Computational Analysis to Optimize the Design of Westfall's Inverted Mixer

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Prepared for:

Westfall Manufacturing Co.

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Table of Contents

List of Tables

List of Figures

Executive Summary

Westfall Manufacturing Co. (Westfall) contracted Alden Research Laboratories, Inc. (Alden) to perform a series of computational fluid dynamic (CFD) analyses in an effort to create a single fin mixer based on the effective fin technology used in the 4-fin 3050 mixer. The results of the evaluations showed that a single central fin, with supporting side fins provided excellent performance. Mixing performance was sensitive to the location of the side fins relative to the central fin, and this relationship was optimized to produce the best mixing performance. A coefficient of variation (CoV) of 0.041was achieved within two (2) duct diameters (2 L/D) downstream of the mixing device with a pressure loss coefficient of 1.24 for the inverted mixer. For reference, the 2800 mixer with a 0.8 Beta has a pressure loss coefficient of 12.1.

1.0 Introduction

Westfall Manufacturing Co. (Westfall) contracted Alden Research Laboratories, Inc. (Alden) to perform a series of computational fluid dynamic (CFD) analyses in an effort to improve the performance of its inverted mixer. [redacted]

The results of the experimental and analytical work to satisfy these objectives are presented in the sections that follow.

2.0 Model Description

The computational fluid dynamic (CFD) model geometry was developed using the commercially available CFD software package ANSYS-Fluent v19.0. The CFD model was built at full-scale and assumed incompressible, turbulent flow through the pipe and mixer. The computational domain generated for each simulation consisted of approximately 6 million tetrahedral and hexahedral cells. 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 2.1.

Table 2.1: CFD Solver Information

CFD Solver Information:	Value:
Cell Count	**5,915,493**
Cell Shape	**Hexahedral/ Tetrahedral**
CFD Code	**ANSYS-Fluent v19.0**
Solver	**Pressure-Based Segregated**
Spacial Discretization	**2nd Order Upwind**
Density Formulation	**Volume-Weighted-Mixing**
Turbulence Model	**k-epsilon, Realizable**
Near-Wall Treatment	**Non-Equilibrium Wall Functions**

The CFD model included approximately ten (10) duct diameters (10 L/D) of 6.07" inside diameter straight inlet piping upstream of the mixer, and twenty (20) duct diameters (20 L/D) of straight outlet piping downstream of the mixer. The inverted mixer section, Figure 2.1, consisted of a center hub fin mixer with two (2) flange fin mixers. An aqueous ammonia injection pipe (0.30" ID) was located approximately 1-3/4" upstream of the center hub mixer. The full model domain is detailed in Figure 2.2. The horizontal locations of the flange wing mixers were adjusted until an optimum location for them was determined which optimized mixing while minimizing the pressure losses across the mixer.

The main fluid was water which entered the model at 368 gpm which equates to a velocity of 4.08 ft/s. Ammonia solution entered the model through the injection quill at 0.22 gpm which equates to a velocity of 1.0 ft/s. The key process flow parameters which were used throughout the CFD simulations are summarized in Table 2.2.

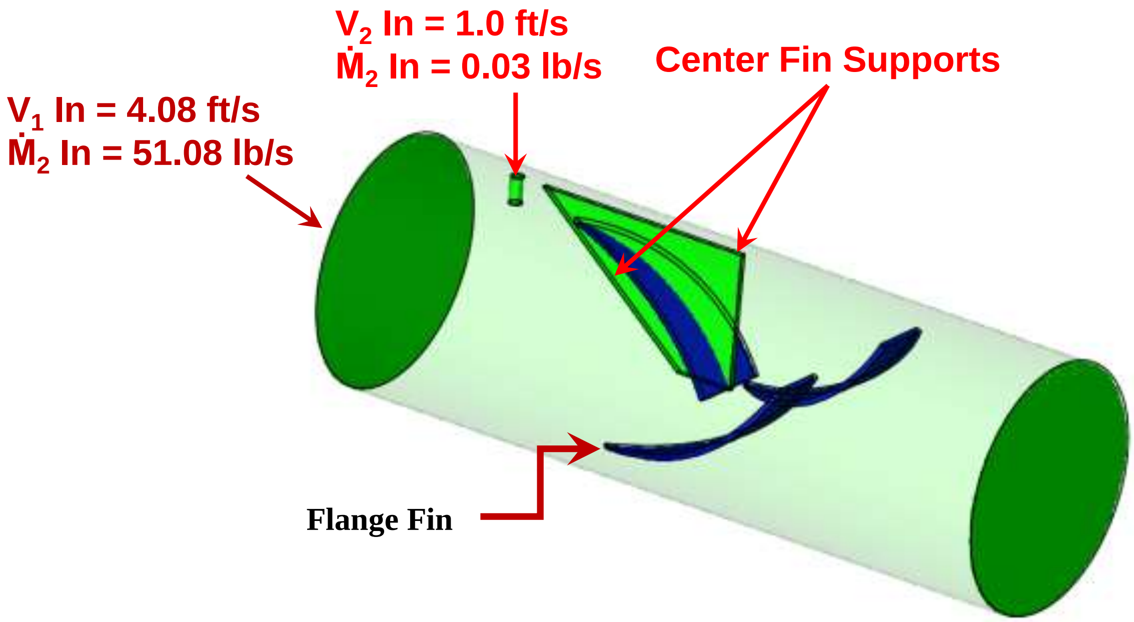

Figure 2.1: Inverted Mixer Section of the CFD Model

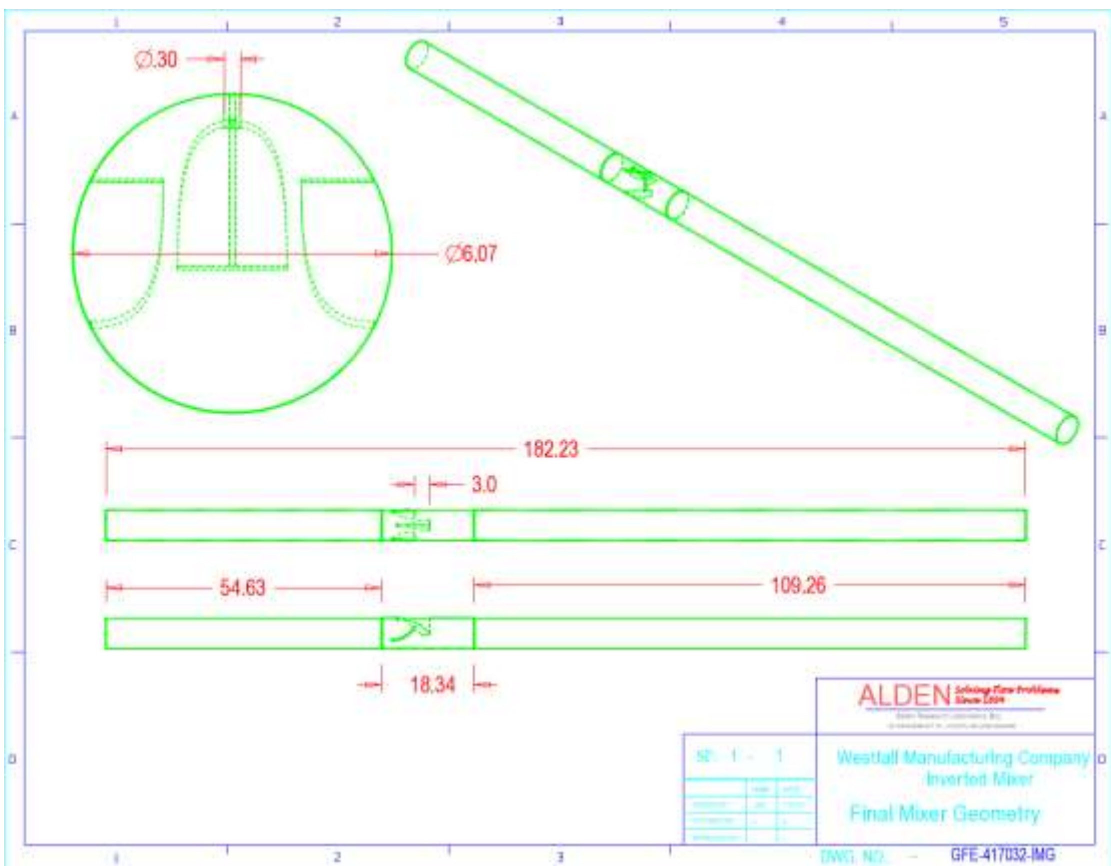

Figure 2.2: Final Inverted Mixer Geometry

Table 2.2: Process Flow Parameters

Pipe Dimensions	Units	Main Pipe	Injection Quill
Pipe ID	(in)	6.07	0.3
Pipe Area	(ft2)	0.20	0.0005

Flow Conditions	Units	Water	Ammonia
Volumetric Flow Rate	(gpm)	367.97	0.22
Volumetric Flow Rate	(CFM)	49.19	0.03
Mass Flow Rate	(lb/s)	51.08	0.031
Velocity	(ft/s)	4.08	1.0

Fluid Properties	Units	Water	Ammonia
Density	(lb/ft3)	62.4	62.4
Temperature	(°F)	70	70

3.0 Model Results

Testing began with the flange fins located 3” downstream of the center hub fin. The flange fins were then incrementally moved upstream until their optimal location with respect to mixing could be determined. Nine (9) test cases were evaluated and are listed sequentially in **Table** 3.1.

Table 3.1: Sequential List of Inverted Fin Mixer Test Cases

Test Case	Flange Fin Location
1	3" Downstream
2	1.5" Downstream
3	0" Downstream
4	1" Upstream
5	2" Upstream
6	4" Upstream
7	6" Upstream
8	5" Upstream
9	3" Upstream

The coefficient of variation (CoV) was measured at 1 diameter increments downstream of the inverted mixer for a total length of 10 diameters. CoV is a measure of uniformity, which is calculated as the standard deviation of the concentration across the pipeline at a given plane, divided by the average concentration. A CoV of zero indicates that the fluids are perfectly mixed.

Figure 3.1 shows the ammonia distributions at various duct diameters downstream of the inverted mixer with the flange fins located 3” upstream of the center hub fin. Figure 3.2 shows the CoV of ammonia versus downstream distance for all of the evaluated mixer designs; the 2800 mixer (0.8 Beta) values have also been included for comparison. An additional plot, Figure 3.3, shows that the mixing is optimized at 2 L/D with the flange fins located 3” upstream of the center hub fin.

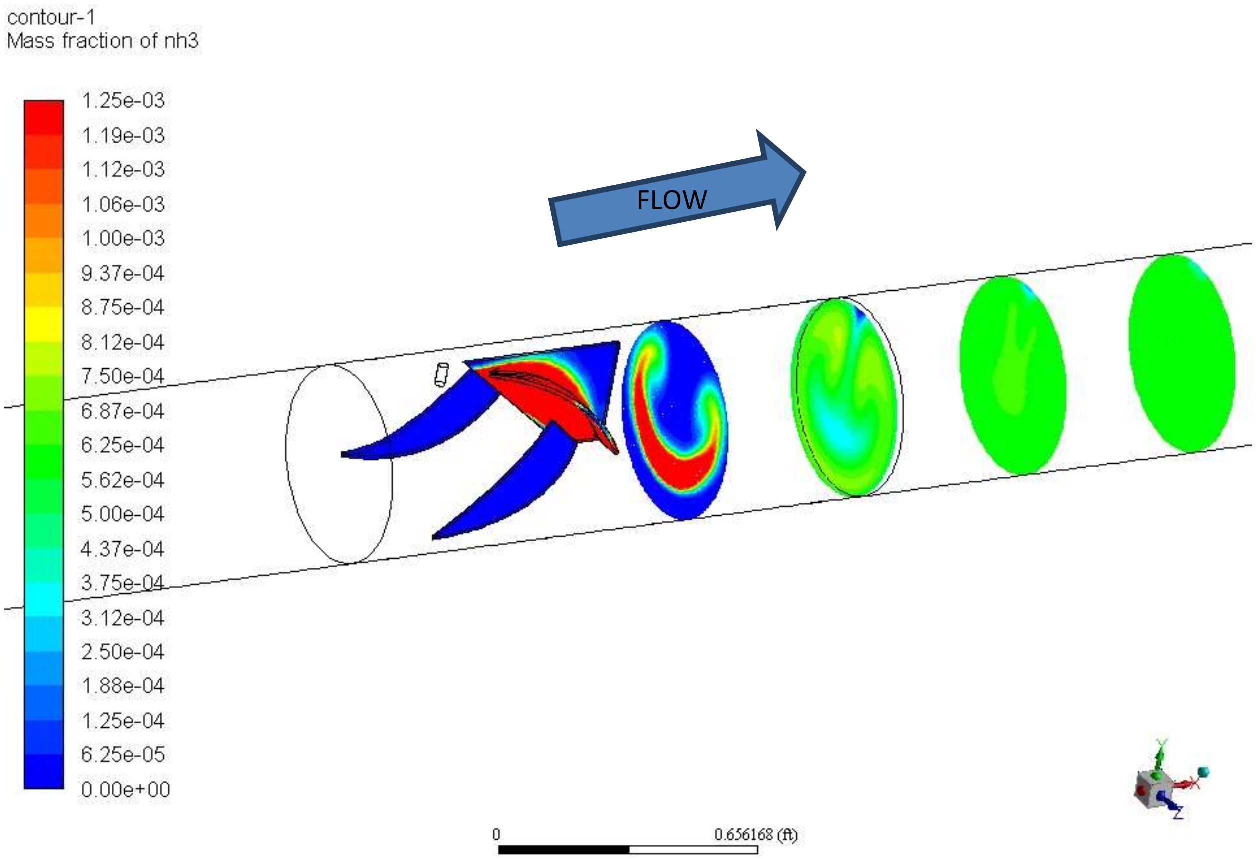

Figure 3.1: Mass Fraction of Ammonia Downstream of Inverted Mixer

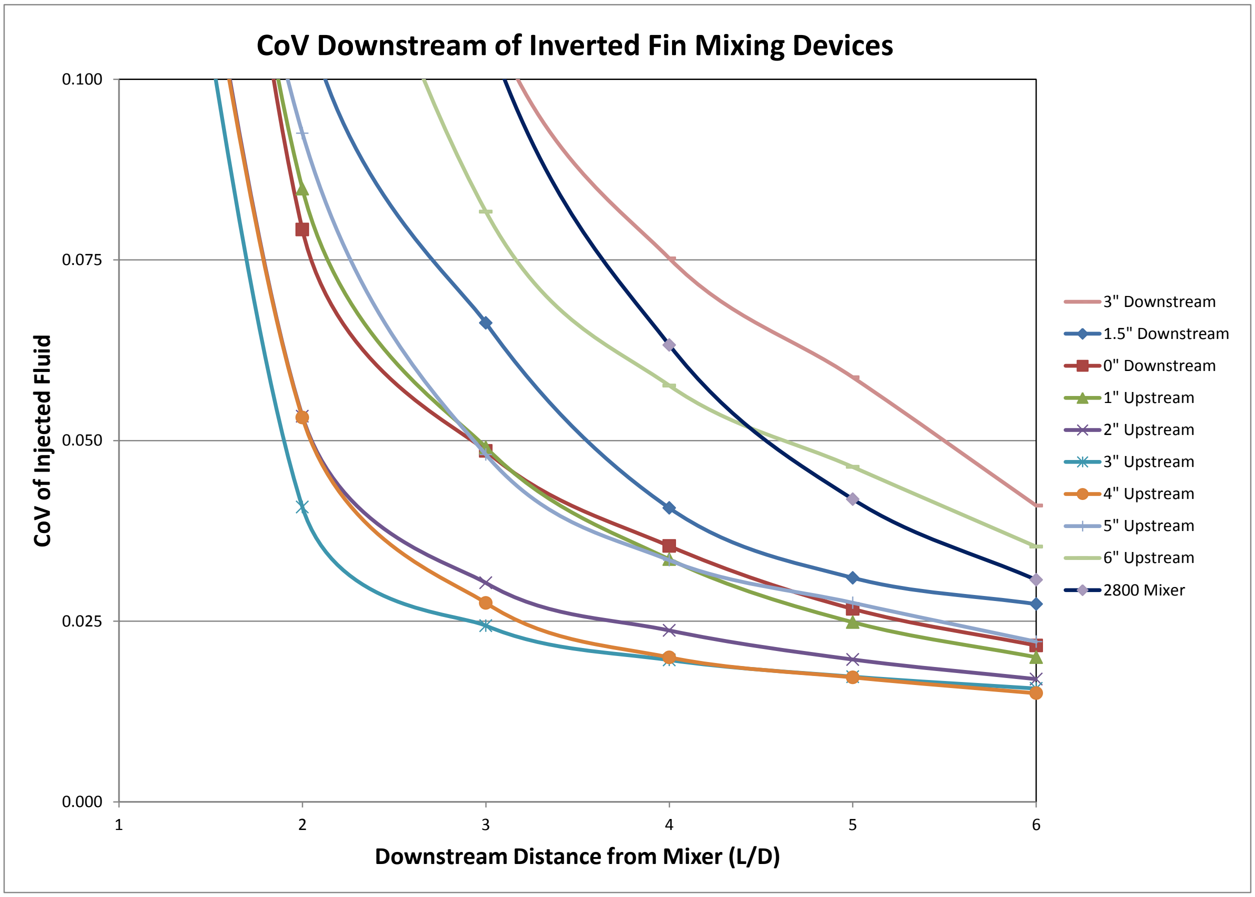

Figure 3.2: CoV of Ammonia Downstream of Mixing Devices

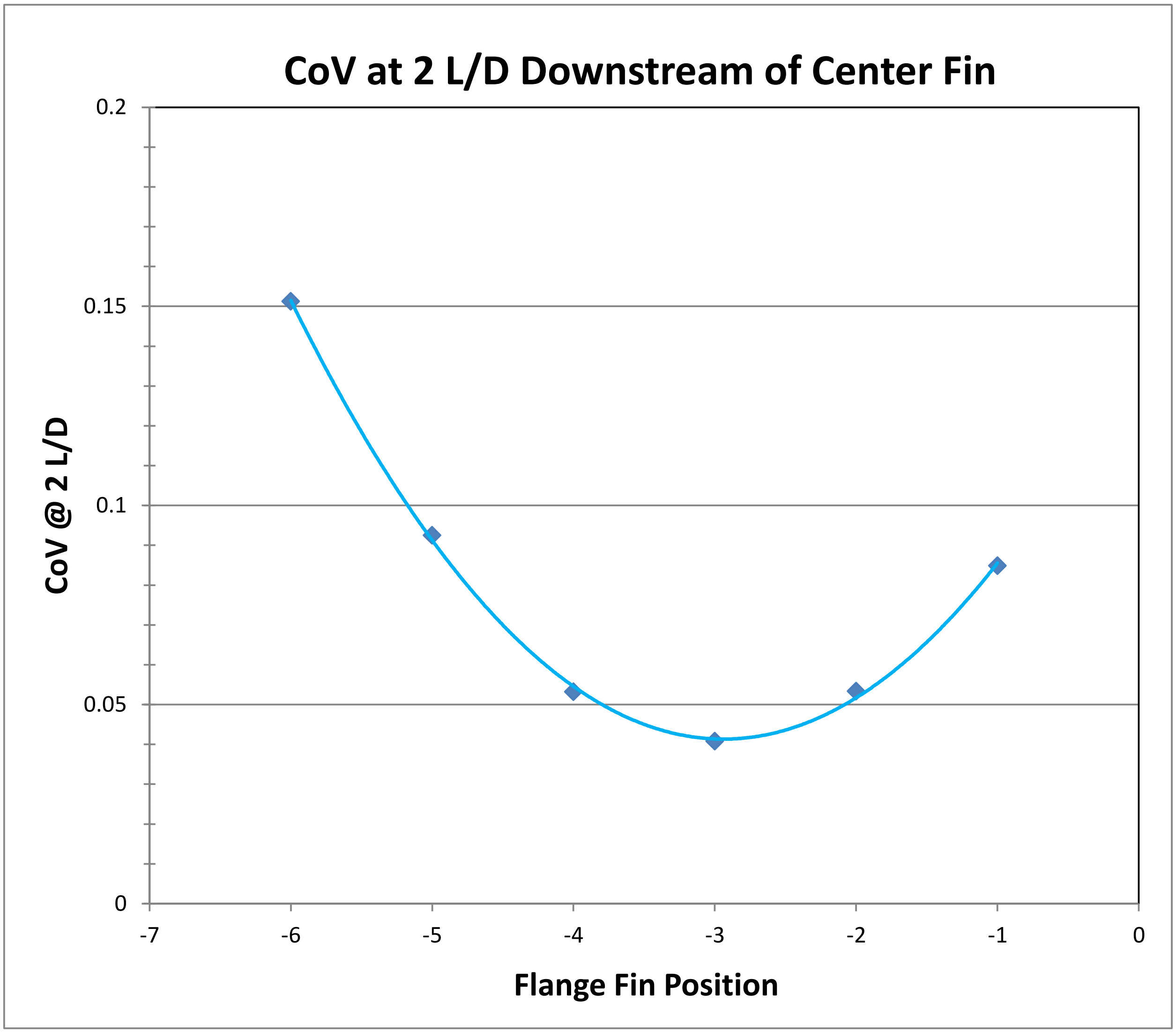

Figure 3.3: CoV of Ammonia at 2 L/D Downstream of Mixer

The inverted mixer also incurs some pressure losses in the pipeline. The pressure loss for the evaluated flow condition is calculated for the mixer, along with a k-value that can be used to calculate the pressure loss at any other flow rate using the following equation in consistent units:

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

Where:

P = pressure

ρ = fluid density

V = average fluid velocity in the pipeline

The total pressure loss for the empty pipe was measured to be 0.05 psi (1.35 iwc). This value was then subtracted from the total pressure loss for the mixer assembly to isolate the inherent pressure loss due to the mixer. The measured pressure losses and mixer k-values are presented below in Table 3.2; again, the 2800 mixer with a 0.8 Beta has been included for comparison. As can be seen in the table, the inverted mixer is much more efficient than the 2800 mixer with regard to pressure loss.

Table 3.2: Total Pressure Loss Results

Flange Fin Location	Total Pressure Loss		Loss Coefficient
	psi	iwc	K
3" Downstream	0.160	4.43	1.43
1.5" Downstream	0.159	4.41	1.42
0" Downstream	**0.223**	**6.18**	**1.99**
1" Upstream	0.161	4.47	1.44
2" Upstream	0.148	4.10	1.32
3" Upstream	0.140	3.89	1.26
4" Upstream	0.137	3.78	1.22
5" Upstream	0.133	3.68	1.19
6" Upstream	**0.130**	**3.60**	**1.16**
2800 Mixer	1.410	39.05	12.1

4.0 Conclusions & Recommendations

The inverted mixer design is very efficient with regard to pressure loss as the loss coefficient ranged between 1 and 2 for all tested geometries. Conversely, the 2800 mixer has a loss coefficient of 12.1 which is significantly higher. The inverted mixer with the flange fins located 3” upstream of the center hub fin provided optimum mixing at 2 L/D downstream of the mixer with a CoV of 0.04. Since the inverted mixer was evaluated at nearly ideal conditions with relatively large lengths of inlet and outlet piping, any future installations that deviate from the evaluated condition should be re-evaluated to determine their performances for those installations.