Flow reversals in a mixer powered high loss race track channel; a CFD study and its application to a real pilot channel

INTRODUCTION

Flow reversals, revealed as surface currents in the opposite direction of the intended flow, are sometimes observed in race tracks or other closed channel type of tanks. The visual trace of these counter currents is typically located to a region above the mixer(s) that extends a few channel widths (or depths) downstream and upstream of the mixer(s). This phenomenon deserves attention as it is often perceived as strange and undesired by customers and as it may have practical consequences. It shall be emphasized that what is seen on the surface doesn't reflect the flow conditions below the surface and typically the intended average circulation velocity around the channel is maintained even when a reversed flow is live. The observation that flow reversals exist in some cases and don't in other, motivate an attempt to find the underlying reason why they appear.

***Figure 1**. Back flow hinders floating sludge from passing through the bend at Tata WWTP, Hungary.*

At two racetracks in Tata WWTP, Hungary, a stream of backward flow (against the mixers) on the surface of the racetracks is reported to occur downstream of the mixers. Movie clips showing the backward flow is stored under PASS case 2012-004902. Hypothetically, this back flow hinders floating sludge to pass through the nearest downstream bend from the mixers. As a result, again hypothetically, the ever newly formed floating sludge accumulates (see Figure 1) and gives rise to a blanket whose trailing edge propagates upstream over time till it eventually covers the whole surface of the pass where the mixers are located. A CFD study was initiated to investigate the underlying causes of the back flow and to examine if raising the mixers to a higher position could eliminate the observed flow reversals and thereby push the sludge blanket past the bend.

GEOMETRY

A top view of the tank is shown in Figure 2 below.

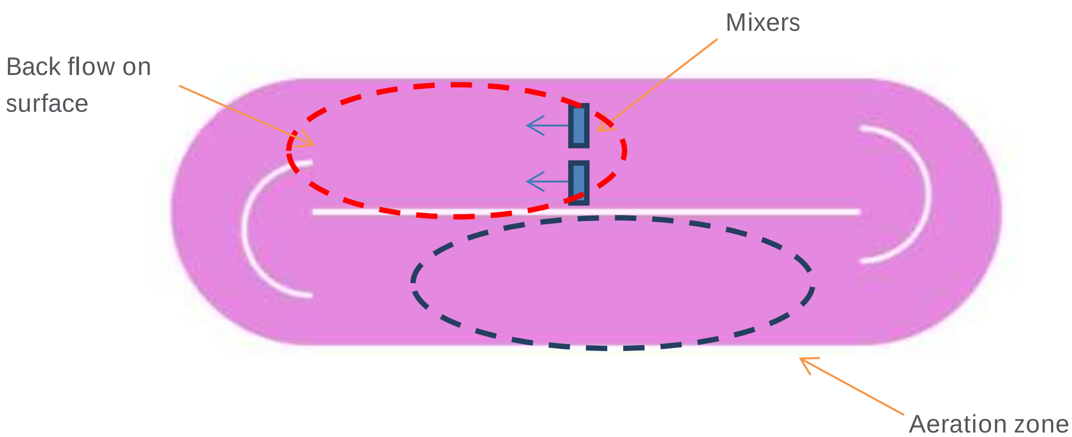

__Figure 2__. Regions where back flow has been observed.

The depth of the tank is 5 meters and the flow is generated by two Flygt mixers (4430.420, 40 rpm) that produce a thrust of 2795 N each. The center of the mixer propellers are located 1.6 meters above the bottom.

In order to simplify the CFD study, losses associated with the aeration system and the aeration was modeled by blocking a part of the tank cross section at the beginning of the aeration zone. Figure 3 shows the different blockage configurations that was usedin this study.

The first simulation (Case 1) was done without any blocking. In the second simulation (Case 2) 50% of the cross section was blocked at both sides of the tank and the third simulation (Case3) 35% of it was blocked only at one side. In these three cases the mixer location was kept 1.6 meters from the bottom. A forth simulation (Case 4) was subsequently carried out with 35% blockage and with the center of the mixer propellers at 3.05 meters above the bottom.

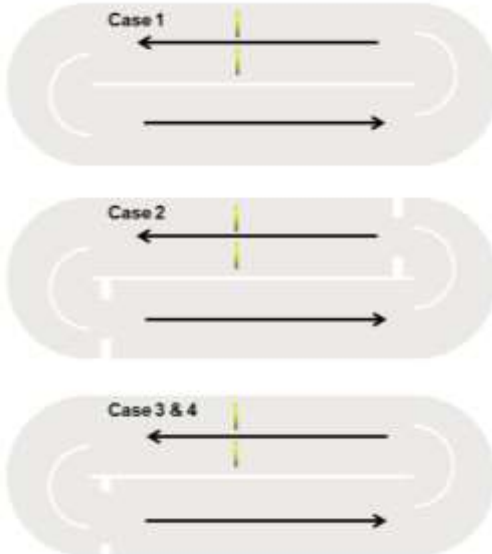

Figure 3. Geometries used in this study. No Blocking (top), Blocking 50% of cross section at both sides (middle), Blocking 35% of cross section at one side (bottom). The only difference between Case 3 and Case 4 is that in Case 3 the mixers are located close to the bottom whereas in Case 4, the mixers are located near the surface. Main flow direction is shown by arrows.

FORMULATION

The basic assumption for the analyses carried out below is that flow reversals in the vicinity of the mixers are triggered by excessive resistance to flow in the race track. Typically, the dominating contributors to the total resistance are losses associated with the bend design and the lay out and operation of the aeration system. The total head loss is expressed by a loss factor, k, and the relation between the mixer thrust force and the mean horizontal velocity is:

$$F = k \cdot \frac{1}{2} \cdot \rho \cdot u^2 \cdot A \qquad (1)$$

where F is the total mixer thrust (N) ρ is liquid density (kg/m^3), u is the mean horizontal velocity (m/s) (known as the bulk flow velocity) and A is the cross sectional area of the channel (m^2).

In order to capture the losses induced by the aeration system without modeling the aeration grid and the presence of air, contractions in the form of abrupt cross section area reductions was introduced in the racetrack For the velocity through the contraction continuity requires:

$$u \cdot A = u_c \cdot A_c \qquad (2)$$

Where u_c and A_c are velocity through the contraction and the cross sectional area of tank at the contraction, respectively.

The bulk velocity for the first simulation calculated from CFD results is around 0.33 m/s, which results in the k factor of:

$$k_1 = \frac{2 \cdot 2795}{0.5 \cdot 998.2 \cdot 0.33^2 \cdot 38} = 2.7$$

In contrast to the situation in the physical channel, this CFD simulation revealed no back flow at the surface downstream of the mixers. See Figures 4 to 10 for case 1. The absence of back currents in the simulation was thought of as being due to a too low loss was being used compared to that prevailing in the physical tank.

In order to increase the losses for the second simulation, obstacles in the form of two contractions was introduced in the channel, where each contraction constituted a 50% area reduction. The resulting bulk flow velocity then became 0.16 m/s which gave rise to a loss factor, k_2

$$k_2 = \frac{2 \cdot 2795}{0.5 \cdot 998.2 \cdot 0.16^2 \cdot 38} = 11.5$$

The second simulation revealed strong back currents on the surface downstream of the mixers. See Figures 4 to 10 for case 2. These back currents appeared to be stronger and extended further than what was apparent from the physical tank. Thus it was judged that the blocking introduced in the second simulation was exaggerated. Hence a third simulation was carried out with an intermediate blocking in order to catch a situation more similar to the one showed in the movies. The steps that are taken to estimate the new area of contraction are described below.

The following relation describes a simplistic description of the contraction loss:

$$k_c = \alpha \cdot \left(\frac{u_c}{u}\right)^2 = \alpha \cdot \left(\frac{A}{A_c}\right)^2 \qquad (3)$$

The constant α, is expected to be the same for different contraction ratios in a unique tank. Having two contractions in case 1, the total loss can be written as

$$k_2 = k_1 + 2 \cdot k_c \qquad => \qquad k_c = \frac{k_2 - k_1}{2} = \frac{11.5 - 2.7}{2} = 4.4$$

Using Equation (3) the constant α is found to be

$$\alpha = 4.4 \cdot \left(\frac{\frac{A}{2}}{A}\right)^2 = \frac{4.4}{4} = 1.1$$

An intermediate loss factor value 5 was chosen in an effort to mimic the flow situation observed in the physical tank. To calculate the required ratio of one single contraction to reach a total loss factor 5, Equation (3) is used:

$$k_c(= k_3 - k_1) = \alpha \cdot \left(\frac{A}{A_c}\right)^2 \quad => \quad k_c(= 5 - 2.7) = 1.1 \cdot \left(\frac{38}{A_c}\right)^2 \quad => \quad A_c = 26.3\ m^2$$

This calculated value for the contraction area is equal to an around 31% blockage. Based on these estimations 35% area reduction was chosen for the third simulation, for which the results revealed a moderate backflow sufficiently similar to the one observed in the physical channel. See Figures 4 to 10 for case 3.

Having a situation where the CFD simulation showed a similar surface flow pattern as did the physical tank, a forth simulation was conducted in order to examine the effects on the surface flow pattern of elevating the mixers to nearer to the surface; the purpose being to eliminate the back currents.

The result of the forth simulation (35% area reduction and elevated mixers) are shown in Figures 4 to 10 for case 4. From these Figures it is apparent that the action of elevating the mixers eliminated the back currents on the surface. Thus a necessary but maybe not sufficient condition to make possible convection of the sludge blanket past bend is at hand.

RESULTS & DISCUSSION

Contours of the horizontal velocity and velocity vectors at different levels of the tank are shown in the Figures 4 to 10. Each Figure shows the horizontal flow pattern at one certain level of the tank for the different situations that were simulated. These were:

Case 1: Tank with no blockage and mixer elevation of 1.6 meters
Case 2: Tank with two blockages, each with 50% area reduction and mixer elevation of 1.6 meters
Case 3: Tank with one blockage, 35% area reduction and mixer elevation of 1.6 meters
Case 4: Tank with one blockage, 35% area reduction and mixer elevation of 3.05 meters

The results of Case 4 show that elevating the mixers eliminated the back currents on the surface.

In Table 1 the bulk flow velocity and total loss factor values (see Equation (1)) for the different simulations are presented:

Table (1): Bulk flow velocity and total loss factor for the different cases.

	Bulk flow velocity [m/s]	Total k (loss factor)
Case 1	0.33	2.7
Case 2	0.16	11.5
Case 3	0.23	5.6
Case 4	0.23	5.6

The results presented in Table 1 and Figures 4 to 10, show that the existence of flow reversal relates to the total loss factor, i. e. the higher the losses are the more pronounced becomes the flow reversal.

In Cases 3 and 4, where the tank geometry is the same and the only difference is the elevation of the mixers, the average bulk flow velocity is the same. This observation indicates that the vertical location of a mixer (mixers) have only a very limited influence on the resulting bulk flow velocity in a channel.

In Case 1 where the losses are solely caused by bend losses and friction losses, the k factor is unexpectedly high. According to Xylem standard loss estimation tool (MIDS), a circular bend with centric guide vane contributes with loss factor k=0.6. Two of these bends and accounting for friction losses sums up to a total k factor around 1.5, while the simulation for Case 1 estimates it to be 2.7. The reason for the high losses in Case 1 is believed to be due to the eccentricity of the guide vanes in the bends. According to Xylem standard loss estimation tool (MIDS), a prolonged eccentric guide vane introduces more than 2 times of the loss introduced by a prolonged centric guide vane. The simulation results indicated that the same is true for a non-prolonged eccentric guide vane.

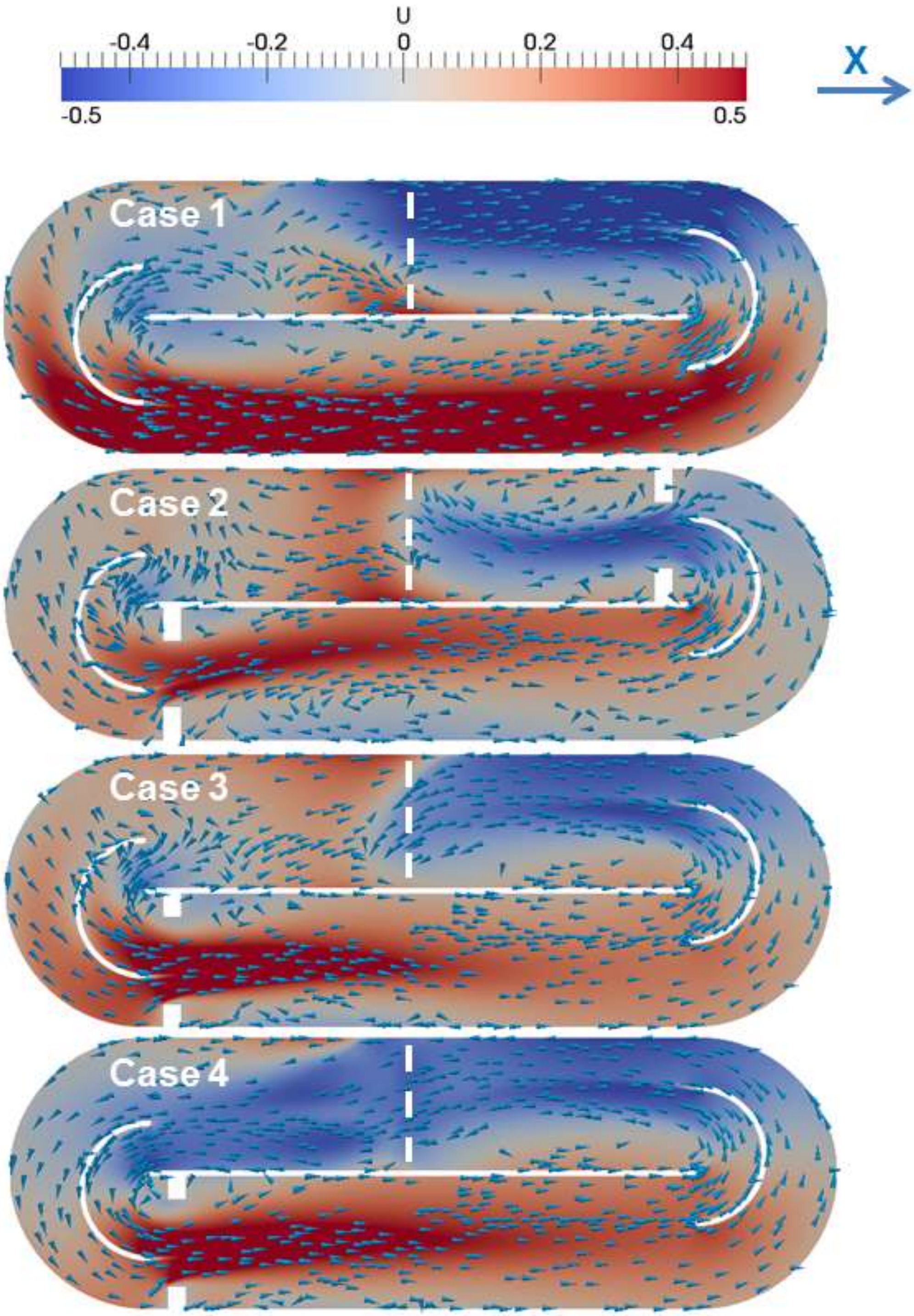

Figure 4. Horizontal velocity contours and velocity vectors at the surface for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Notice how the elevation of the mixers from near bottom (Case 3) to near the surface (Case 4) completely removes the back currents over the mixers. Red color indicates flow direction from left to right and blue color indicates flow direction from right to left. Mixers positions are shown by dashed lines.

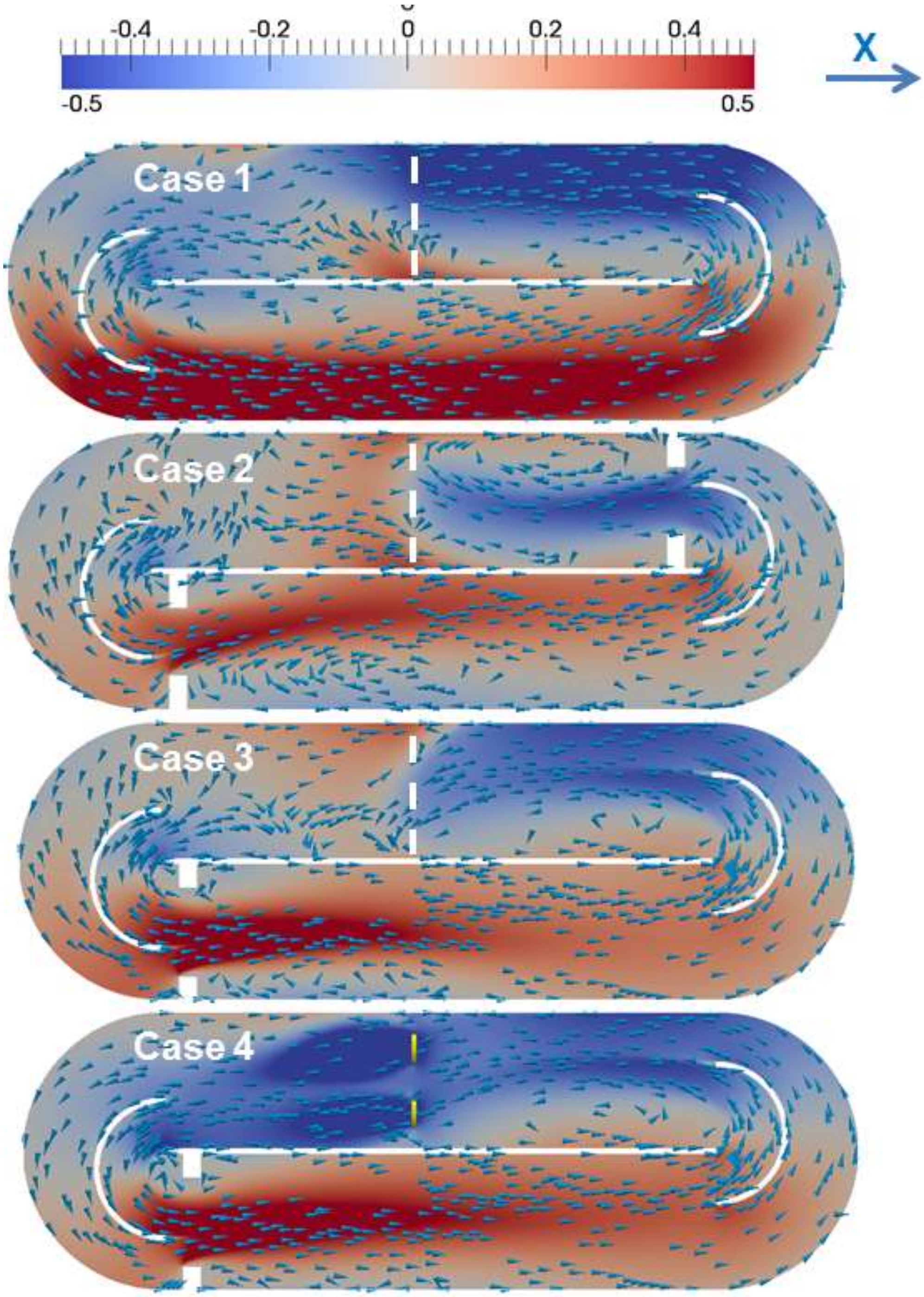

Figure 5. *Horizontal velocity contours and velocity vectors* ***1 meter below surface*** *for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Red color indicates flow direction from left to right and blue color indicates flow direction from right to left. Mixers positions are shown by dashed lines.*

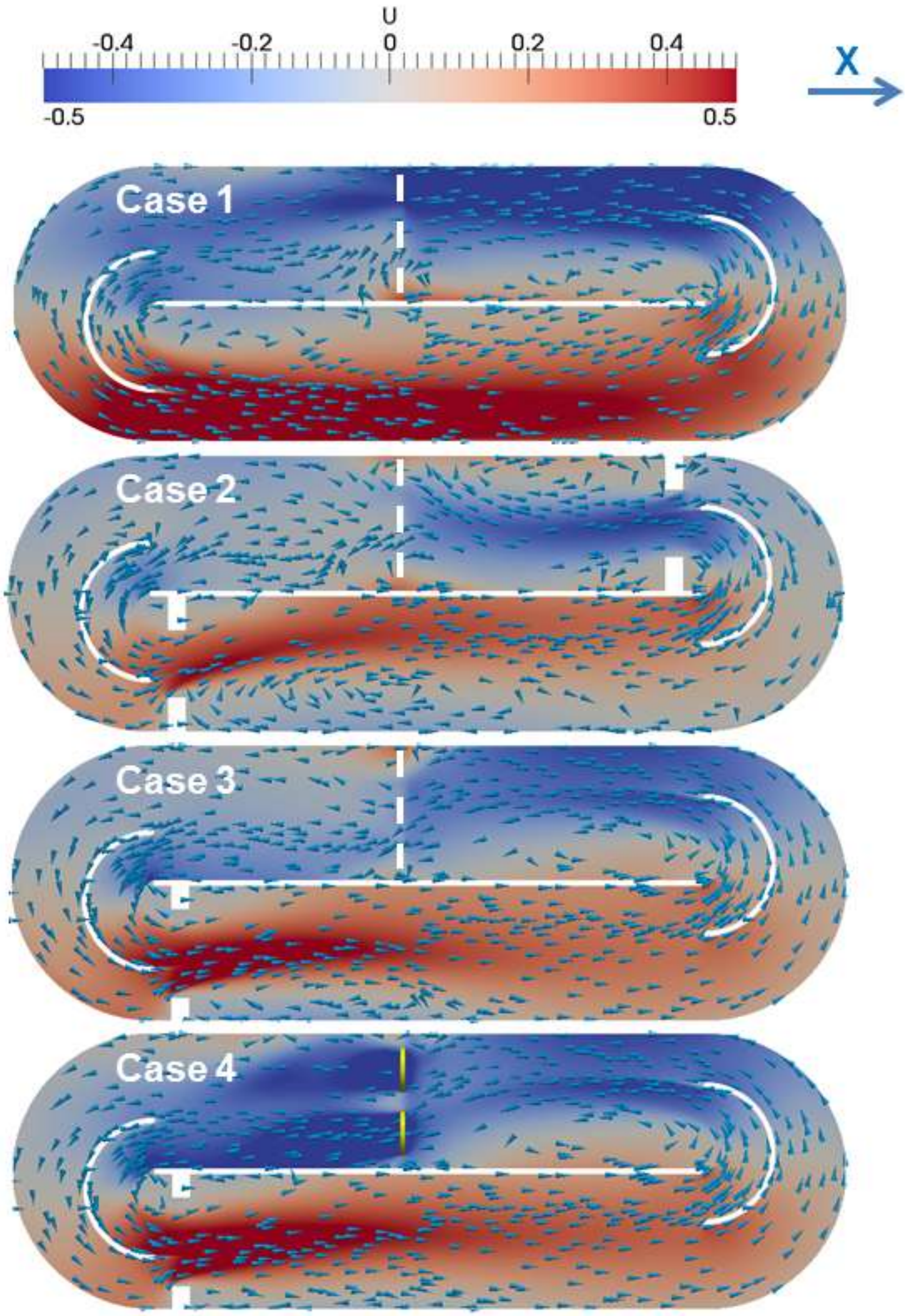

Figure 6. *Horizontal velocity contours and velocity vectors* ***2 meters below surface*** *for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Red color indicates flow direction from left to right and blue color indicates flow direction from right to left. Mixers positions are shown by dashed lines.*

xylem
Let's Solve Water

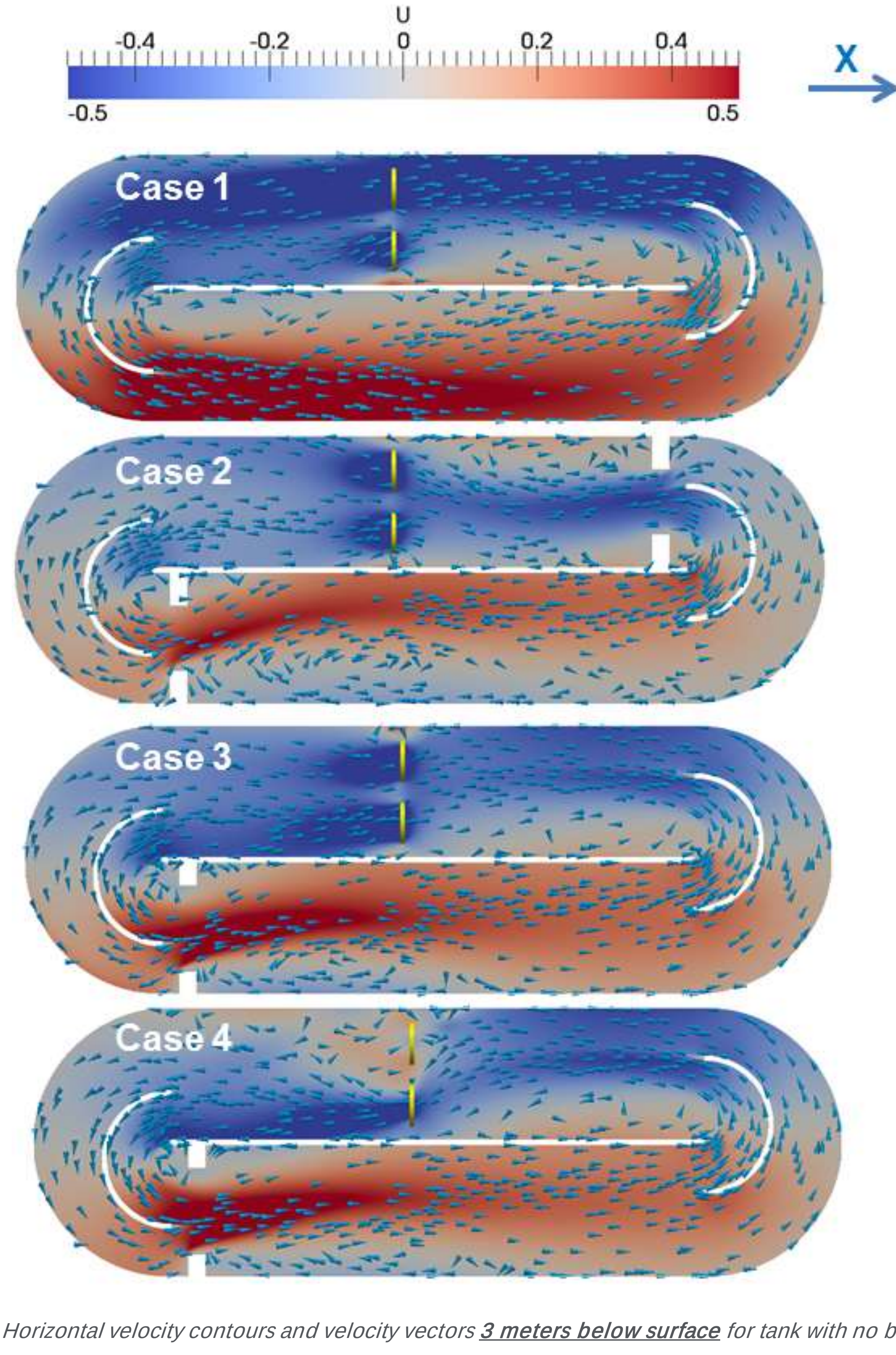

***Figure 7**. Horizontal velocity contours and velocity vectors **3 meters below surface** for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Red color indicates flow direction from left to right and blue color indicates flow direction from right to left.*

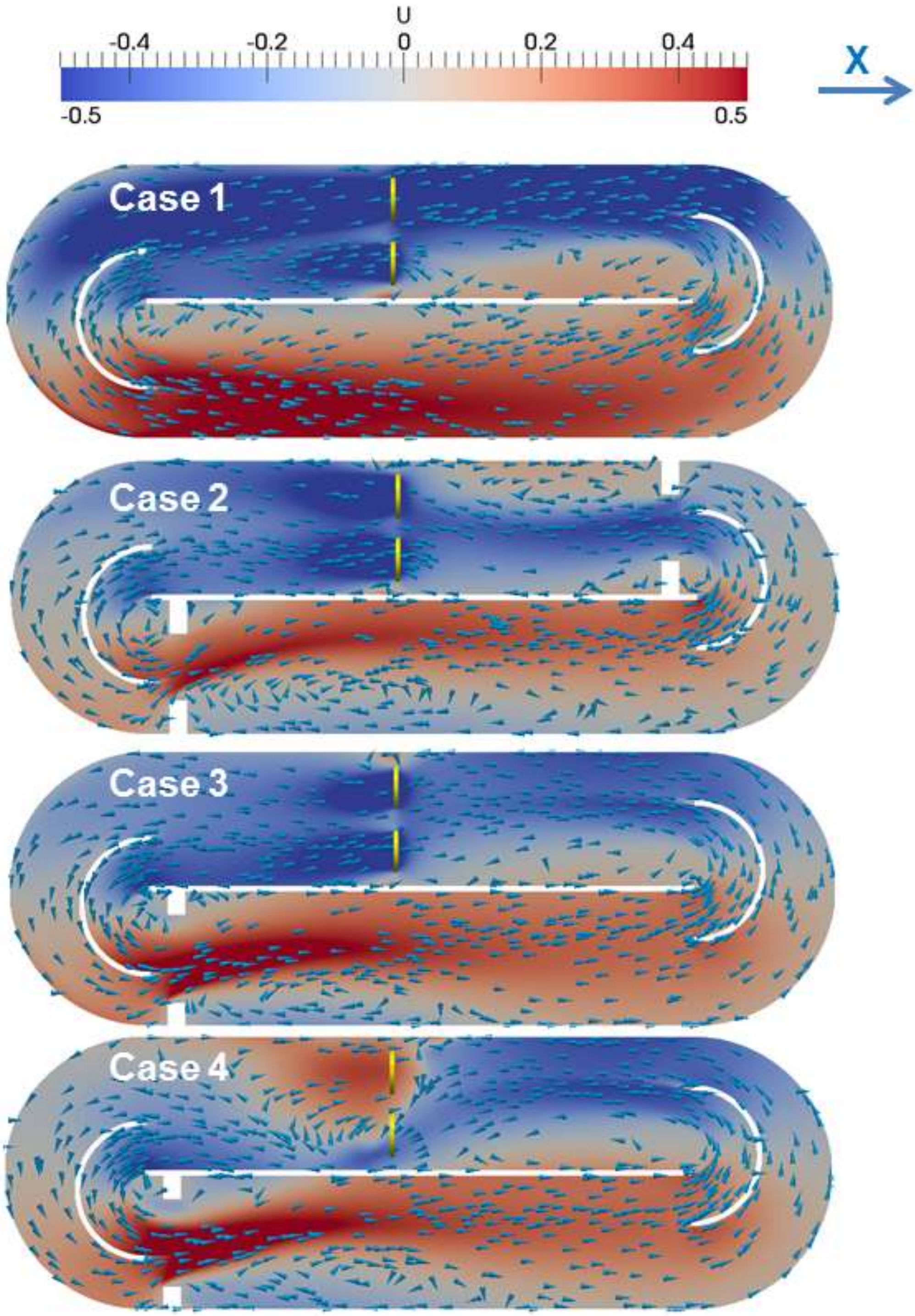

Figure 8. *Horizontal velocity contours and velocity vectors* ***4 meters below surface*** *for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Red color indicates flow direction from left to right and blue color indicates flow direction from right to left.*

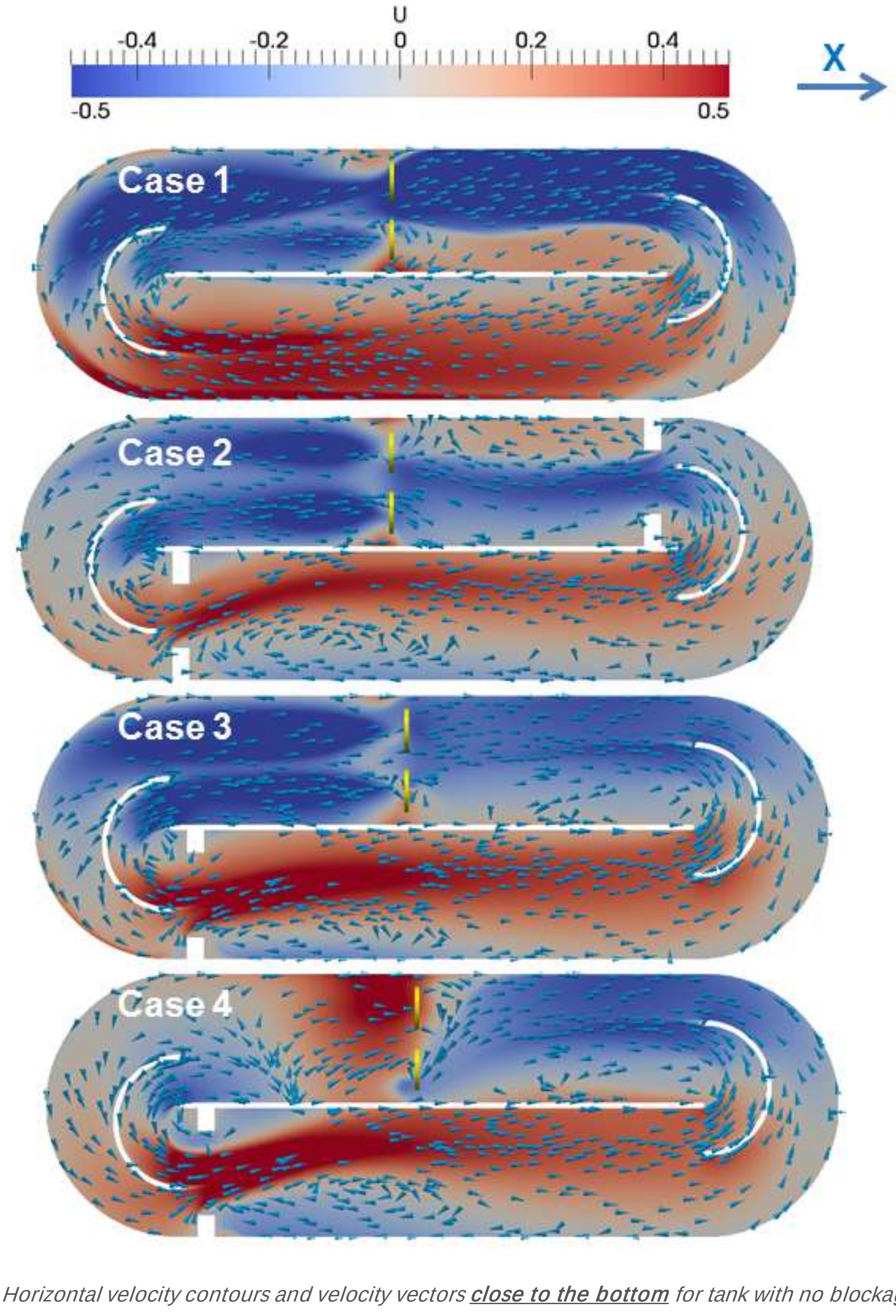

__Figure 9__. Horizontal velocity contours and velocity vectors ***close to the bottom*** *for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). Red color indicates flow direction from left to right and blue color indicates flow direction from right to left.*

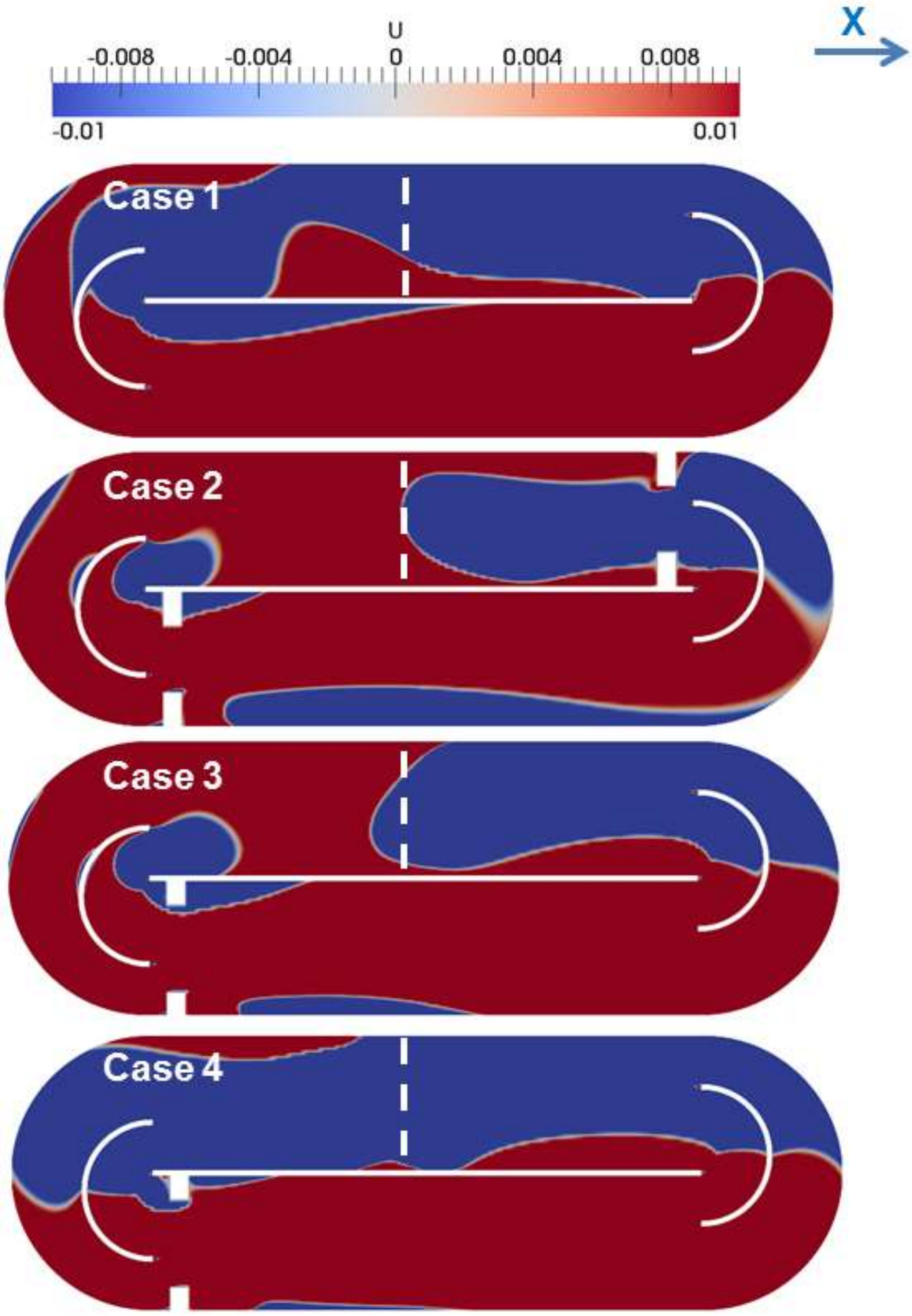

__Figure 10__. Horizontal velocity contours __at the surface__ for tank with no blockage (case 1), 50% blockage at both sides (case 2), 35% blockage at one side (case 3), 35% blockage at one side and hiostered mixers (case 4). The color scale is deliberately chosen in a way to distinguish the flow direction. Red color indicates flow direction from left to right and blue color indicates flow direction from right to left. Mixers positions are shown by dashed lines.

Case 3
At surface

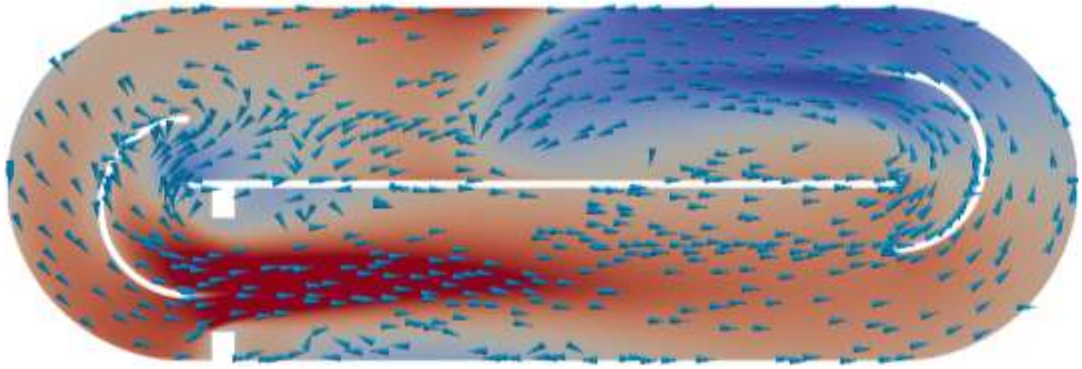

***Figure 11**. Horizontal velocity contours **__at the surface__** for case 3 (mixers are located close to the bottom)*

Case 4
At bottom

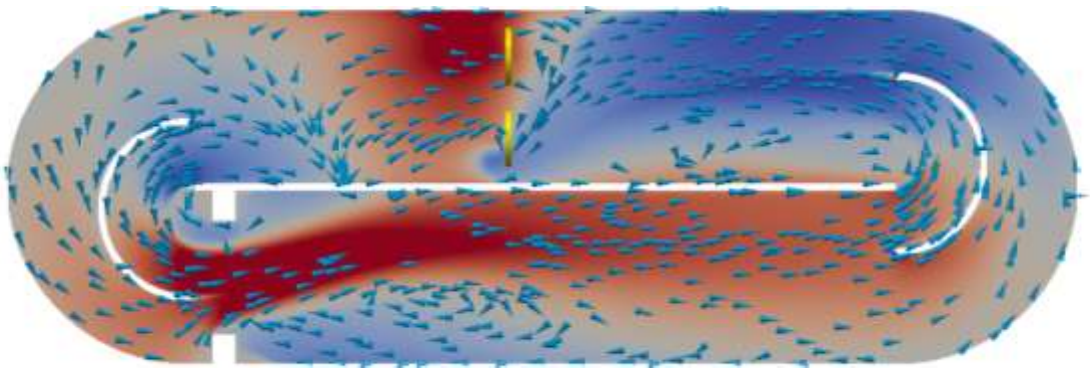

***Figure 12**. Horizontal velocity contours **__at the bottom__** for case 4 (mixers are located closer to the surface)*

Elevating the mixers relocates the reverse flow from the surface to the bottom of the tank. See Figures 11 and 12. This improves the flow pattern locally on the surface and forms the necessary condition for floating sludge to be pushed through the bend by the main flow.

The proposed solution to elevate the mixers was successfully carried out by the Xylem Hungary staff and allegedly the problem with sludge accumulation was solved.

CONCLUSIONS

The CFD study showed that elevating the mixers removes the regions with reverse flow from the surface of the tank but relocates them to bottom of the tank. Allegedly elevating the mixers solved the floating sludge issue in the physical tank. According to this study, elevating the mixers had no effect on the bulk flow velocity.

The extent and intensity of the flow reversals depend on the total loss factor of the tank. The higher the losses are, the more pronounced becomes the flow reversal.

The occurrence of flow reversal in the physical tank is due to the unexpectedly high losses in the tank which is believed to be caused by a combination of the eccentricity of the guide vanes and the aeration system.

AUTHORS

Magnus Fahlgren
Faranggis Bagheri