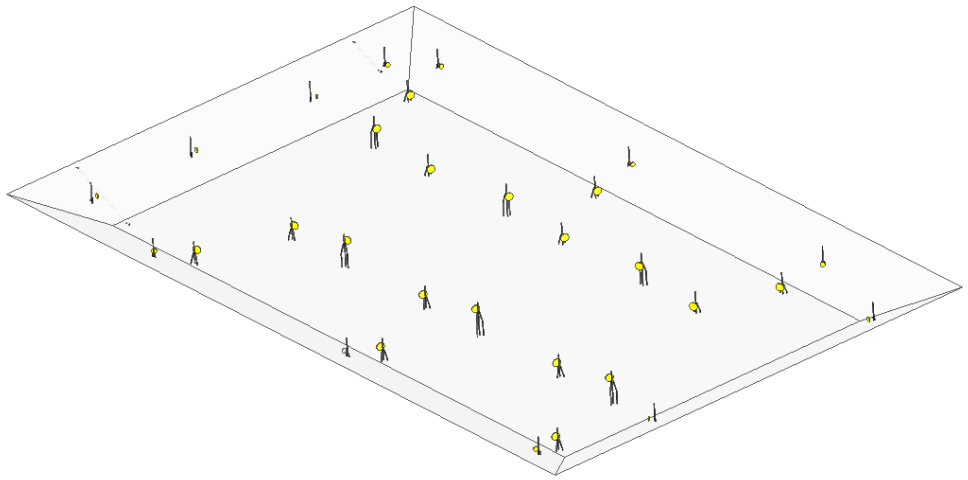
GeoSketch: ISO VIEW



Tank Dimensions:

- Tank length: 125 m
- Tank width: 80 m
- Liquid height from datum: 5.5 m

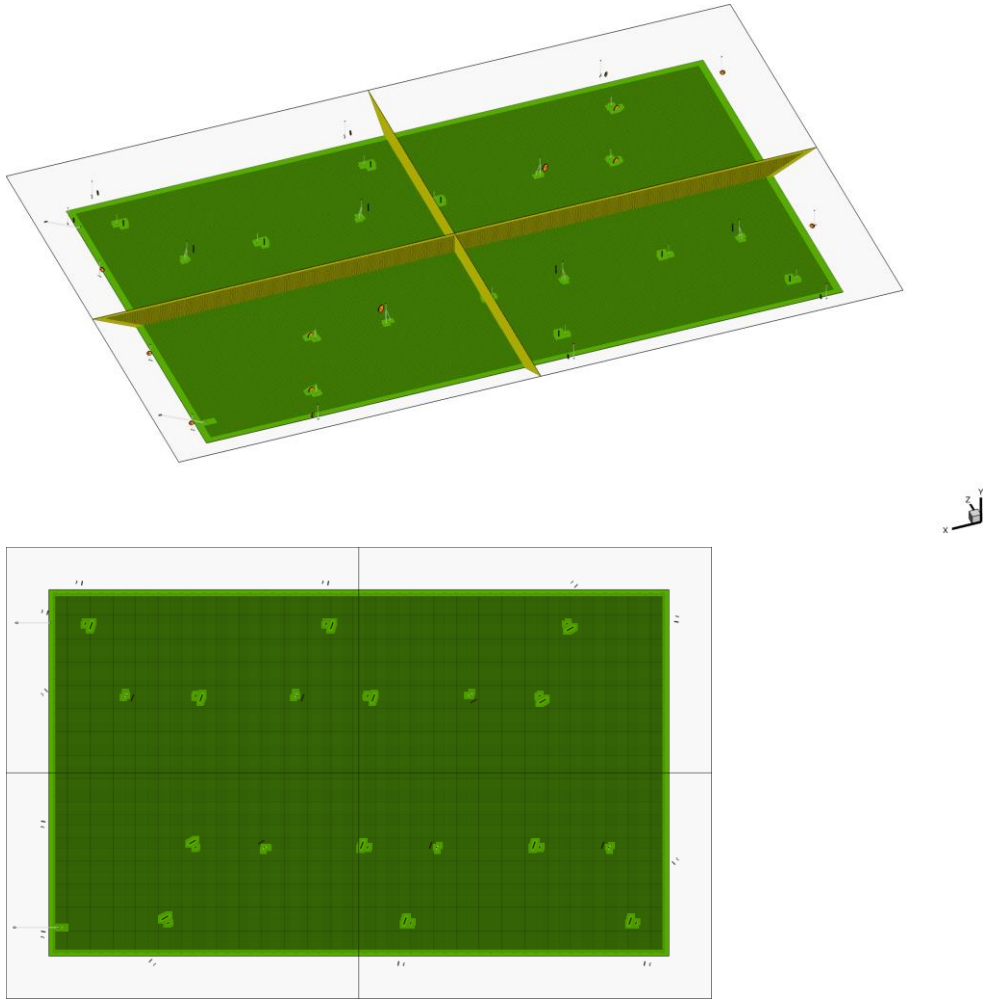
Model Description: Boundary conditions



For all the models:

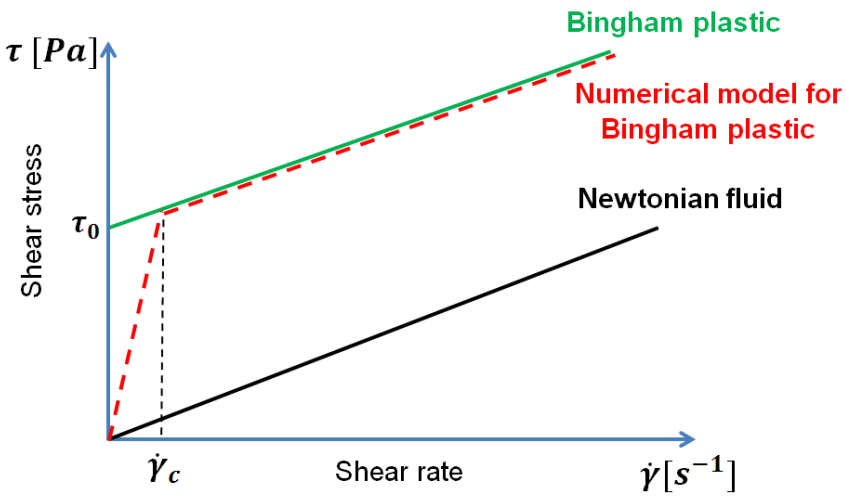
- **Solid walls** have been modeled as incompressible adiabatic walls with wall function to account for boundary layer effect.
- **Top surface** is approximated as inviscid slip boundary (splashing and air entrainment effects are disregarded).
- **Mixers** are modeled as momentum sources
- **The inflow(s)** has been modeled as mass flow inlet.
- **The outflow(s)** has been modeled as a pressure outlet.

Model Description: Computational Mesh



- Computational mesh was created with the help of **ANSA software**.
- A Hex-dominant type of mesh was employed for the entire tank, with a grid resolution ranging from 1 mm to 75 mm
- A total of 5 layers have been used in order to account for boundary layer effects.
- Total mesh count for the model≈ 48 M

Rheology



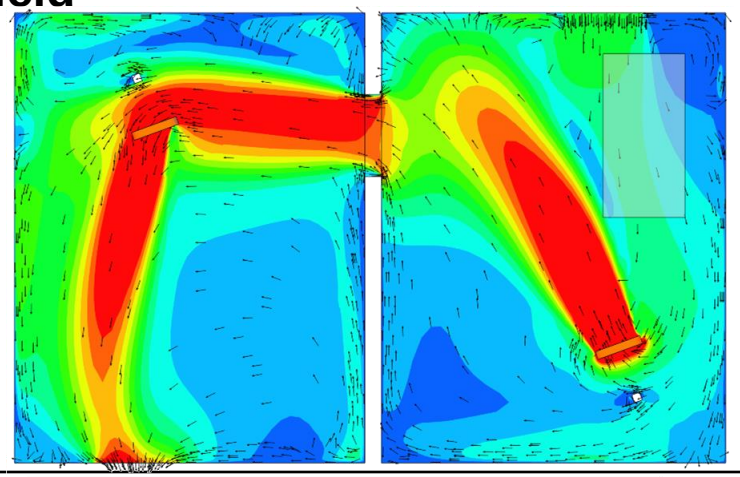
Liquid properties:

- Bingham plastic modeled using Herschel Bulkley model :
  - $\boldsymbol{\tau} = \boldsymbol{\tau_0} + \mathrm{k}\,\dot{\boldsymbol{\gamma}}^{n}$,
  - Yield stress $\boldsymbol{\tau_0} = 2.5$ Pa,
  - Consistency factor: $\mathbf{k} = 2.25$ Pa.s^{n}
  - Flow index $\mathbf{n} = 0.5$
  - Critical shear rate $\dot{\boldsymbol{\gamma}}_{\boldsymbol{c}} = 0.1\ Hz$

CFD Results Evaluation

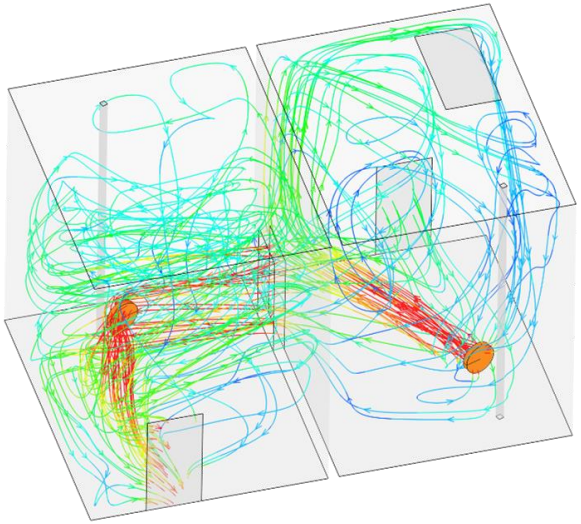
Velocity magnitude [m/s]/[ft/s] and Vector Field

Showing the velocity vector field helps to identify direction of the motion and gives a clear indication if recirculation zones are present. Note that vectors can be combined with contour plot to give both feeling of direction and magnitude.



Flow pattern visualization (Streamlines)

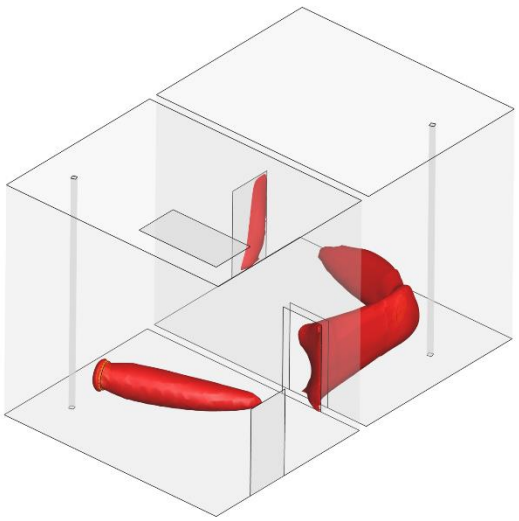
The liquid flow pattern in the tank can be visualized by flow streamlines. The streamlines shown below are initiated from the mixers and colored by velocity magnitude.



CFD Results Evaluation

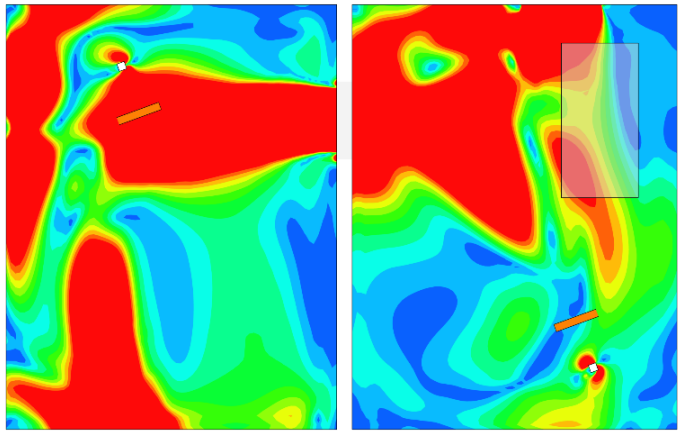
Iso-surfaces

Plotting velocity iso-surfaces (surface with a constant value of velocity magnitude) allows to visualize various velocity levels in the same figure.



Wall shear stress at the bottom of the tank

In the regions with low values of the wall shear stress [Pa] there will be risk of sedimentation. This should be considered as one of the design criteria.



CFD Results Evaluation

Bulk Flow Velocity, Two definitions

Concept of bulk flow velocity originates from channel flow theory and applies well to annular tanks, loop reactors and circulation channels, termed **Type A** (see examples in figures below). For circular, square and rectangular tanks, termed **Type B,** secondary currents and hydrodynamic currents are often dominating, so bulk flow velocity requires another definition. In general, bulk flow velocity concept should be used with care and bulk flow velocity values should be kept separate from measurable mean velocity values and treated, primarily, **as a sizing parameter**. The two definitions of bulk flow velocity are:

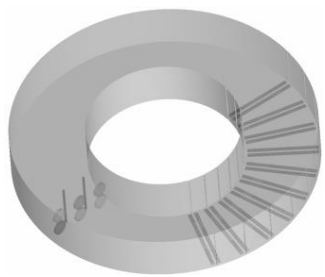
Type A

$$V_{bulk}^{A} = \frac{\dot{m}}{\rho A}$$

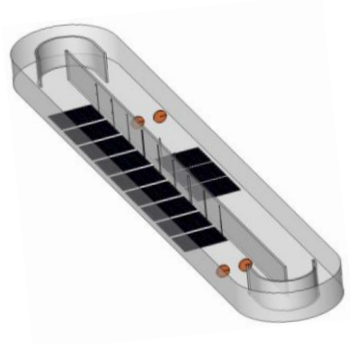
Type B

$$V_{bulk}^{B} = \frac{\overline{V^2 + 2k/3}}{\bar{V}}$$

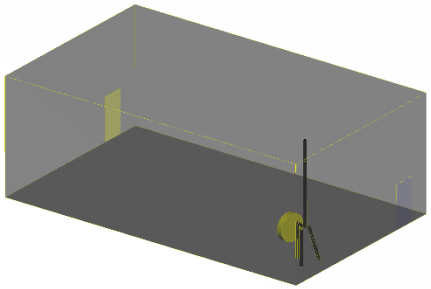
For **Type A:** "$\dot{m}$" is mass flow rate, "ρ" is fluid density and "A" cross sectional area in race track.
For **Type B:** "*V*" is velocity magnitude, "*k*" is turbulent kinetic energy and " $\bar{}$ " denotes volume average.



Annular geometry



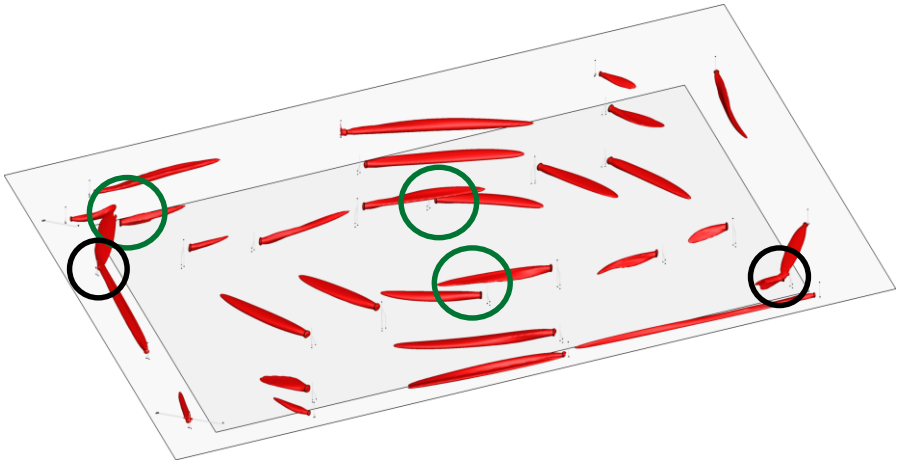
Loop reactor



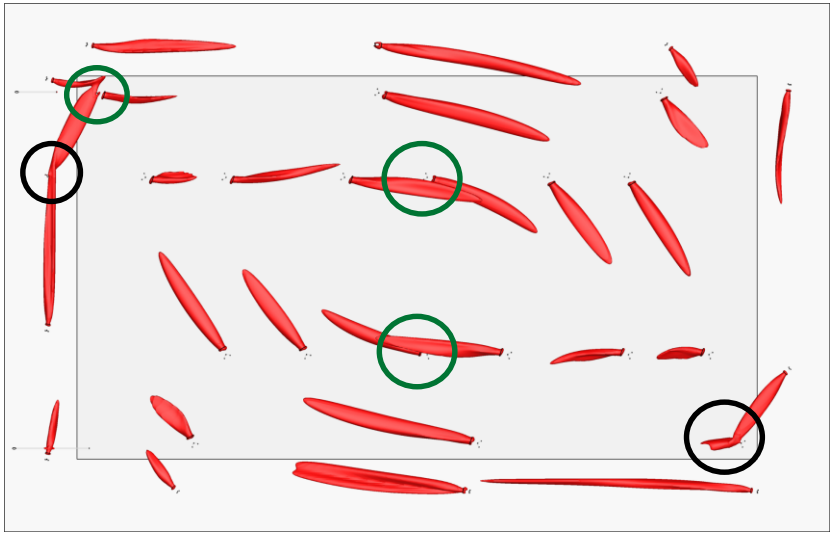
Rectangular Tank

Velocity isosurface at 1.0 m/s

Iso View

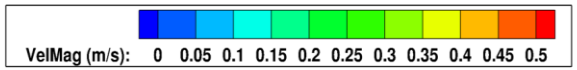


Top View

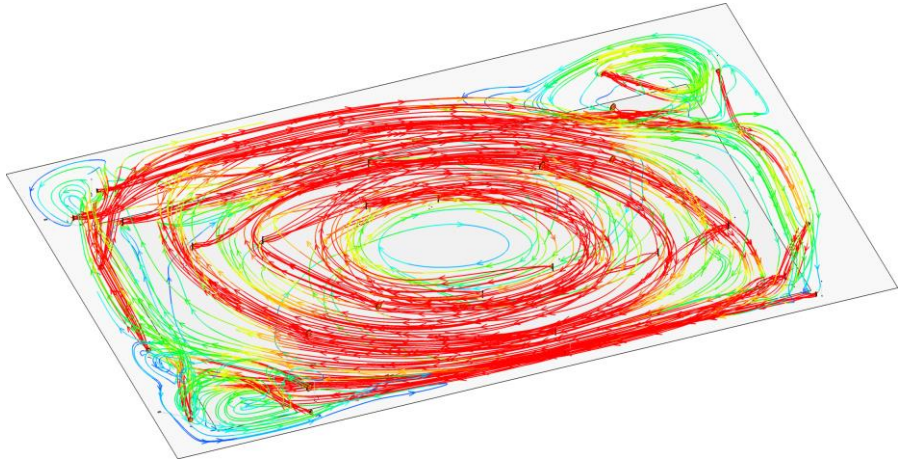


- Iso-contours of velocity magnitude of 1.0m/s are shown to highlight the Water jets emanating from the mixer.
- Most of the water jets are strait and are directed along the mixer direction indicating favorable working conditions for those mixers.
- It should be noted however that some of the mixers (three of them marked with black circles) are hit by the jet produced by a mixer upstream from their location. That might pose a risk for shear stresses and vibrations for that mixer potentially reducing their lifetime. The cases marked with a green circle appear to be subject to that risk as well but there is a significant height difference between the mixers so that and the real interaction is minimal. This is better seen in the Iso View.
- It is recommended to move those mixers at risk or the ones behind them producing the impacting jet in order to avoid this situation.

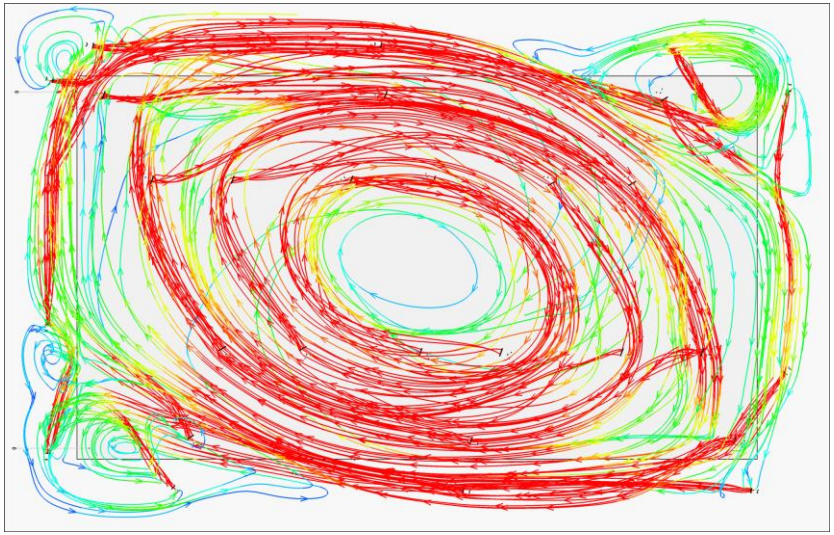
Velocity streamlines



Iso View



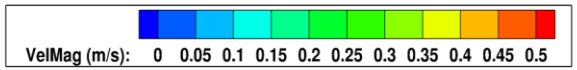
Top View

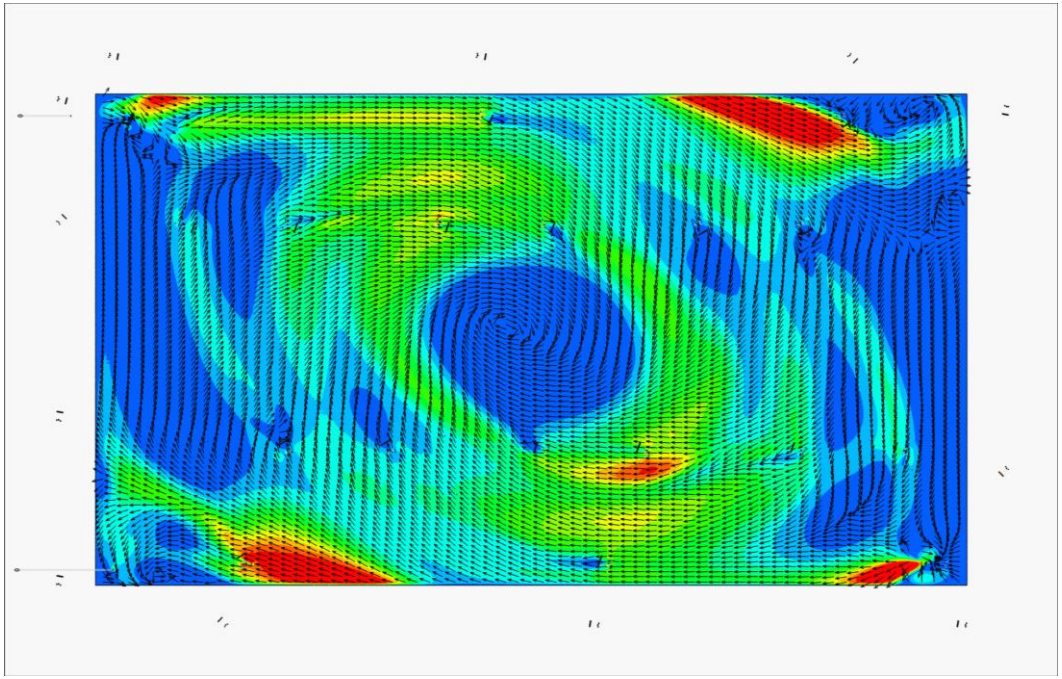


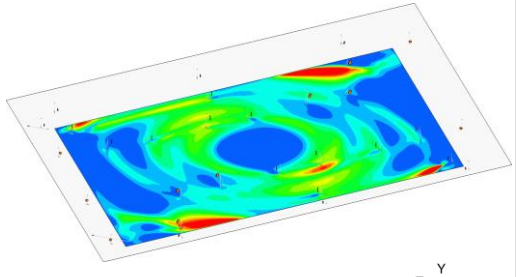
Bulk Velocity Type B = 0.54 m/s

- The streamlines are showing general flow in three dimensional perspective.
- It is observed that a large circulation over the whole tank is formed with high velocities. The four corners locally demonstrate some smaller semi-counter rotating vortices, commonly occurring when a global recirculation flow is present in a square or rectangular tank.
- One possibility is to turn direction and possible move a few select mixers in those areas to enhance those counter rotating vortices and thus reduce the disruptive flow. **Those modifications should be coordinated with the modifications proposed in the previous slide.**

Velocity vectors @y = 0.1 m





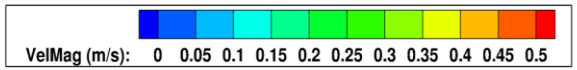


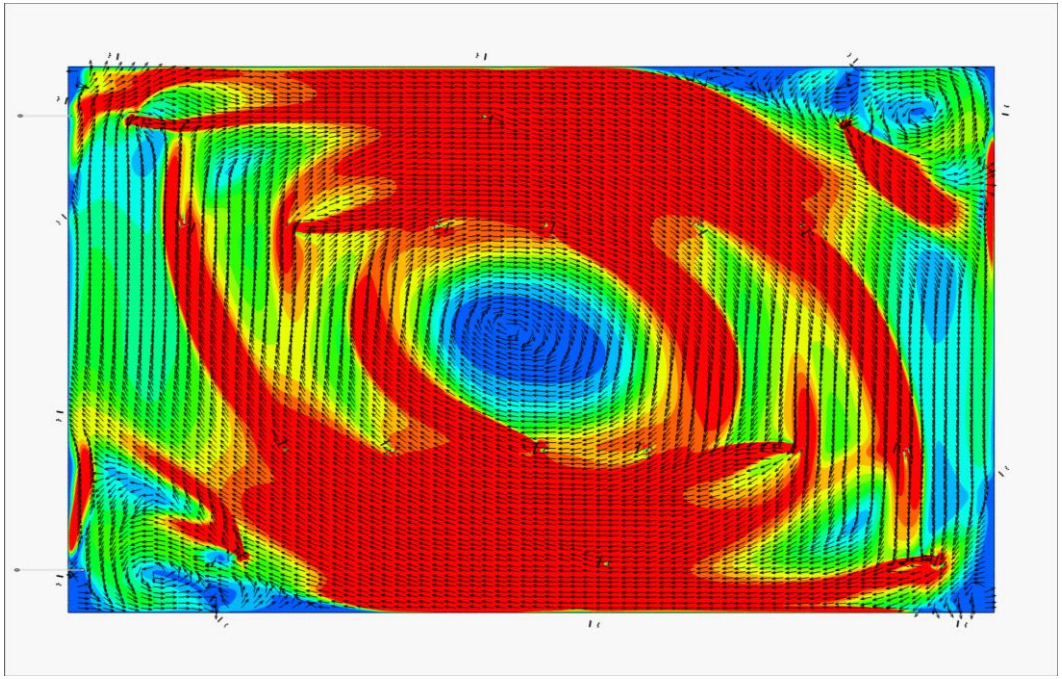
plane @y = 0.1 m

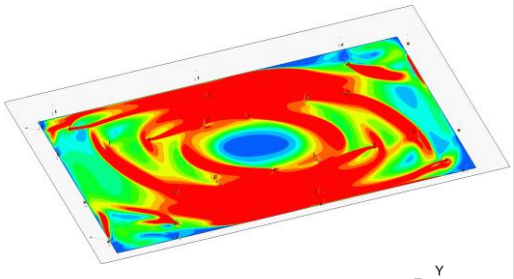
Bulk Velocity Type B = 0.54 m/s

- The plane at height (0.1 m) is chosen to display the contours of velocity magnitude along with velocity vector field.
- Low velocity zones are directly connected to temporary sedimentation. Here, some low velocity zones are visible, one in the middle related to the large recirculation motion that always entrails low velocities in the center and some on the sides related to the rectangular form of the tank.
- The liquid is Non-Newtonian with a high viscosity so low velocity zones will still yield relatively high shear stresses. See **slide #25** for more details on sedimentation risk.

Velocity vectors @y = 1.72 m





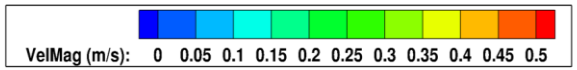


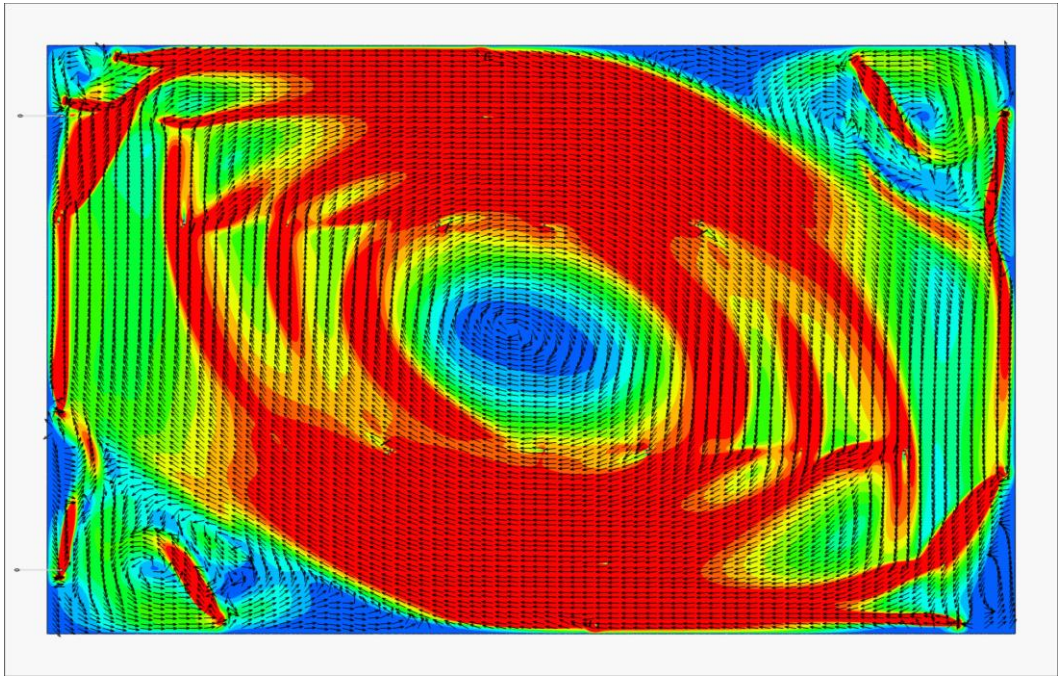
plane @y = 1.72 m

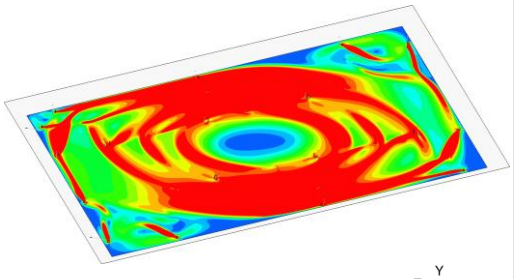
Bulk Velocity Type B = 0.54 m/s

- The plane at the mixer height (1.72 m) is chosen to display the contours of velocity magnitude along with velocity vector field.
- The large circulation motion is visible. Also the counter rotating vortices in the corners are also visible.
- Some low velocity zones are present associated to the main and the secondary (corner) vortices.

Velocity vectors @y = 2.97 m





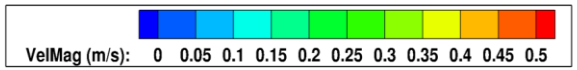


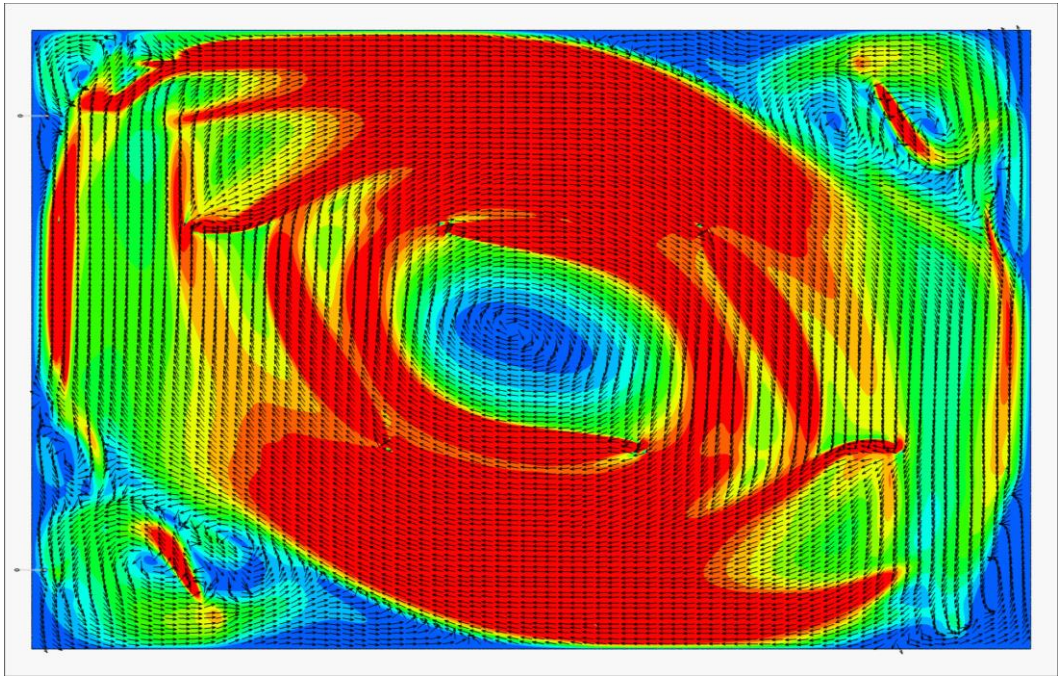
plane @y = 2.97 m

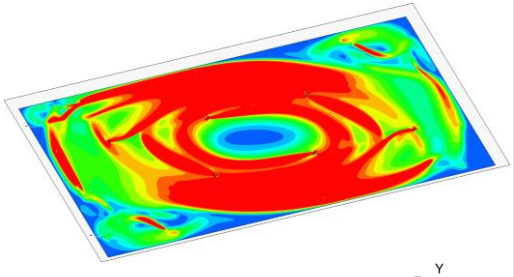
Bulk Velocity Type B = 0.54 m/s

- The plane at the mixer height (2.97 m) is chosen to display the contours of velocity magnitude along with velocity vector field.
- The large circulation motion is visible. Also the counter rotating vortices in the corners are also visible.
- Some low velocity zones are present associated to the main and the secondary (corner) vortices.

Velocity vectors @y = 3.88 m





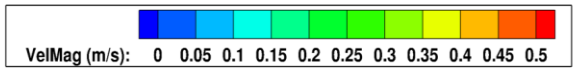


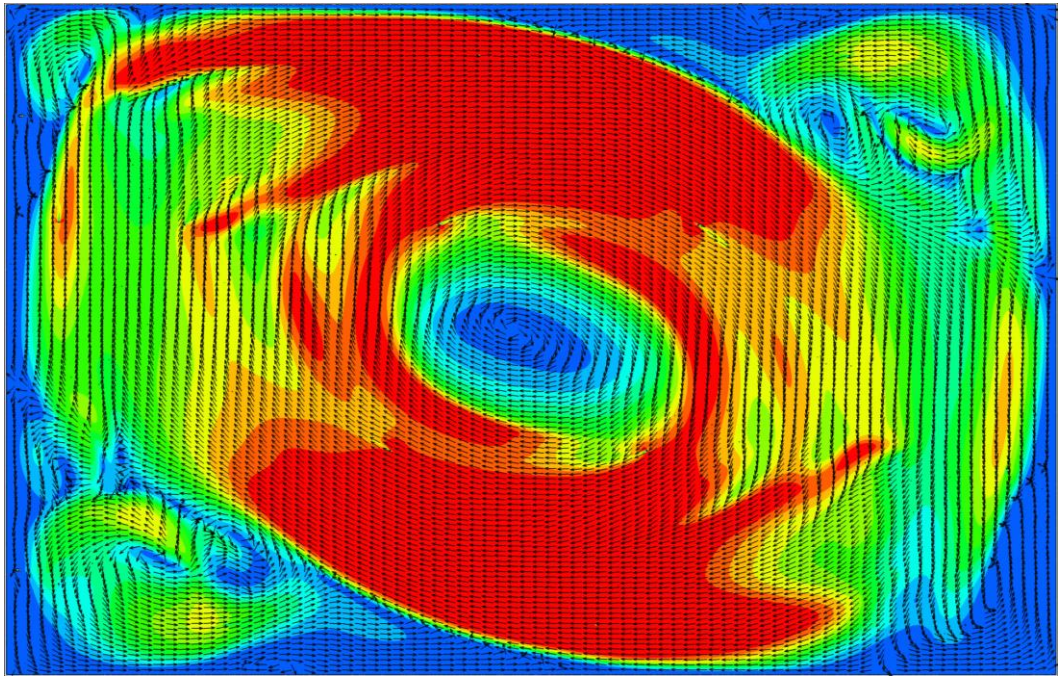
plane @y = 3.88 m

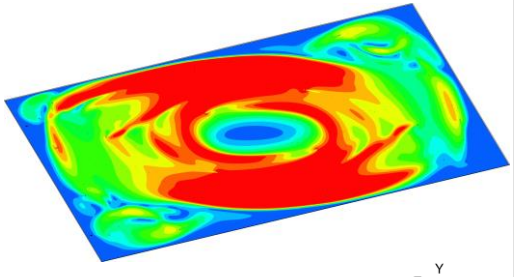
Bulk Velocity Type B = 0.54 m/s

- The plane at the mixer height (3.88 m) is chosen to display the contours of velocity magnitude along with velocity vector field.
- The large circulation motion is visible. Also the counter rotating vortices in the corners are also visible.
- Some low velocity zones are present associated to the main and the secondary (corner) vortices.

Velocity vectors @y = 5.4 m





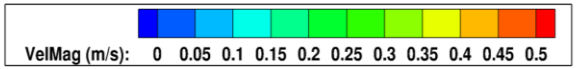


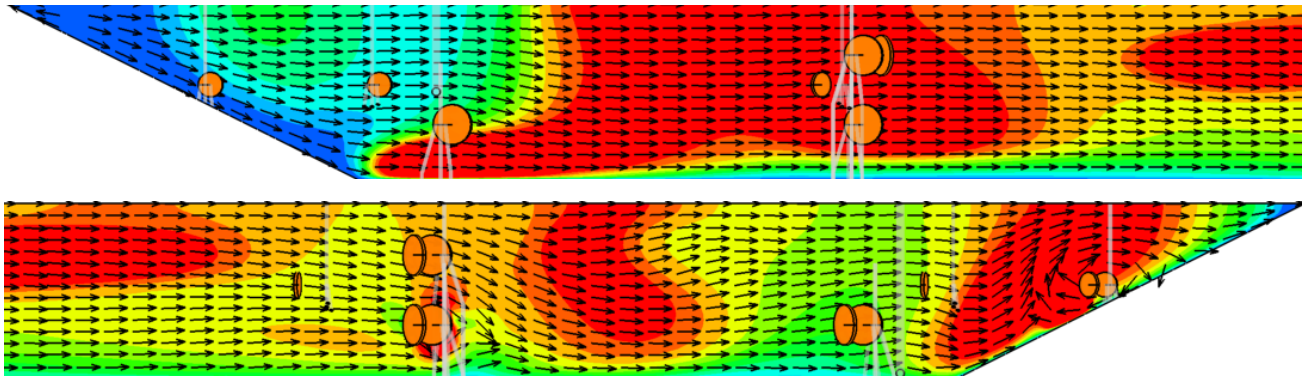
plane @y = 5.4 m

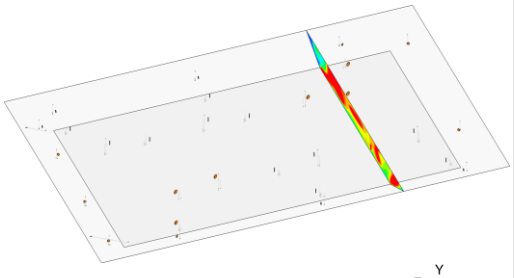
Bulk Velocity Type B = 0.54 m/s

- The plane close to tank top (5.4 m) is chosen to display the contours of velocity magnitude along with velocity vector field.
- The large circulation motion is visible. Also the counter rotating vortices in the corners are also visible.
- Some low velocity zones are present associated to the main and the secondary (corner) vortices.

Velocity vectors @x = -30 m







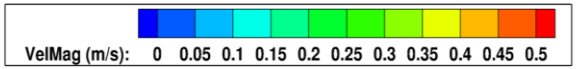
plane @x = -30 m

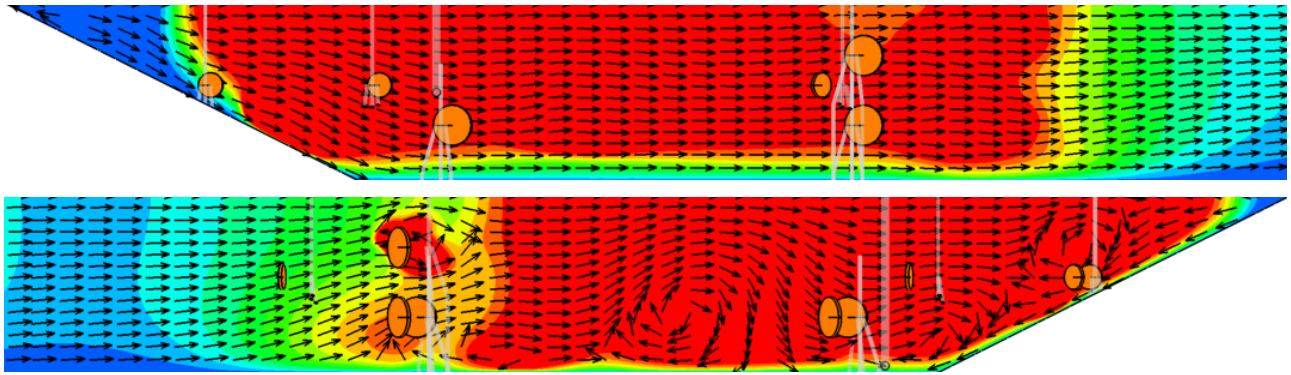
Bulk Velocity Type B = 0.54 m/s

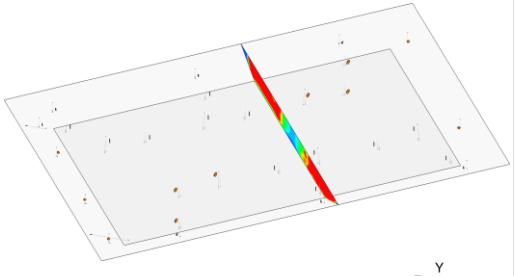
- The vertical plane (X = -30 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- No significant low velocity zones are visible.

Velocity vectors @x = -10 m







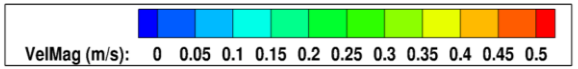
plane @x = -10 m

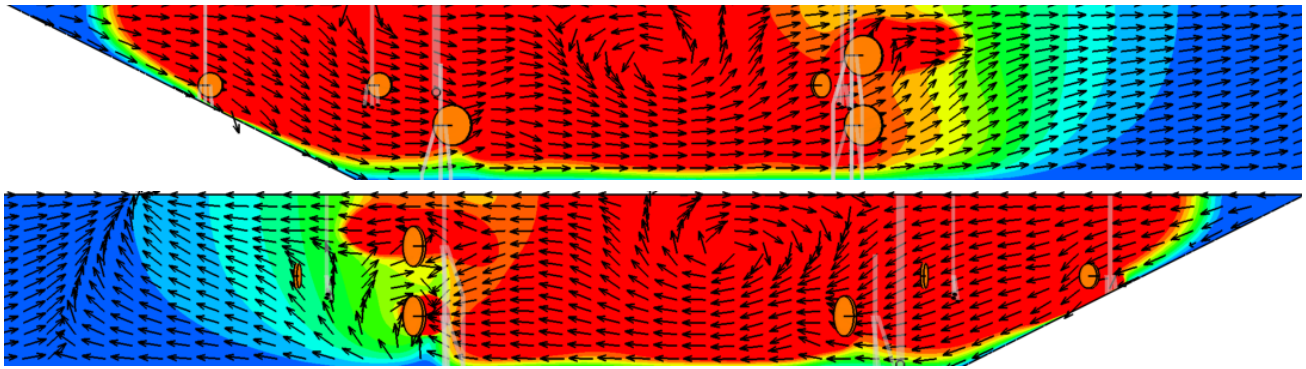
Bulk Velocity Type B = 0.54 m/s

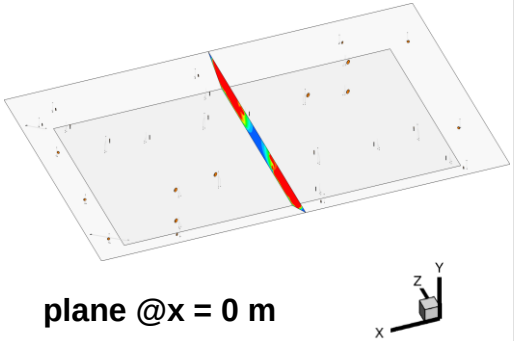
- The vertical plane (X = -10 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- No significant low velocity zones are visible.

Velocity vectors @x = 0 m







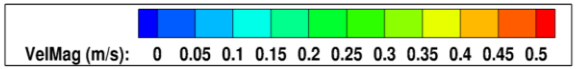
plane @x = 0 m

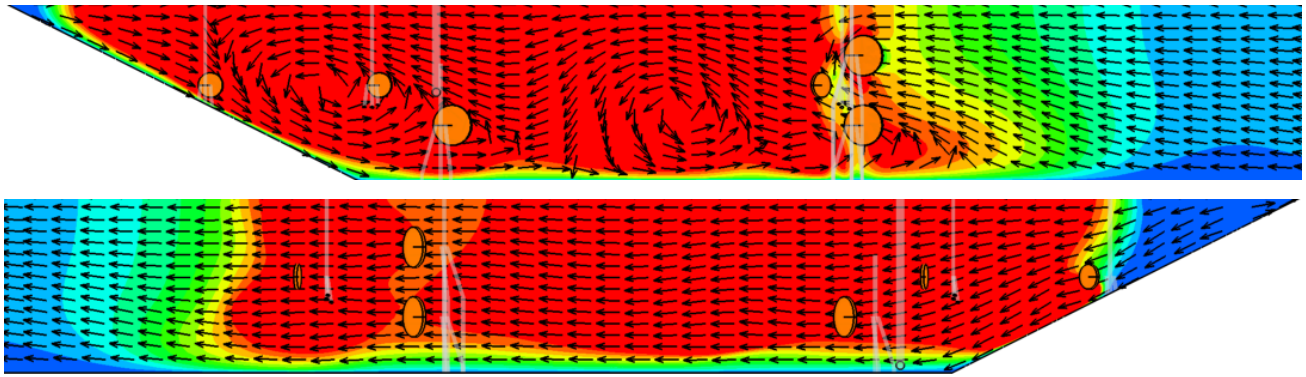
Bulk Velocity Type B = 0.54 m/s

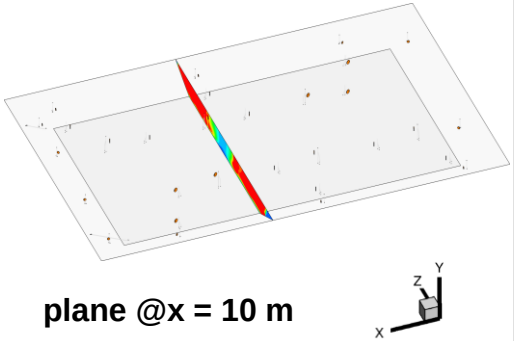
- The vertical plane (X = 0 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- There is a low velocity zone associated with the large circulation zone.

Velocity vectors @x = 10 m







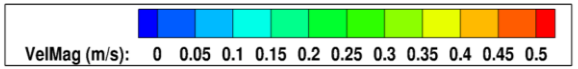
plane @x = 10 m

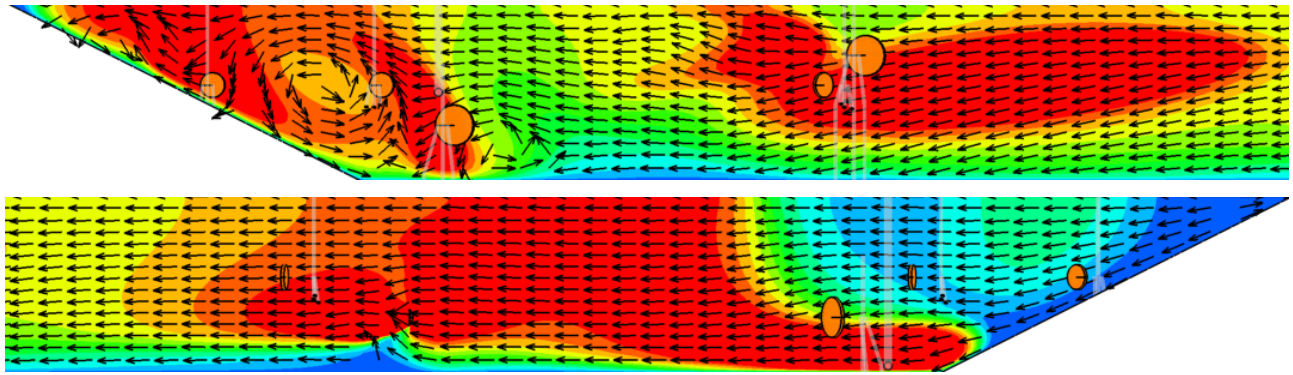
Bulk Velocity Type B = 0.54 m/s

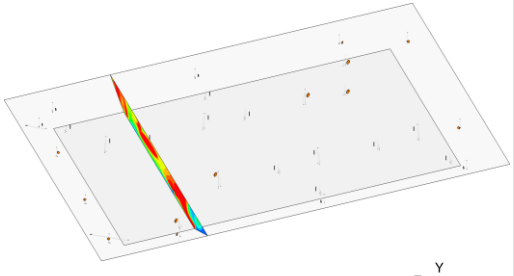
- The vertical plane (X = 10 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- No significant low velocity zones are visible.

Velocity vectors @x = 30 m







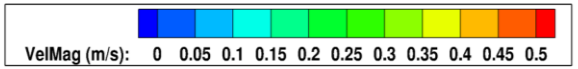
plane @x = 30 m

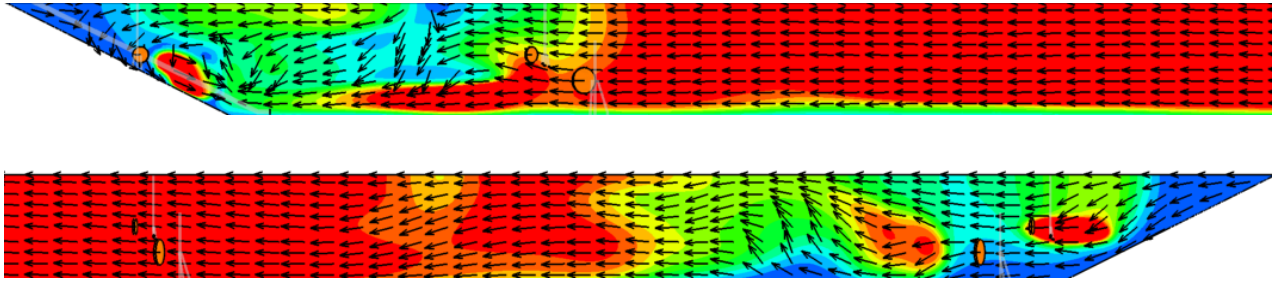
Bulk Velocity Type B = 0.54 m/s

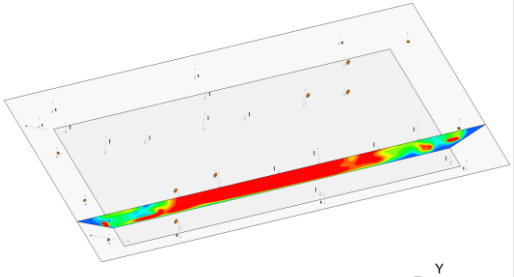
- The vertical plane (X = 30 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- No significant low velocity zones are visible.

Velocity vectors @z = -20 m





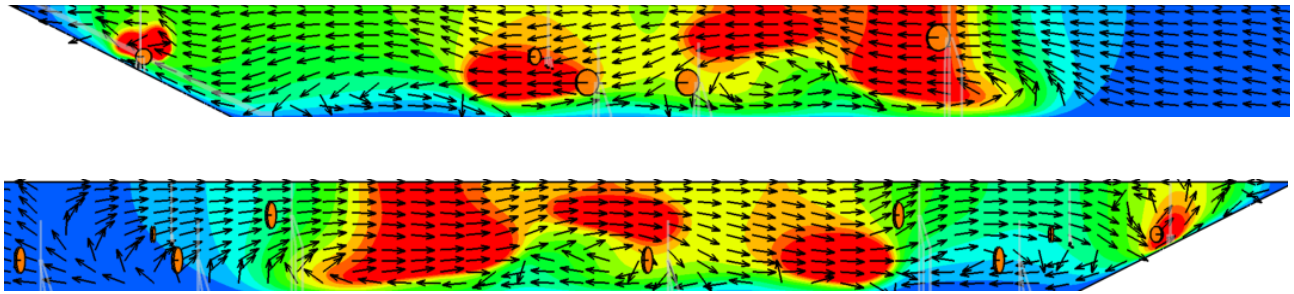


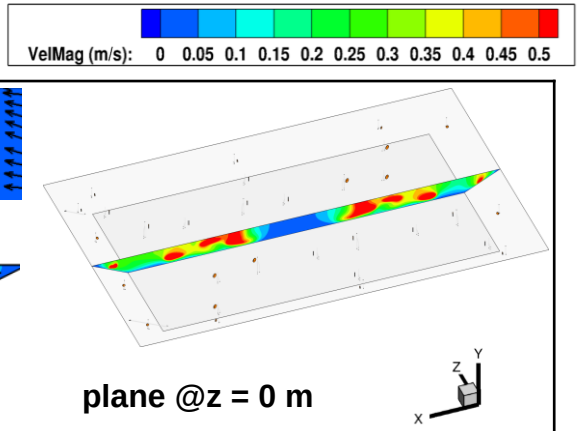
plane @z = -20 m

Bulk Velocity Type B = 0.54 m/s

- The vertical plane (Z = -20 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.
- No significant low velocity zones are visible.

Velocity vectors @z = 0 m





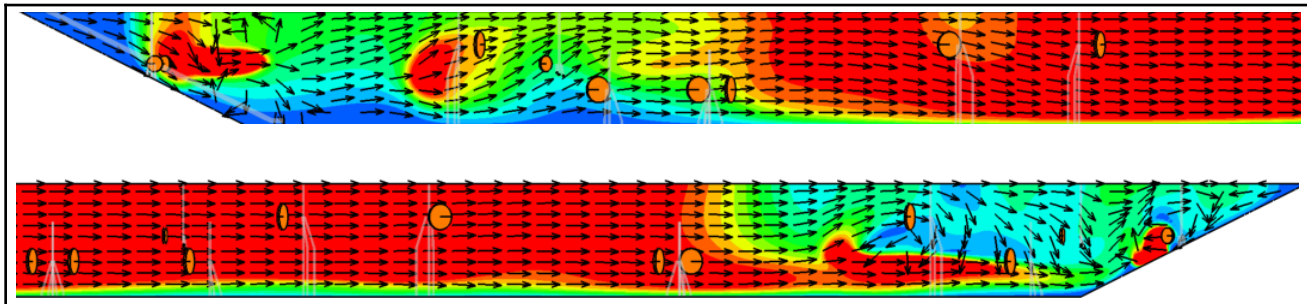
plane @z = 0 m

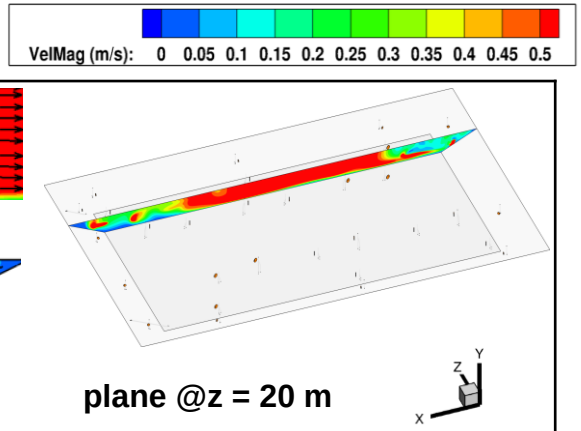
Bulk Velocity Type B = 0.54 m/s

- The vertical plane (Z = 0 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- There is a low velocity zone associated with the large circulation zone.

Velocity vectors @z = 20 m



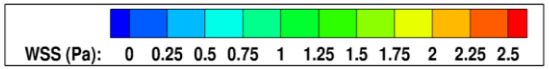


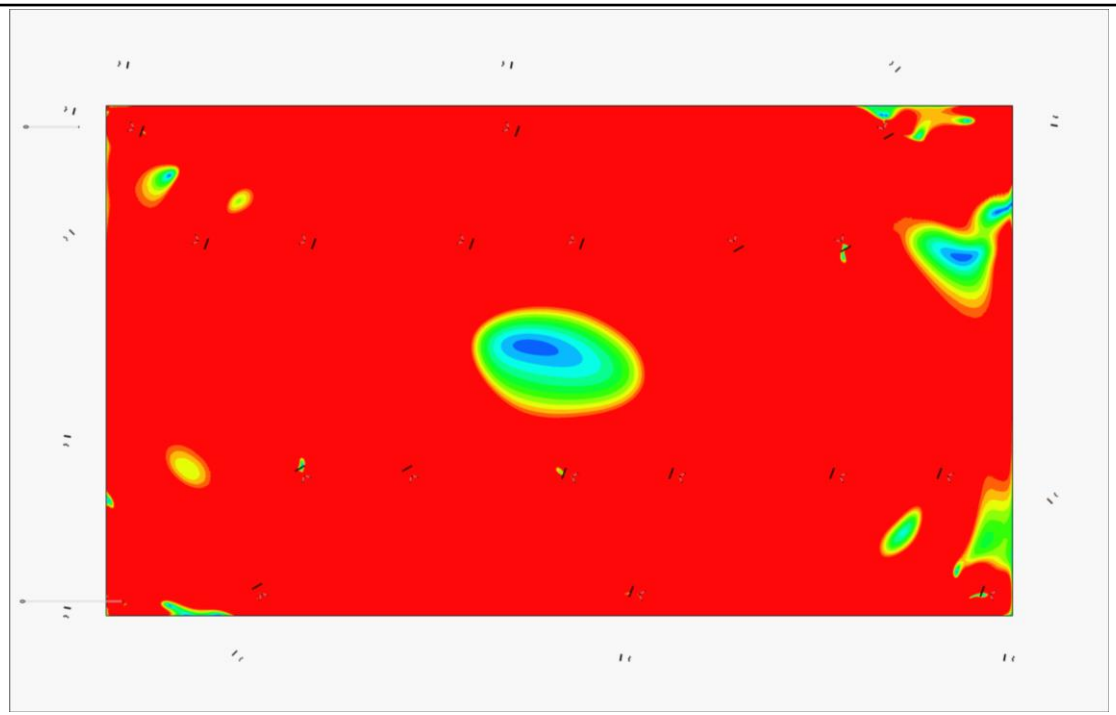
Bulk Velocity Type B = 0.54 m/s

- The vertical plane (Z = 20 m) is chosen to display the contours of velocity magnitude along with velocity vector field. The view is cut in two pieces for better visibility.

- No significant low velocity zones are visible.

Wall Shear Stress (WSS) at tank bottom





- The wall shear stress is shown at the bottom of the tank. Maximum value in the color bar corresponds to the estimated yield stress for this fluid.
- There is only a small region in the middle with some risk for sedimentation and some even smaller near the corners.
- All the zones are small and will be subject to move due to transient effects.

Summary/Conclusions

1. The proposed mixer solution yields good flow conditions.

2. Resulting Flow Conditions:
   a) The bulk flow velocity is **0.54 m/s** (**Type B** calculation).
   b) The flow in the tank is dominated by a large central flow and a few smaller counter rotating near the corners.
   c) A few mixers (three) might be subject to shear forces and vibrations as jets generated from other mixers, placed upstream, are impacting on them.
3. There is a temporary sedimentation chance in the center but the risk for persistent sedimentation is very small.

4. Conclusion: As a result of the above mentioned evaluation - mixing is judged **adequate**.