COMPUTATIONAL FLOW MODEL OF WESTFALL'S 4000 OPEN CHANNEL MIXER

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By

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INTRODUCTION

Alden Research Laboratory Inc. (Alden) was contracted by Westfall Manufacturing Inc. (Westfall) to evaluate the performance of the 3-stage 4000 mixer for use in open channel applications. The objective of this mixer is to achieve a low coefficient of variation (CoV) of the injected fluid at the outlet of the mixer, with as little pressure loss as possible. This report discusses the head loss and mixing capabilities of the leading tab low head mixer installed in a 36-inch mixer within a 10-ft by 10-ft channel used for water treatment.

COMPUTATIONAL MODEL DESCRIPTION

The model geometry was developed using the commercially available three-dimensional CAD and mesh generation software, GAMBIT V2.4.6. The computational domain generated for the model consisted of approximately 4 million hexahedral and tetrahedral cells.

Numerical simulations were performed using the CFD software package FLUENT 13.1, a state-of-the-art, finite volume-based fluid flow simulation package including program modules for boundary condition specification, problem setup, and solution phases of a flow analysis. Advanced turbulence modeling techniques, improved solution convergence rates and special techniques for simulating species transport makes FLUENT particularly well suited for this study.

Alden used FLUENT to calculate the three-dimensional, incompressible, turbulent flow through the pipe and around the flow conditioner. A stochastic, two-equation k-ε model was used to simulate the turbulence. Detailed descriptions of the physical models employed in each of the Fluent modules are available from Ansys/Fluent, the developer of Fluent V13.1.

MODEL BOUNDARY CONDITIONS

The tests were conducted in 10-ft by 10-ft open channel similar to what would be used for chlorination of drinking water. A 36” diameter 4000 mixer was integrated into a bulkhead across the channel that directs any water flowing down the channel through the mixer. The mixer centerline was placed at the midpoint of the channel’s span, and 4-ft off the channel floor. The mixer length is 8’-1 ¾”, or 2.715 diameters. The model inlet is 10-ft upstream of the mixer bulkhead, and the outlet is 30-ft downstream of the bulkhead (Figure 1).

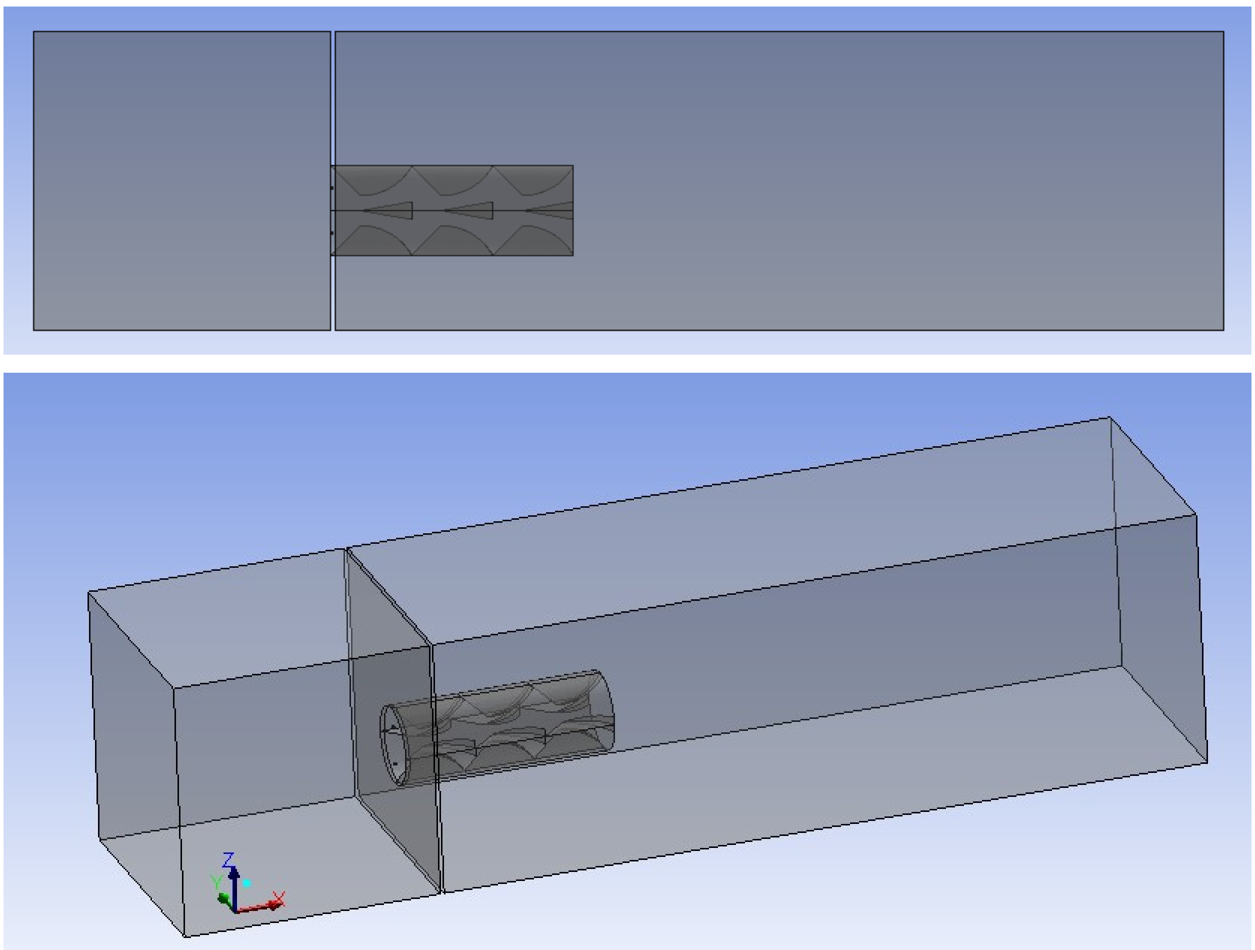


Figure 1 - CFD Model Domain

It has been determined through previous testing that the mixer performs similarly at different flow rates provided the flow is turbulent (Re > 4,600), so only one water flow rate was tested. . A uniform velocity was imposed at the model inlet, corresponding to 6,342 gpm (9.13 MGD) at a temperature of 60°F.

To measure mixing, a chlorine solution was injected into the mixer through two injection port locations at the mixer inlet plane, upstream of the 12 o'clock and the 6 o'clock mixer tabs. The solution was injected at a rate such that it would mix out to 982-ppm in the channel (6.23 gpm), though it could be mixed at a much lower rate with similar results.

Two configurations of the mixer were tested:

- The 4000 mixer (Figure 2)
- The 4000 mixer with inlet and diffuser (Figure 3)

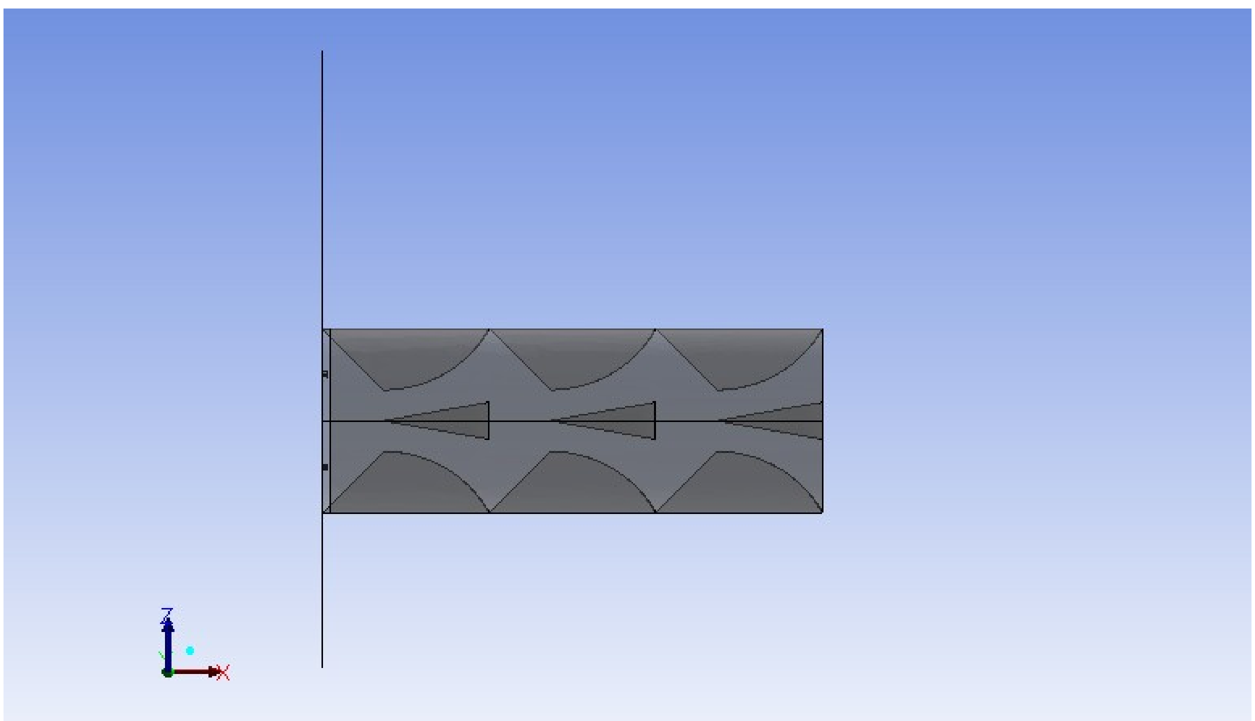


Figure 2 - 4000 Open Channel Mixer

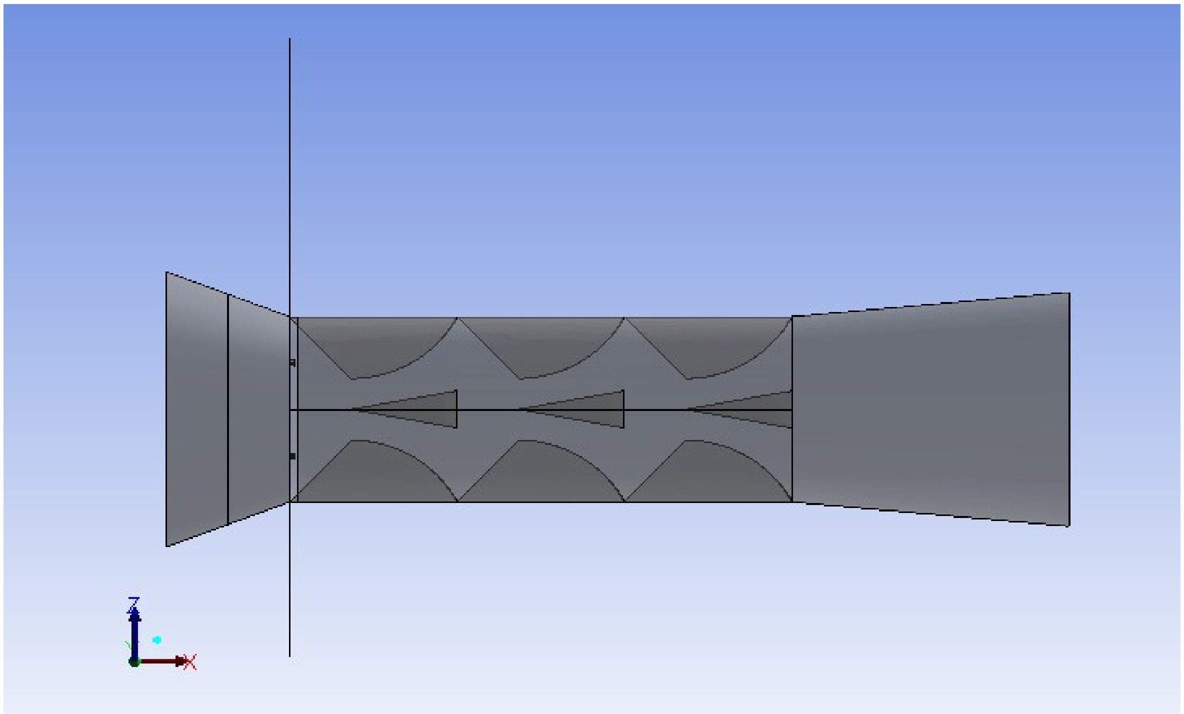


Figure 3 - 4000 Open Channel Mixer with Inlet and Diffuser

The inlet and diffuser outlet cones are intended to reduce the head loss of the mixer at a given flow rate, or to increase the flow rate at a given head loss. The inlet cone is 2’-0” (0.667D) long, and has an included angle of 40°. The outlet cone is 4’-6” (1.5D) long, and has an included angle of 10°.

The mixers were analyzed with the mixer pipe inlet flush with the bulkhead, however to avoid overhung loads on the bulkhead, the mixers could be installed so that their center of gravity is in the bulkhead plane for a better structural design, and ease of installation/recovery of the mixer. Moving the mixer forward in the bulkhead will not change the pressure loss across the mixer with inlet and diffuser, and will slightly increase the pressure loss across the mixer only configuration.

RESULTS AND DISCUSSION

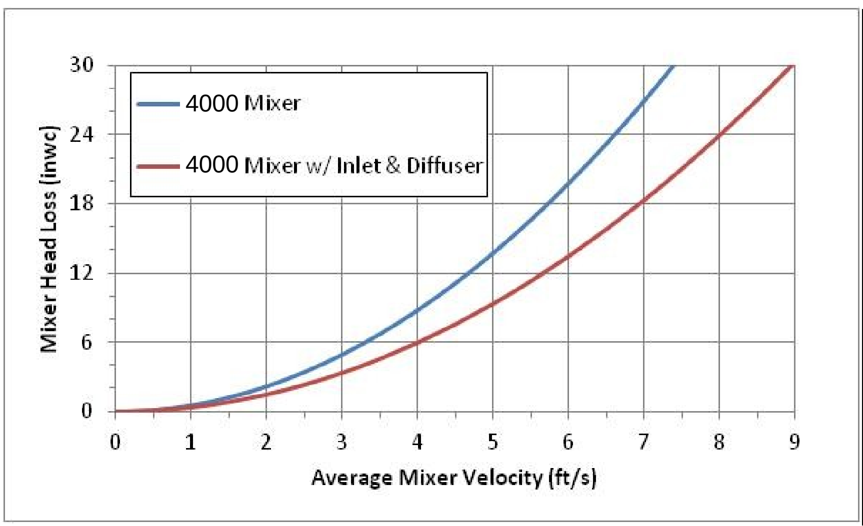
The pressure loss across each of the mixer configurations was calculated in the CFD model at the specified flow rate, and a loss coefficient (k-value) was calculated (Table 1), where the k-value is defined using consistent units:

$$k = \frac{\Delta p}{\frac{1}{2}\rho V^2}$$

Once the mixer loss coefficient is calculated, predictions of the mixer pressure loss can be made across the expected flow range (Figure 4).

Table 1 - 4000 Open Channel Mixer Flow Results

Flow Results:	Units	4000 Mixer Only	With inlet/diffuser
Mixer Diameter	(in)	36.0	36.0
Water Flow Rate	(gpm)	6,342	6,342
Dosing Flow Rate	(gpm)	6.23	6.23
Average Mixer Velocity	(ft/s)	2.00	2.00
Water Density	(pcf)	62.4	62.4
Mixer Head Loss	(inwc)	2.20	1.50
Mixer k-value		2.95	2.01



Mixer Velocity (ft/s)	4000 Mixer (inwc)	+ Inlet & Diffuser (inwc)
0	0.0	0.0
1	0.5	0.4
2	2.2	1.5
3	4.9	3.4
4	8.8	6.0
5	13.7	9.4
6	19.8	13.5
7	26.9	18.4
8	35.2	24.0
9	44.5	30.3
10	54.9	37.5

Figure 4 - Westfall 4000 Open Channel Mixer Head Loss Chart

The inlet and diffuser cones were found to reduce the mixer pressure loss by 32% at a given flow rate, or increase flow rate by 18% at a given head loss. Of the decrease in pressure loss, 52% is attributable to the inlet cone, and 48% is attributable to the diffuser.

Mixing performance was evaluated at the model outlet, which is a plane across the channel 30-ft downstream of the mixer bulkhead, and results are presented in Table 2.

Table 2 - 4000 Open Channel Mixer Mixing Results 30-ft Downstream of the Bulkhead

Mixing Results:	Units	4000 Mixer Only	With Inlet/Diffuser
Average Volume Fraction	(ppm)	982	982
Minimum Volume Fraction	(ppm)	977	946
Maximum Volume Fraction	(ppm)	1,000	1,031
Standard Deviation	(ppm)	8	18
Coefficient of Variation	(CoV)	0.008	0.018

Both mixers offer excellent mixing performance, with very low CoV values 10 mixer diameters downstream of the bulkhead (30-ft), though the mixing in the configuration without the inlet and diffuser (CoV = 0.008) is better that the configuration with the inlet and diffuser (CoV = 0.018). A significant amount of mixing occurs at the outlet of the mixers where the high velocity swirling flow exiting the mixer interacts with the bulk flow on the downstream side of the bulkhead (Figure 5, Figure 6). This is why the mixer with the diffuser has a higher CoV; the diffuser reduces energy loss of the flow through the mixer by limiting the turbulent momentum transfer with the bulk fluid as it slows and expands the flow, however this also reduces the energy available for mixing once the flow exits the diffuser.

A mixer with only an inlet cone, and without a diffuser cone would have roughly the same mixing performance of the mixer alone (CoV = 0.008), but with a pressure loss approximately halfway between the two configurations (k = 2.50). The cause of the excessive pressure loss without the inlet cone can be seen in Figure 7 where there is a large separated flow region at the walls in the first stage of the mixer, however with the inlet cone, the flow remains attached to the mixer walls throughout.

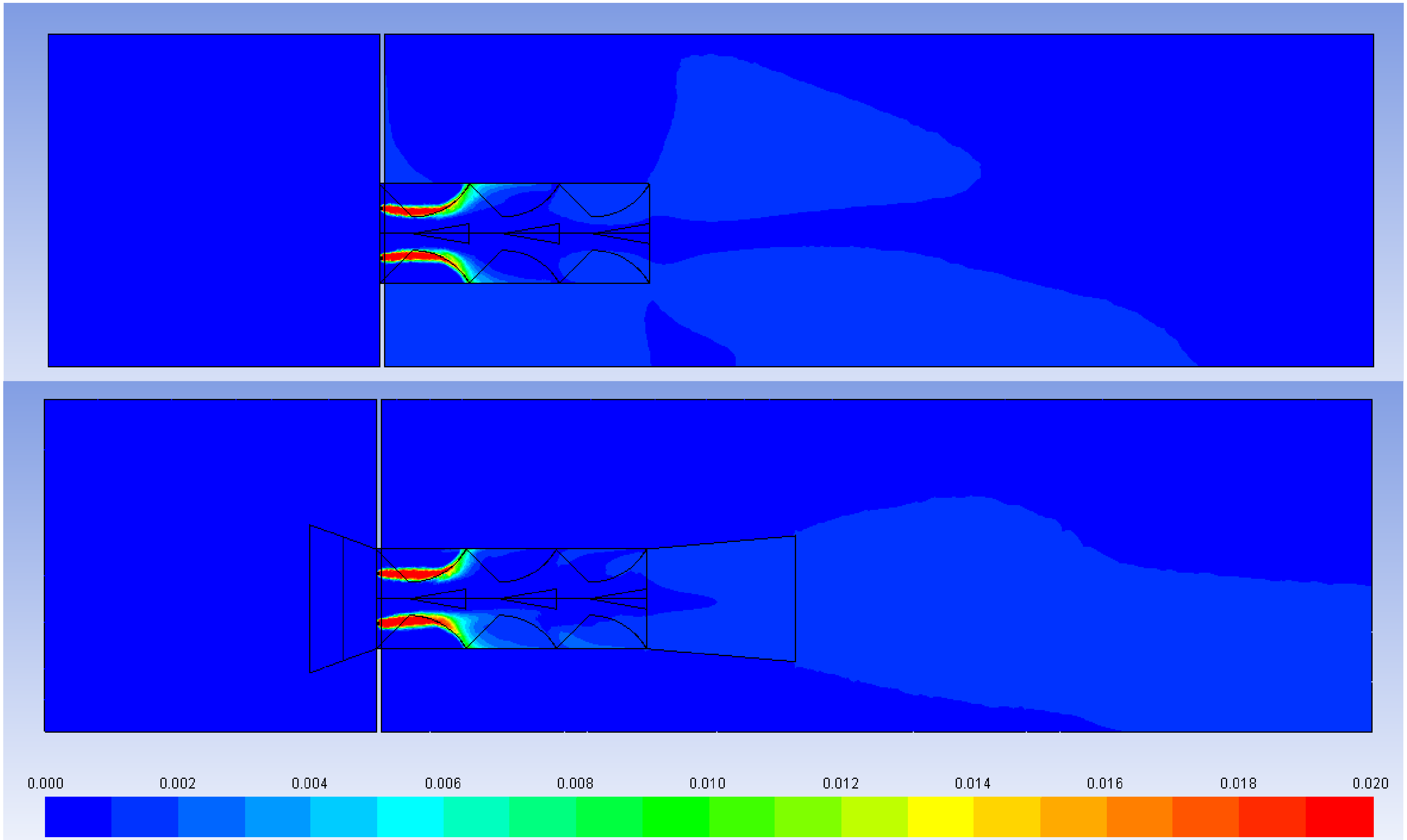


Figure 5 - Volume Fraction of Injected Solution on Mixer Centerline for 4000 Mixer (above) and with Inlet and Diffuser (below)

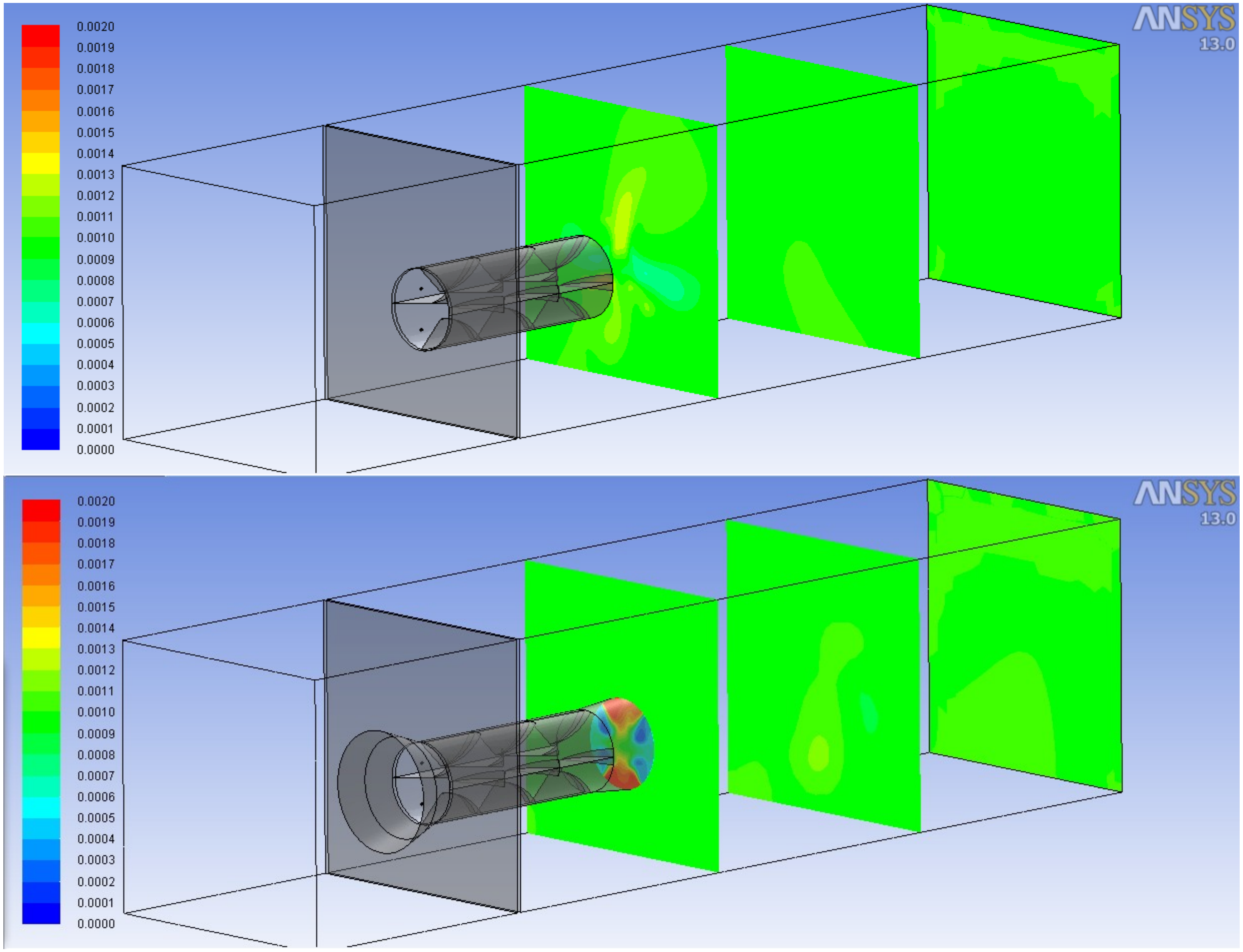


Figure 6 - Volume Fraction of Injected Solution at 10-ft, 20-ft, and 30-ft Downstream of the Bulkhead for 4000 Mixer (above) and with Inlet and Diffuser (below)

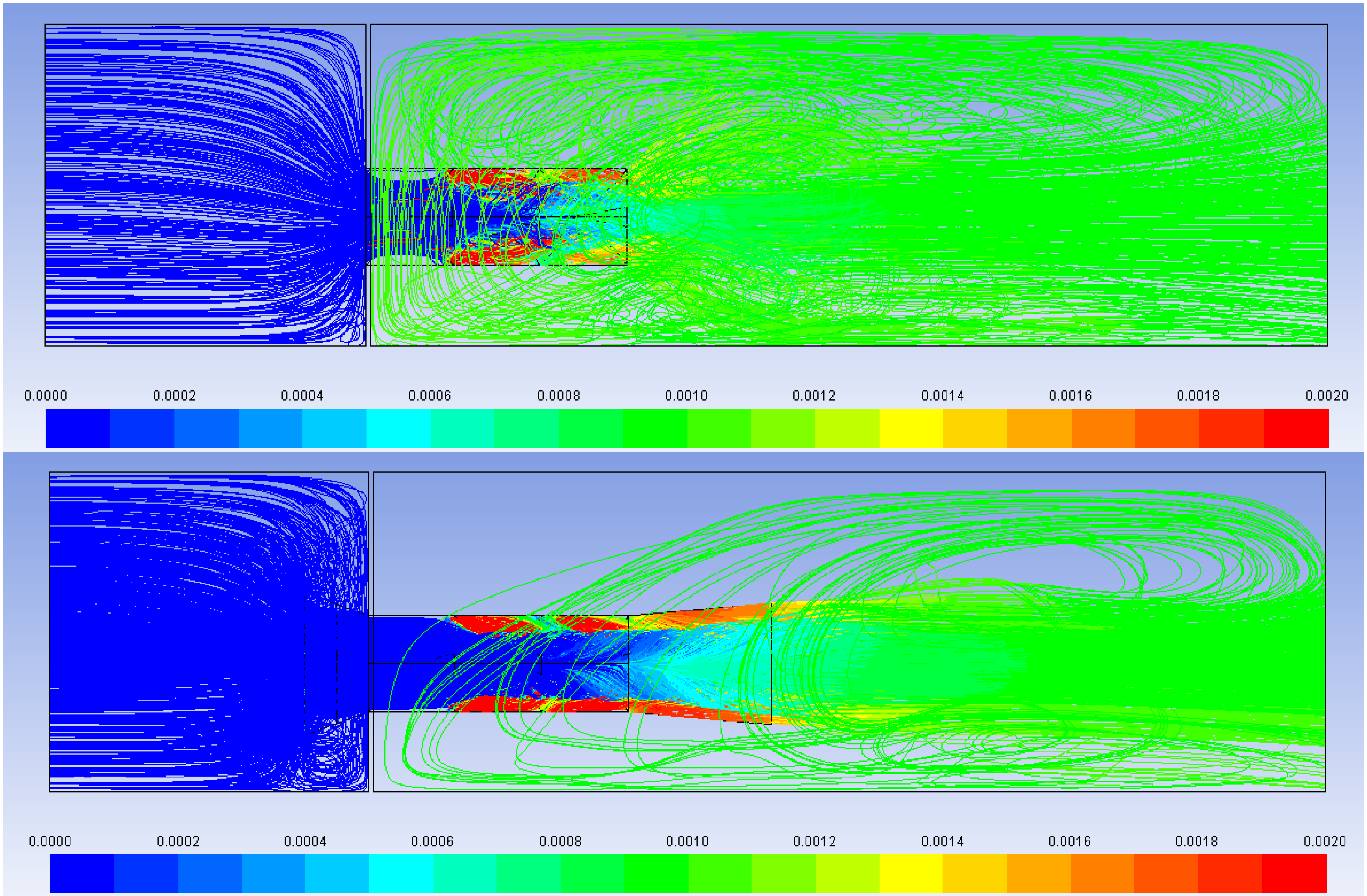


Figure 7- Pathlines Colored by Volume Fraction of Injected Solution for 4000 Mixer (above) and with Inlet and Diffuser (below)

CONCLUSIONS AND RECOMMENDATIONS

The Westfall 4000 Mixer will work very well as an open channel mixer in either configuration tested. The low pressure loss characteristics are very desirable for pressure limited operation, and the raked angles prevent fouling. Also, the mixer tabs break up any swirling flow, which at high velocities or low submergence depths could cause air-entraining vortices to form, which would reduce flow rate.

The best configuration for mixing was found to be the 4000 mixer without inlet or outlet cones; while the addition of inlet and outlet cones was found to be the best configuration for pressure loss. For most applications, it seems that a good balance could be achieved by using only the inlet cone without the diffuser to reduce the pressure loss, but maintain excellent mixing performance. Also, pressure loss may be able to be lowered a bit further, and the inlet cone length reduced, by using a 3-segment inlet cone that transitioned from an 80° cone to a 40° cone to a 10° cone before finally entering the mixer.

In this simulation, there were two injection points for the mixer, located on the mixer inlet plane. It is recommended that at least two injection points are used for each mixer, to be placed directly upstream of a mixer tab. The injection point does not need to be on the mixer inlet plane, but can be moved upstream as much as 1 mixer diameter from the mixer inlet, or the inlet cone if one is used.

Since the pressure loss coefficient of the mixer is known, the mixer could also be used for flow rate indication by measuring the water surface elevation difference across the mixer, assuming the bulkhead is sealed adequately to the channel walls.

In many open channel conditions, the water surface elevation can change significantly with flow rate, and this should be taken into account when designing the mixer installation. For best results, the downstream end of the mixer should be submerged under all operating conditions, and the mixers should have the capacity to pass the maximum required flow at the available head without overtopping the channel.

In order to satisfy both the low flow and high flow requirements, it would be beneficial to locate the mixer centerline approximately 1.5 diameters above the channel floor. Also, provided the channel is wide enough, installing 4 x 18” mixers rather than 1 x 36” mixer would lower the minimum operable water level by approximately 3-ft, while maintaining the same maximum cross sectional mixer area, the same pressure loss, and the same maximum flow rate.