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COMPUTATIONAL ANALYSIS OF WESTFALL'S OPEN CHANNEL MIXER FOR THE COLBORNE SEWAGE TREATMENT PLANT

Alden Report No:
415011-1R1

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Table of Contents

List of Figures

List of Tables

Introduction

Alden Research Laboratory Inc. (Alden) was contracted by Westfall Manufacturing Inc. (Westfall) to analyze the level of mixing and head loss increase that can be expected from installing a fin-type open channel mixer in a 300mm wide x 500mm deep open channel at the Colborne Sewage Treatment Plant in Colborne, Ontario. The flow in the pipeline was analyzed at minimum and maximum flows, with no mixer, and with up to three fin-type mixers.

Model Description

The model geometry was developed using the commercially available three-dimensional CAD and mesh generation software, GAMBIT V2.4.6. The computational domains generated for the model consisted of approximately 5.5 million tetrahedral and hexahedral cells.

Alden used the CFD software package ANSYS-Fluent v15.0 to calculate the full-scale, three-dimensional, incompressible, turbulent flow through the pipe and mixer. A stochastic, two-equation realizable 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. CFD solver information is presented in Table 1.

Table 1 CFD Solver Information

CFD Solver Information:	Value:
Mesh Name	415011_Colborne_C
Cell count	5,458,937
Cell Shape	Hexahedral / Tetrahedral
CFD Code	ANSYS-Fluent v15.0.7
Solver	Pressure-based Segregated
Spacial Discritization	2nd Order Upwind
Density Formulation	Constant (Incompressible)
Turbulence Model	k-epsilon, realizable
Near-Wall Treatment	Non-equalibrium Wall Functions

The analysis was conducted in an open channel, with a width of 300mm, and a normal liquid depth of 500mm. Water entered at the upstream end of the channel (left side of Figure 1) with a uniform velocity profile, and a uniform 5% turbulent intensity. Two flow rates were investigated, representing the minimum expected flow (1,000 m3/d), and the maximum expected flow (4,000 m3/d). The flows and dimensions used in the flow model are listed in Table 2.

A 100g/L alum solution was injected into the model through a ½" sch40 steel pipe that protruded from the sidewall of the channel at the same elevation as the top of the mixers (400mm from the channel floor). The alum was injected so that the final average concentration would be 100 mg/L. The injection lance was angled downstream at a 45° angle to minimize the amount of debris that would catch on the pipe. The injection outlet was located 150mm directly upstream of the top of the first mixer.

The mixers consist of a center fin, which acts as a support, and also straightens any large-scale swirling flow. The leading edge of the central fin is swept backwards at 45° to shed any debris that may be in the flow. The majority of the mixing is accomplished by the leading tab mixing element that is attached to the center fin. This leading tab creates two strong counter-rotating vortices that cause vigorous local mixing, and induce bulk circulation in the channel. Alum is then injected into the inception point of these vortices on the first mixer (Figure 3).

Due to the narrow channel width, the width of the mixer was restricted to half of the width of the channel (150mm), with a 75mm gap on either side to allow debris to pass. The mixer extends to 80% of the height of the channel. This particular channel is expected to have a low maximum velocity (0.31-m/s), and is expected to have a nearly constant liquid depth, which makes this channel well suited to this mixer.

At very higher water velocities (much higher than investigated here), there could be surface waves that are generated by the mixer, which would entrain air and increase the mixer head loss. Also, if the liquid level varied significantly, the mixing performance could vary as a function of liquid level. Neither of these factors are a concern for the Colborne installation.

Three mixers were included in the model as zero-thickness surfaces. The model was run with 5 mixer configurations to evaluate the mixing performance of each configuration, and also the head loss at the minimum and maximum flow rates:

1. No Mixer
2. Mixer 1 only
3. Mixer 1 and 2 only
4. Mixers 1 and 3 only
5. Mixers 1, 2, and 3.

Mixers are numbered from upstream (1) to downstream (3), and mixer locations are shown in Figure 3.

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Figure 1 Entire Model Elevation View (top) and Plan View (bottom)

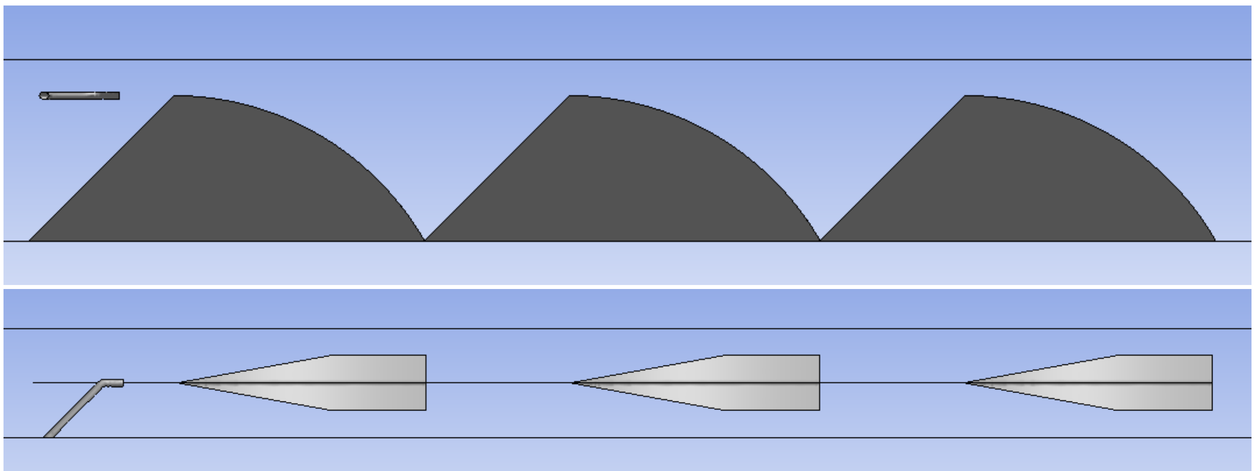


Figure 2 Mixer and Injection Elevation View (top), and Plan View (bottom)

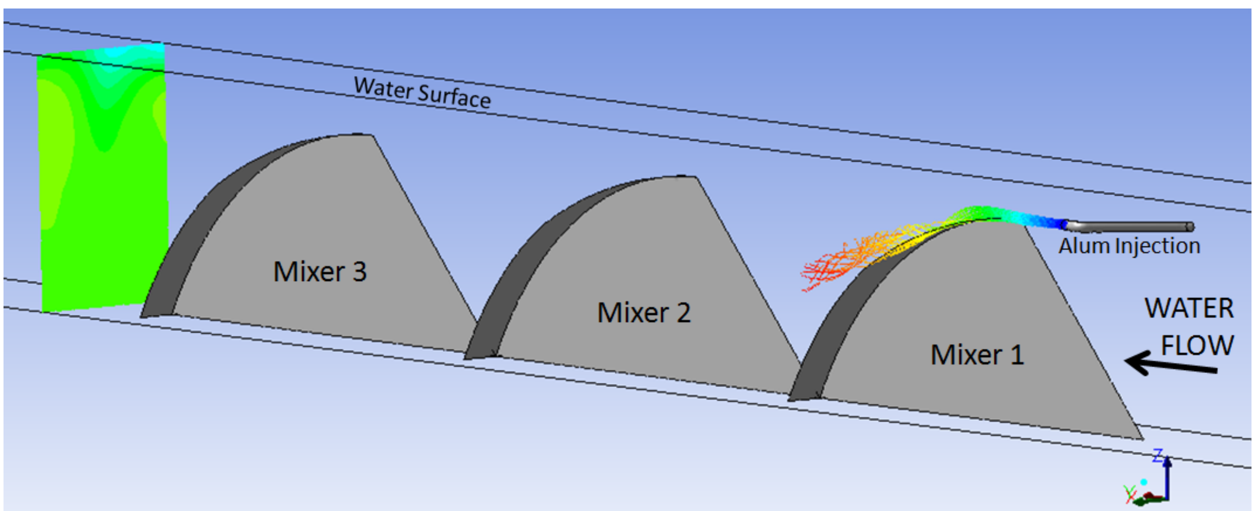


Figure 3 Model Layout, Isometric View

Table 2 - Process Flow Information

Channel Information:	Units:	Value:
Channel Width	(mm)	300
Channel Depth	(mm)	500
Channel Sectional Area	(m2)	0.15
Channel Hydraulic Diameter	(mm)	462
Water Density	(kg/m3)	998.00
Water Viscosity	(kg/m-s)	0.001

Process Flow Information:	Units:	Minimum Flow	Maximum Flow
Water Flow			
Volume Flow Rate	(m3/d)	1,000	4,000
Mass Flow Rate	(kg/s)	11.55	46.20
Average Velocity	(m/s)	0.077	0.309
Alum Injection (100 g/L Solution)			
Volume Flow Rate	(lpm)	0.694	2.778
Mass Flow Rate	(g/s)	11.55	46.20
Average Concentration	(mg/L)	100	100

Results

The channel was analyzed at minimum and maximum expected flows for each of the five mixer configurations. In each configuration, the head loss across the mixer was calculated by subtracting the measured head loss from the head loss with no mixer. The tabulated results are presented in Table 3, and plotted in Figure 5 and Figure 6. A contour plot of the liquid surface elevation over the mixers is presented in Figure 4 with maximum flow, and with all three mixers to show the relationship of the wavy surface to the mixer locations.

The maximum allowable pressure loss for the mixer was stated to be 180mm for the Colborne installation, however the highest head loss measured (with 3 mixers at maximum flow), was only 13mm higher than the case without mixers. This is quite low, so none of the mixer configurations tested here should present a head loss problem at the Colborne Sewage Treatment Plant.

Table 3 Head Loss Results

Mixer Head Loss	Units:	Minimum Flow	Maximum Flow	k-Value
No Mixer	(mm)	0.0	0.0	
Mixer 1 Only	(mm)	0.3	4.3	**0.89**
Mixer 1 and 2 Only	(mm)	0.6	8.6	**1.78**
Mixer 1 and 3 Only	(mm)	0.6	8.8	**2.69**
Mixer 1, 2, and 3	(mm)	0.9	13.0	**1.82**

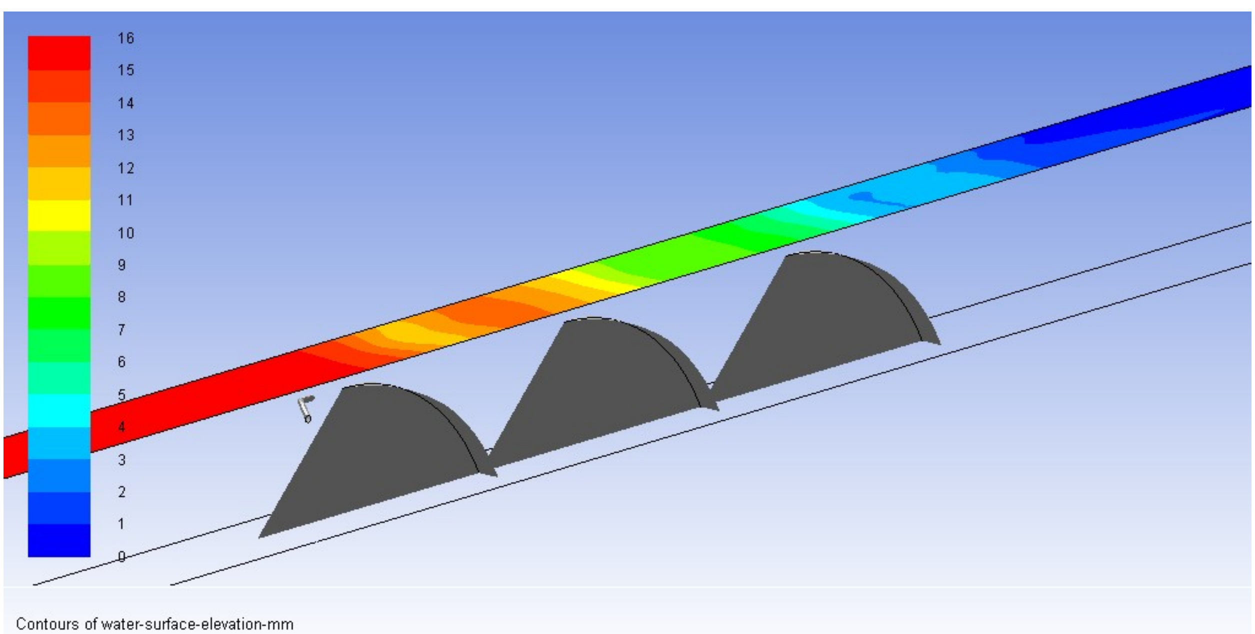


Figure 4 Contour of Liquid Surface Elevation with Maximum Flow and All 3 Mixers

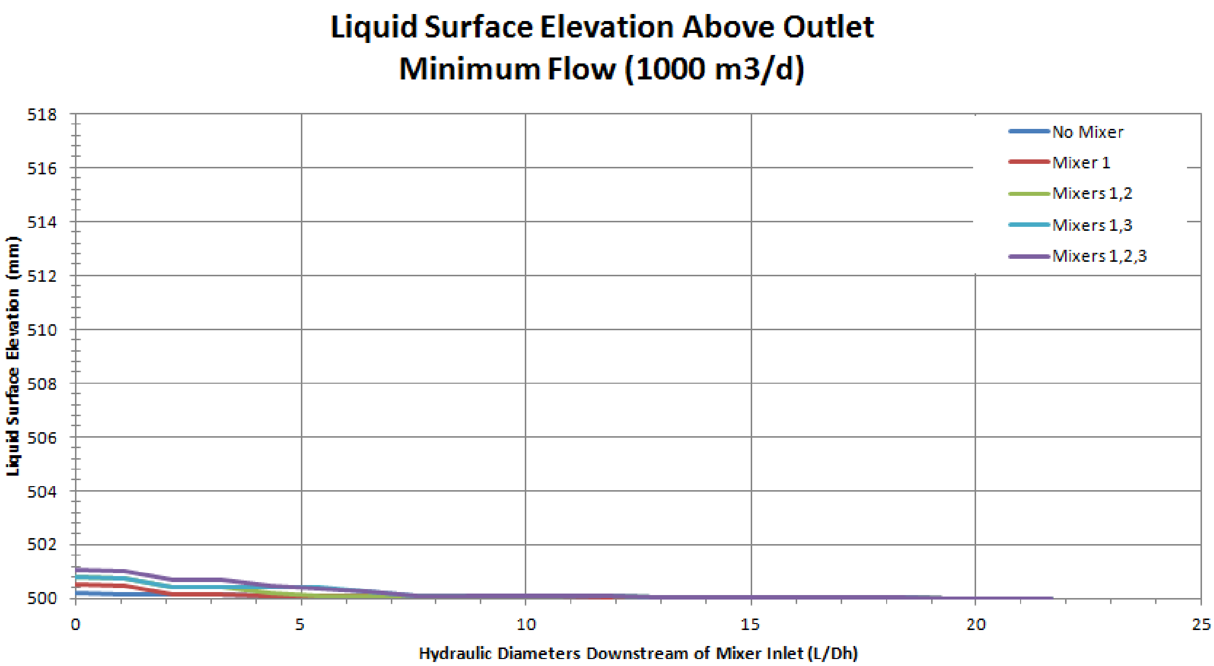


Figure 5 Liquid Surface Elevation, Minimum Flow

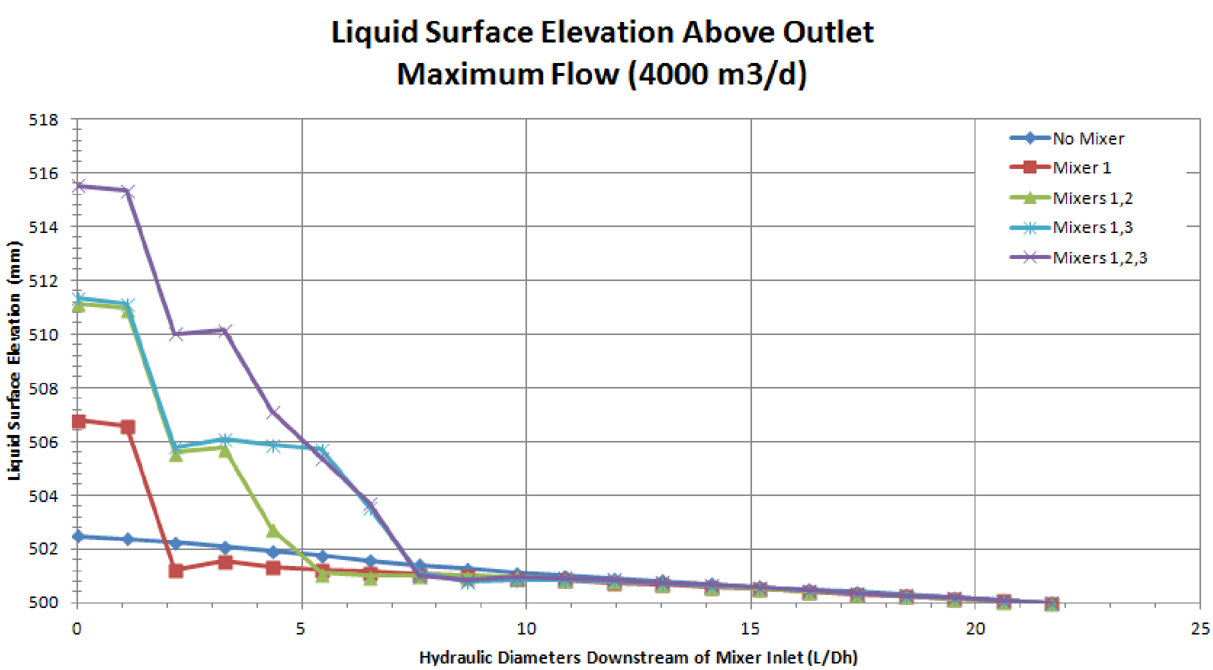


Figure 6 Liquid Surface Elevation, Maximum Flow

The mixing performance was analyzed by measuring the coefficient of variation (CoV) of alum concentration at planes spaced at 0.5m intervals, beginning at the leading edge of the first mixer. For the sake of applying these results to other channels, the results are also presented in terms of downstream length divided by the hydraulic diameter (L/Dh). For this channel, one hydraulic diameter is 462mm.

Without a mixer, the CoV of alum concentration after 10m (21.7 hydraulic diameters) is above 0.600, which indicates poor mixing. A CoV equal to zero indicated a perfectly uniform concentration.

With one mixer, the mixing improves to a CoV of 0.134 at minimum flow, and 0.196 at maximum flow after 10m (21.7 hydraulic diameters).

Two different configurations with two mixers were tested: "Mixers 1 and 2", and "Mixers 1 and 3". Both configurations gave comparable mixing results, though the "Mixers 1 and 3" configuration provided slightly better mixing, with a CoV of 0.035 at minimum flow and 0.064 at maximum flow after 10m (21.7 hydraulic diameters).

The best mixing was created with all three mixers, with a CoV of 0.016 at minimum flow, and 0.030 at maximum flow after 10m (21.7 hydraulic diameters).

Tables and plots of CoV results at various locations downstream of the mixer are presented for minimum flow in Table 4 and Figure 7, and for maximum flow in Table 5 and Figure 8.

Figures showing pathlines and contours of alum concentration are presented in Figure 9 - Figure 13.

Table 4 CoV of Alum Concentration, Minimum Flow

CoV of Alum Concentration:

Downstream Distance:		Minimum Flow (1,000 m3/d)				
(m)	L/Dh	No Mixer	Mixer 1	Mixers 1,2	Mixers 1,3	Mixers 1,2,3
0.5	1.08	3.866	3.732	3.731	3.731	3.731
1.0	2.17	2.241	1.209	1.209	1.209	1.209
1.5	3.25	1.672	0.619	0.620	0.619	0.620
2.0	4.33	1.385	0.444	0.387	0.444	0.387
2.5	5.42	1.220	0.354	0.239	0.352	0.238
3.0	6.50	1.109	0.308	0.184	0.283	0.176
3.5	7.58	1.040	0.276	0.152	0.184	0.109
4.0	8.67	0.992	0.252	0.130	0.118	0.063
4.5	9.75	0.955	0.231	0.115	0.087	0.044
5.0	10.83	0.925	0.215	0.104	0.071	0.034
5.5	11.92	0.897	0.200	0.096	0.061	0.028
6.0	13.00	0.871	0.189	0.089	0.055	0.025
6.5	14.08	0.846	0.179	0.084	0.050	0.022
7.0	15.17	0.822	0.170	0.080	0.047	0.021
7.5	16.25	0.797	0.163	0.076	0.044	0.019
8.0	17.33	0.773	0.156	0.073	0.042	0.018
8.5	18.42	0.748	0.150	0.070	0.040	0.018
9.0	19.50	0.724	0.144	0.067	0.038	0.017
9.5	20.58	0.698	0.139	0.065	0.037	0.016
10.0	21.67	0.673	0.134	0.062	0.035	0.016

Table 5 CoV of Alum Concentration, Maximum Flow

CoV of Alum Concentration:

Downstream Distance:		Maximum Flow (4,000 m3/d)				
(m)	L/Dh	No Mixer	Mixer 1	Mixers 1,2	Mixers 1,3	Mixers 1,2,3
0.5	1.08	6.036	5.718	5.718	5.723	5.719
1.0	2.17	3.207	1.532	1.533	1.532	1.534
1.5	3.25	1.850	0.851	0.846	0.852	0.846
2.0	4.33	1.351	0.580	0.527	0.580	0.528
2.5	5.42	1.142	0.467	0.340	0.466	0.341
3.0	6.50	0.996	0.410	0.270	0.377	0.274
3.5	7.58	0.916	0.372	0.228	0.285	0.203
4.0	8.67	0.843	0.345	0.198	0.206	0.152
4.5	9.75	0.791	0.320	0.171	0.162	0.117
5.0	10.83	0.755	0.299	0.149	0.133	0.089
5.5	11.92	0.728	0.279	0.131	0.112	0.070
6.0	13.00	0.707	0.263	0.119	0.099	0.059
6.5	14.08	0.689	0.250	0.109	0.090	0.052
7.0	15.17	0.674	0.239	0.101	0.083	0.046
7.5	16.25	0.660	0.229	0.095	0.078	0.042
8.0	17.33	0.647	0.221	0.089	0.075	0.039
8.5	18.42	0.634	0.214	0.084	0.071	0.036
9.0	19.50	0.623	0.208	0.080	0.069	0.034
9.5	20.58	0.611	0.202	0.076	0.066	0.032
10.0	21.67	0.600	0.196	0.073	0.064	0.030

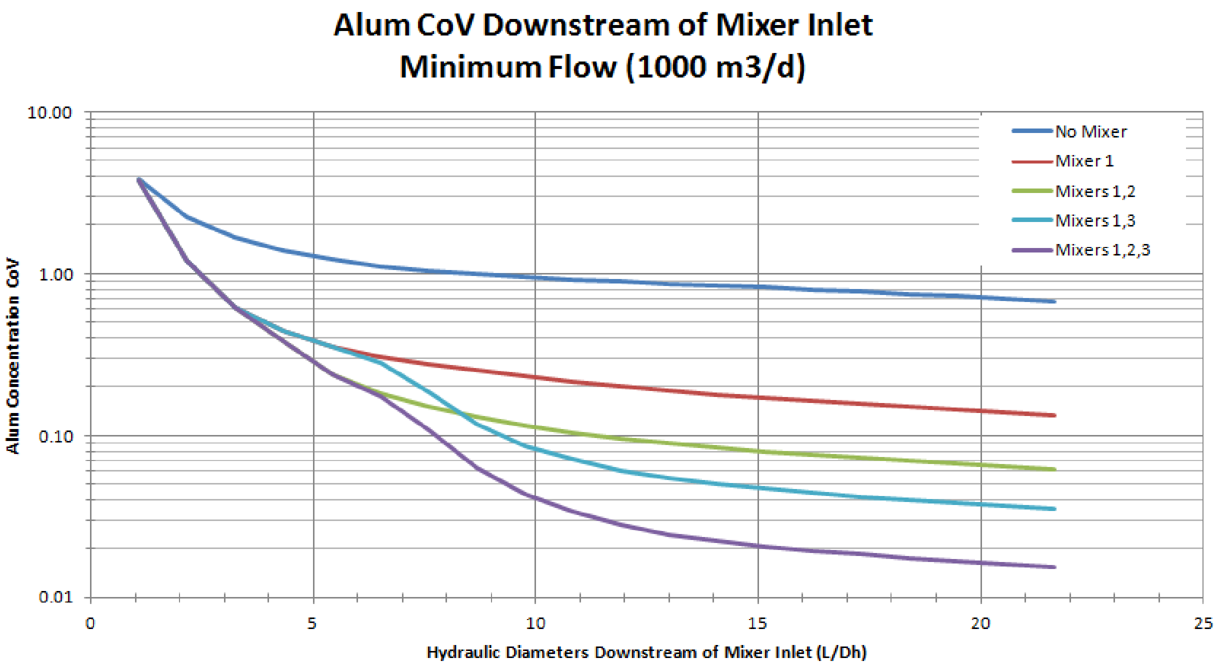


Figure 7 Alum CoV, Minimum Flow

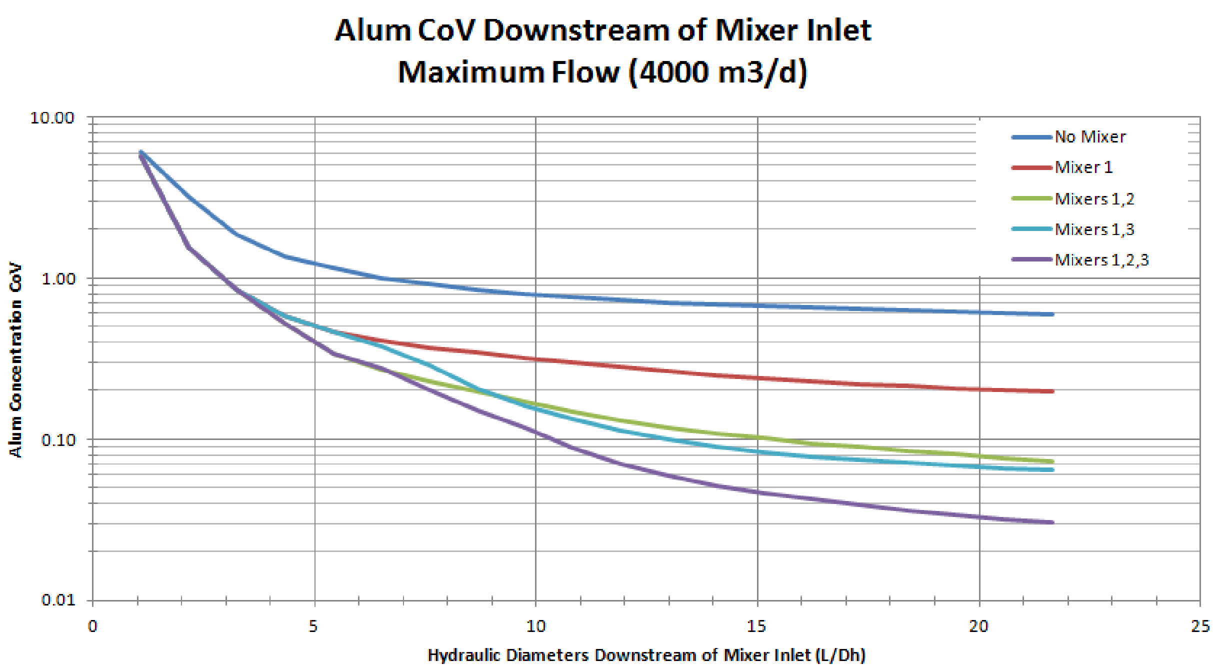
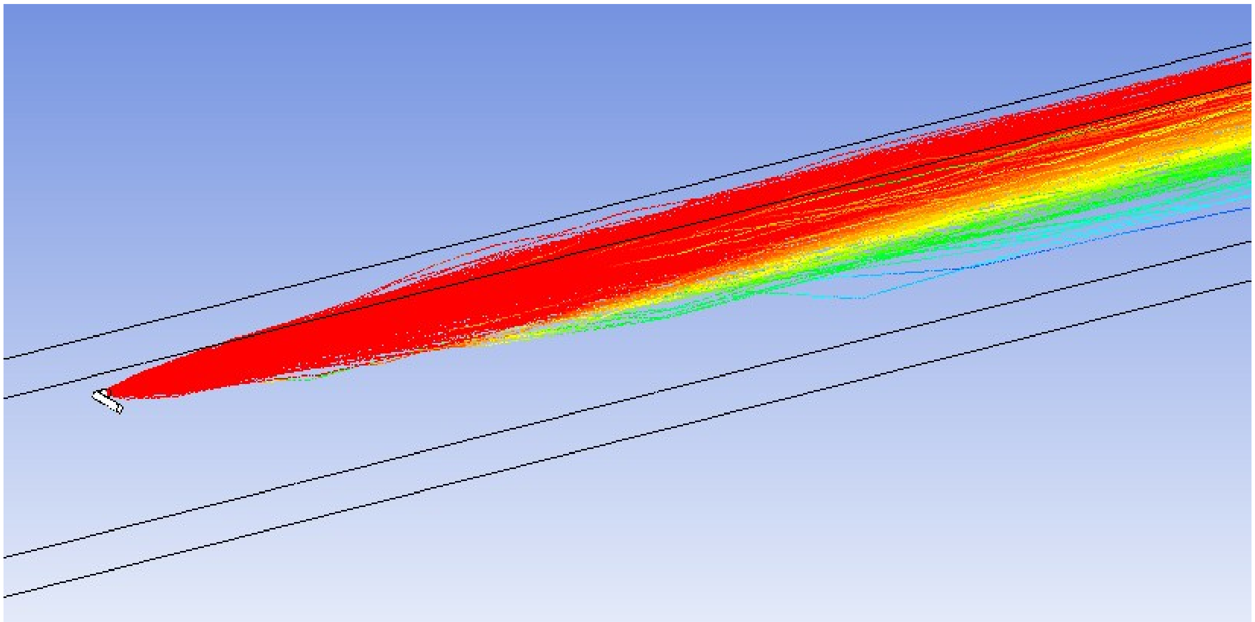


Figure 8 Alum CoV, Maximum Flow



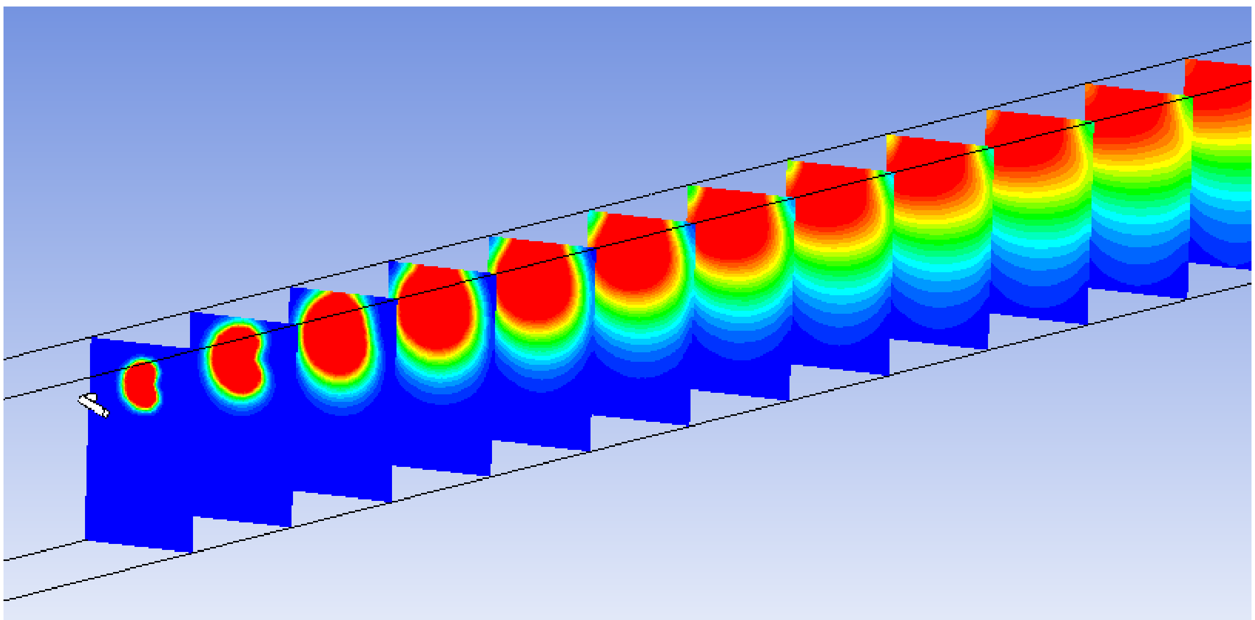
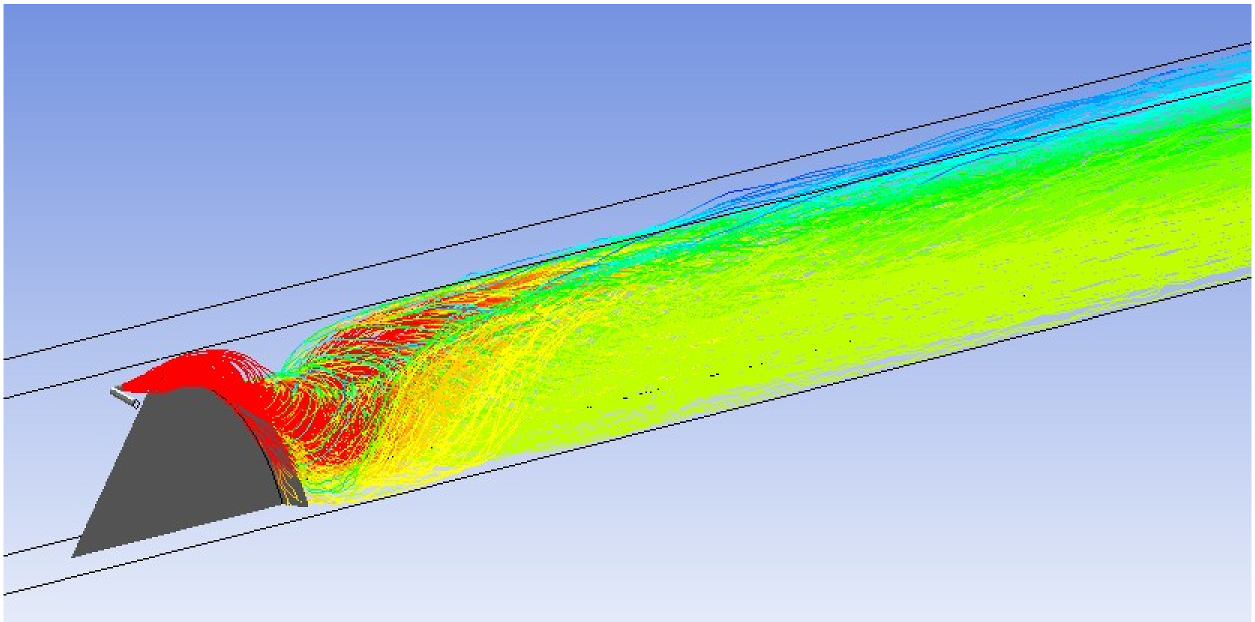


Figure 9 Pathlines (top) and Contours (bottom) of Alum Mass Fraction (Green = 100 g/L), No Mixer at Maximum Flow



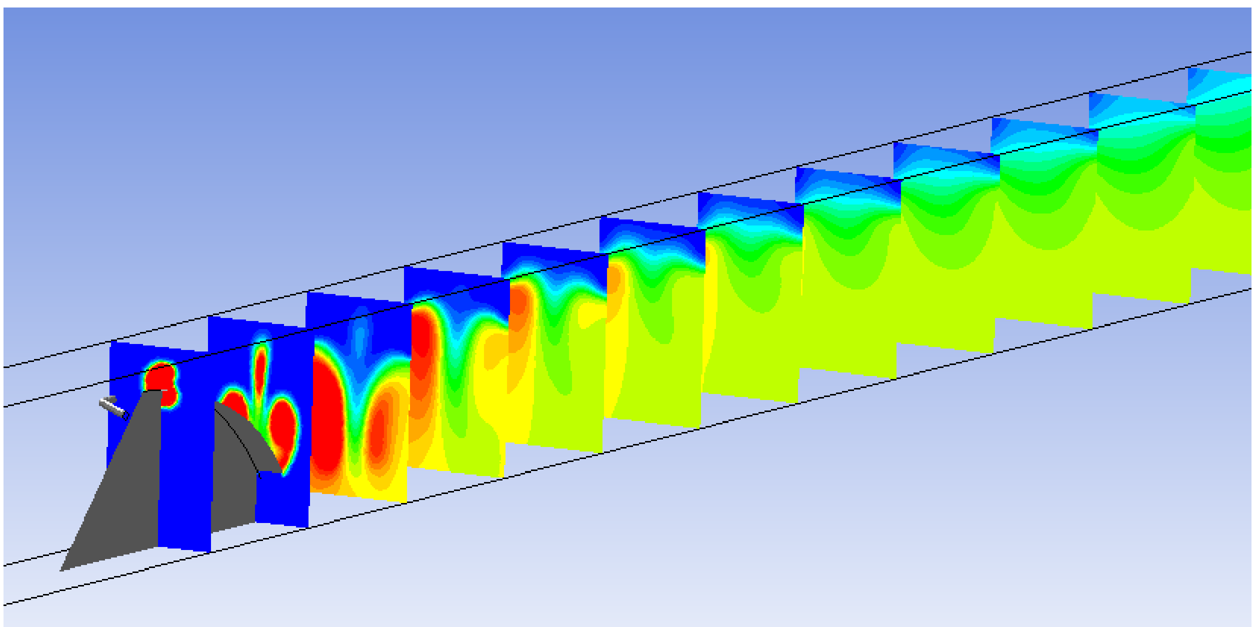


Figure 10 Pathlines (top) and Contours (bottom) of Alum Mass Fraction (Green = 100 g/L), Mixer 1 at Maximum Flow

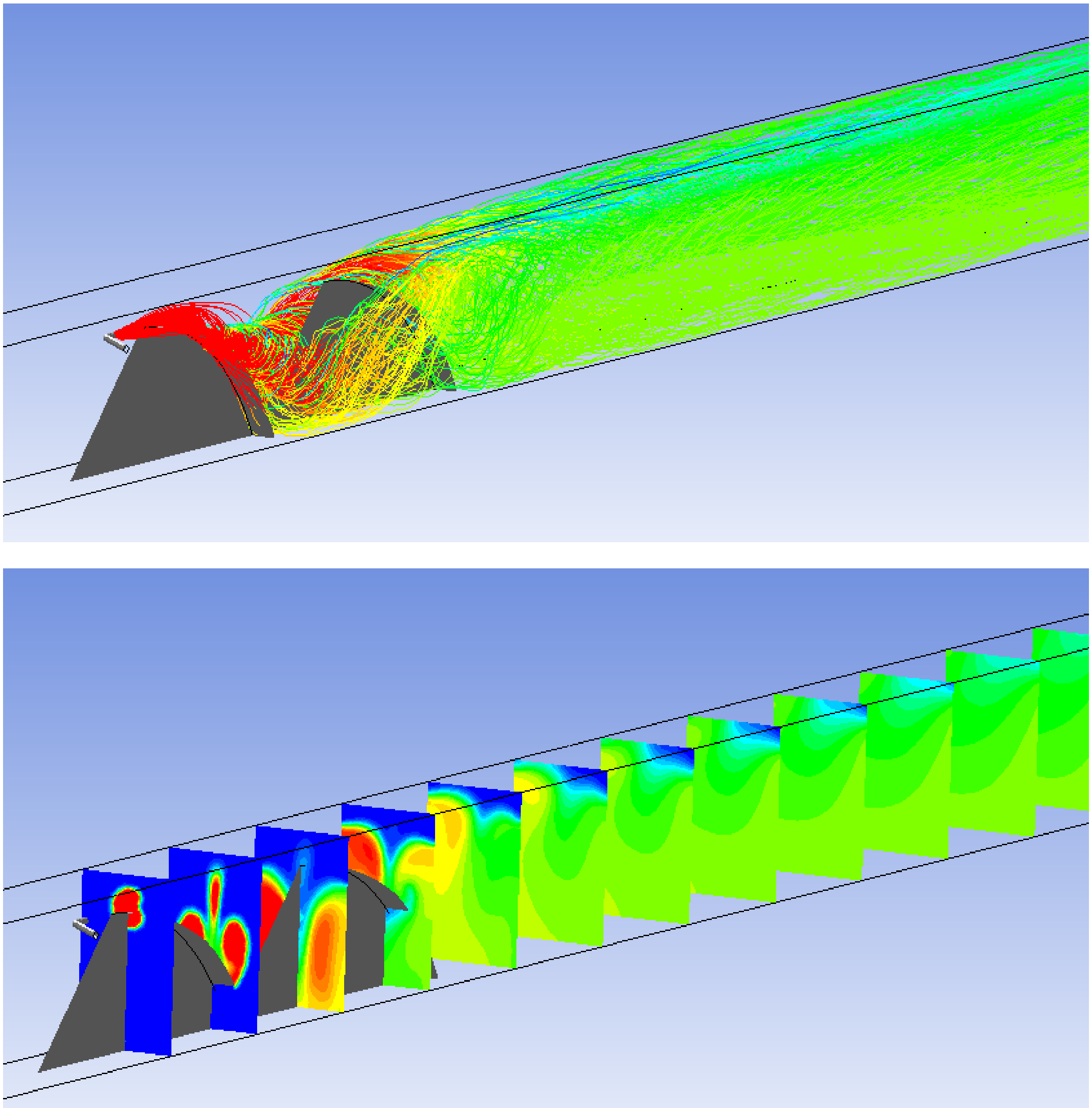


Figure 11 Pathlines (top) and Contours (bottom) of Alum Mass Fraction (Green = 100 g/L), Mixers 1 and 2 at Maximum Flow

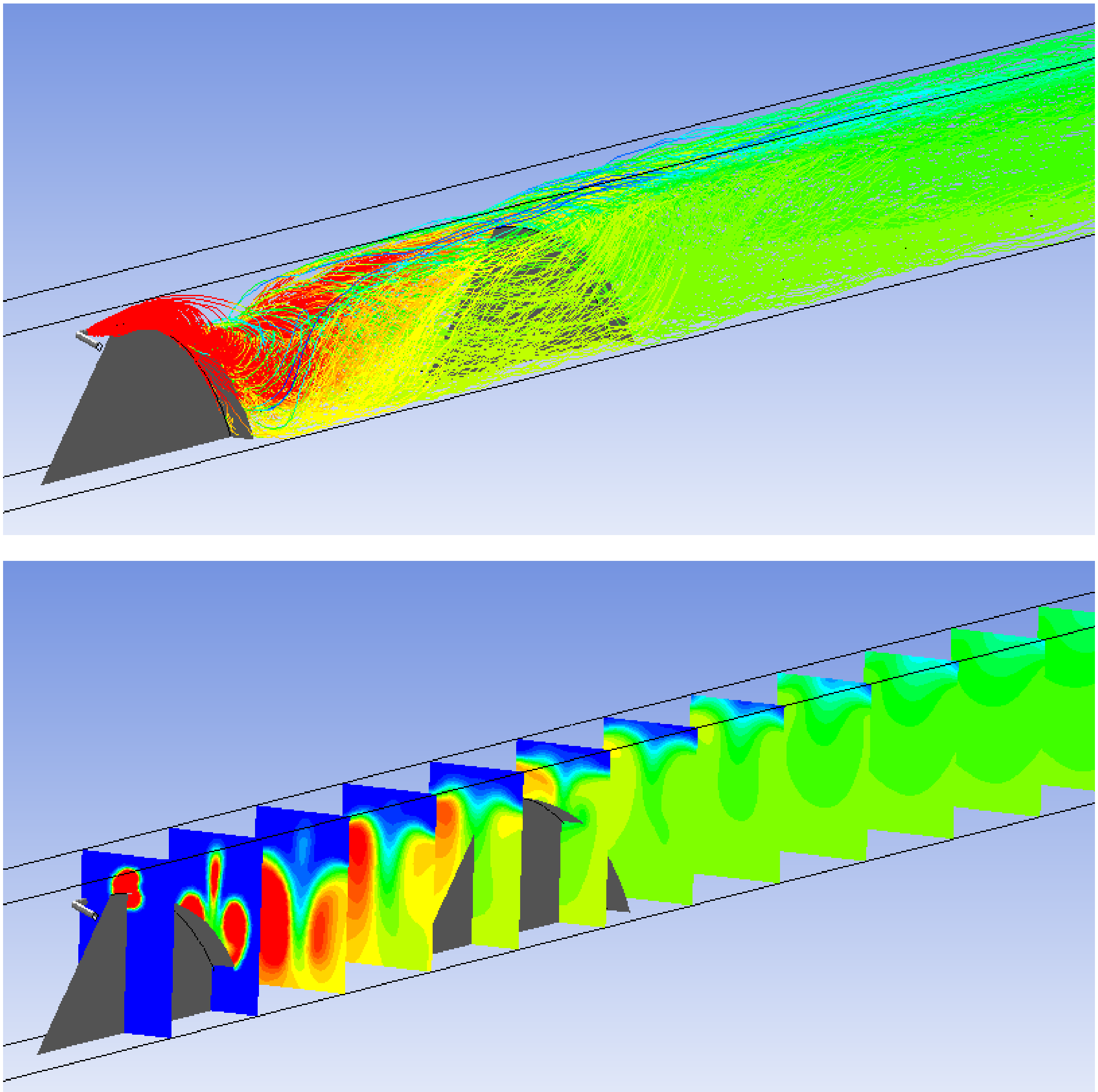
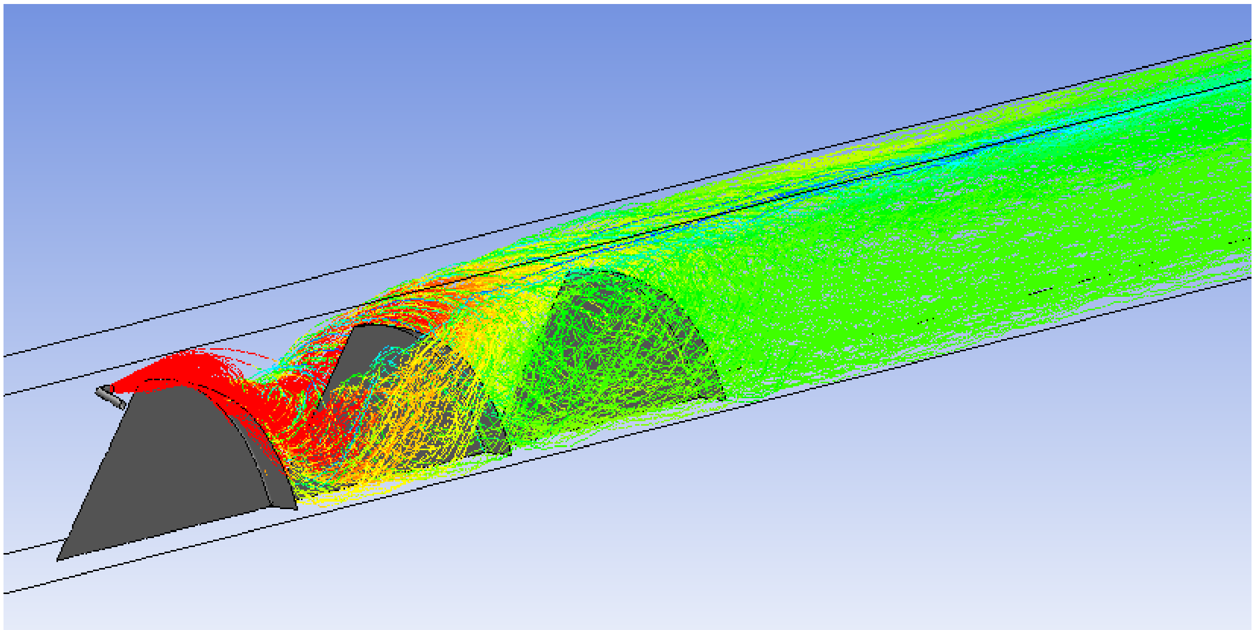


Figure 12 Pathlines (top) and Contours (bottom) of Alum Mass Fraction (Green = 100 g/L), Mixers 1 and 3 at Maximum Flow



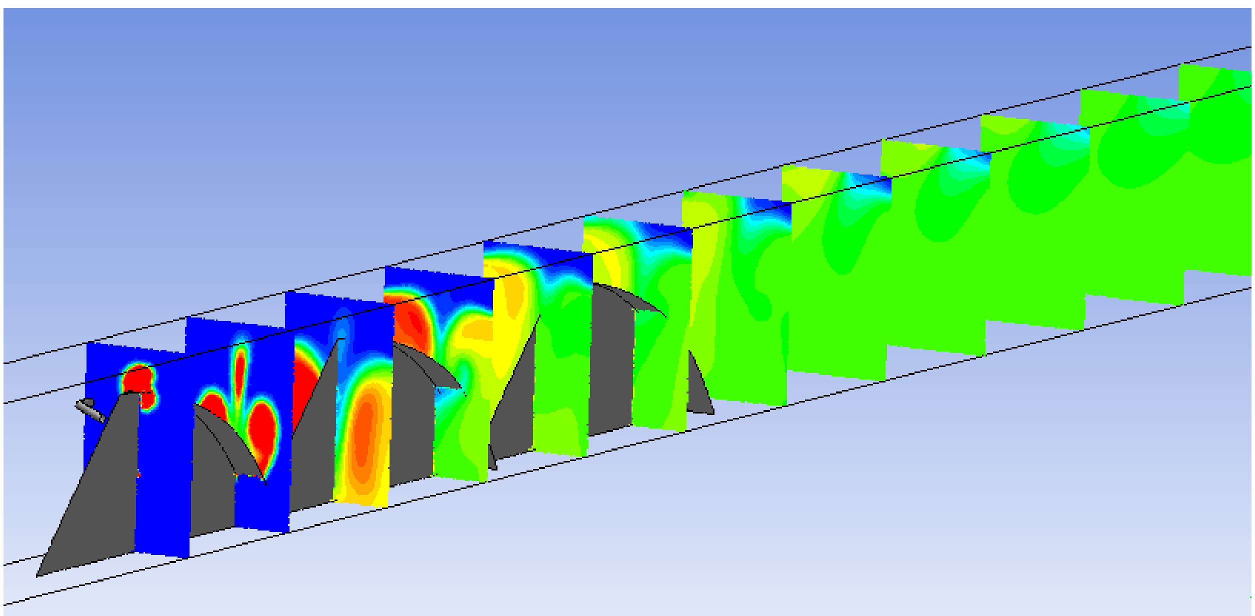


Figure 13 Pathlines (top) and Contours (bottom) of Alum Mass Fraction (Green = 100 g/L), Mixers 1, 2, and 3 at Maximum Flow