COMPUTATIONAL FLOW MODEL OF WESTFALL'S 36-IN LEADING TAB LOW-HEAD MIXER

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By

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Submitted to:

WESTFALL MANUFACTURING COMPANY

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INTRODUCTION

Alden Research Laboratory Inc. (Alden) was contracted by Westfall Manufacturing Inc. (Westfall) to aid in the development of a novel leading tab flow conditioner.

The objective of a flow conditioner is to reduce flow meter measurement error by: eliminating swirl, quickly impose a fully-developed velocity profile within the pipe, and minimize turbulence regardless of the flow conditions upstream. A successful flow conditioner will accomplish this with minimal pressure loss, and with the shortest pipe length possible.

The leading tab concept, when coupled with anti-swirl plates, is proving quite effective at reducing swirl and improving the flow distribution at short distances downstream of the conditioner. Turbulence levels are also maintained at fairly low levels, which helps improve measurement accuracy. The principle by which the conditioner operates is that the tabs create vortices that mix the flow by turning it “inside-out”, and then quickly dissipate at the pipe wall leaving a uniform flow in its wake. By turning the flow inside-out, the flow conditioner is an effective static mixer as well, and the low head loss design makes it attractive in applications where pressure head is limited.

This report discusses the head loss and mixing capabilities of the leading tab low head mixer installed in a 36-inch pipe. Water is flowing through the pipe at 32-MGD, and a small flow of ferric-sulfate solution is injected directly upstream of the mixer.

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 2 million hexahedral and tetrahedral cells.

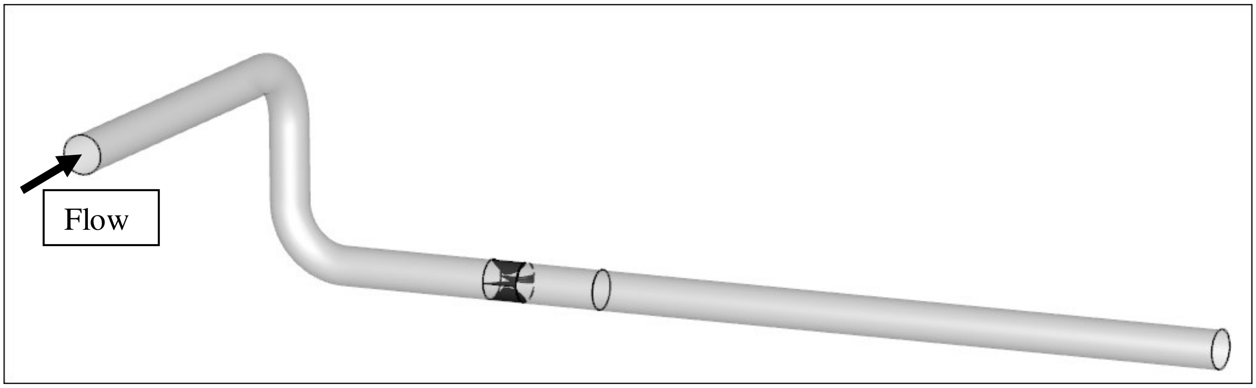
Numerical simulations were performed using the CFD software package FLUENT V6.3.26, a state-of-the-art, finite volume-based fluid flow simulation package including program modules for boundary condition specification, problem setup, and solution phases of a flow analysis. Advanced turbulence modeling 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, anisotropic, two-equation k-ε model was used to simulate the turbulence. The anisotropic model was required to properly resolve the secondary flows that developed as a result of changes in geometry. Detailed descriptions of the physical models employed in each of the Fluent modules are available from Fluent, Inc., the developer of Fluent V6.3.26.

MODEL BOUNDARY CONDITIONS

The tests were conducted in 36-inch I.D steel pipe, and the test section consisted of two 90° bends in perpendicular planes separated by 2 pipe diameters. This configuration provides both non-uniform velocity profiles and swirling flow. The mixer should be able to perform adequately given any reasonable upstream pipe layout, so a reasonable worst-case configuration has been simulated.

The upstream end of the mixer was placed 4 pipe diameters downstream from the second bend, and is used as the datum for comparison of mixing with and without the mixer installed. It has been determined through previous testing that the mixer performs similarly at different flow rates, provided the flow is turbulent, so only one water flow rate was tested: 32-MGD at ambient pressure and temperature. A uniform velocity inlet was imposed at the model inlet, which was placed 10 pipe diameters upstream of the first bend. A uniform static pressure boundary condition was imposed at the model outlet, which was placed 20 pipe diameters downstream of the mixing device's leading edge so that the impact of the flow conditioner could be documented as a function of downstream distance. On all surfaces, no-slip impermeable adiabatic wall boundary conditions were applied with roughness heights set to 0.00015-ft as appropriate for steel pipe.



Water flow in a 36-in ID steel pipe, after two out-of-plane 90° bends.
The flow conditioner is installed 4D downstream of the second bend.

A baseline case was evaluated at the tested flow rate without a flow conditioner for comparison of pressure loss, and mixing.

To measure mixing, a 50% ferric sulfate solution was injected through four lances at the mixer's leading edge (at L/D = 0) at a solution volume fraction of 286ppm. The mixing of the solution was then monitored downstream.

A Dimensioned drawing of the mixer is included at the end of this report.

RESULTS AND DISCUSSION

The goal of the mixer is to achieve a uniform concentration of the injected material in as short a downstream distance as possible.

Flow Characteristics:

The basic beneficial flow characteristics that the leading tab flow conditioner creates are:

- Two strong counter rotating vortices that are generated at the edges of the tabs in the bulk flow (away from the wall). These vortices very quickly exchange momentum between the flow at the center of the pipe with the flow at the wall.
- The tendency of these vortices to quickly migrate to the wall in the wake of the tabs due to the tab angle, and the vortex pair's close proximity to each other. Once attached to the wall, the vortices quickly decrease in intensity due to high shear stress at the pipe wall, through which rotational momentum is lost, and excessive turbulence is dissipated.
- Axial fins that effectively eliminate swirl near the pipe walls, where the rotational inertia is greatest.
- Relatively low pressure loss associated with this device (5.1 inwg with water flowing at 32 MGD in a 36" I.D. pipe, or a k-value of 0.557).
- Tapered leading edges and other geometric features that prevent fouling.

Pressure Loss:

Pressure loss was measured across the flow conditioner by comparing pressure at the test section inlet with and without the conditioner installed. From the results, a k-value of 0.557 was calculated using the pressure loss value, and a water density of 62.5-lbm/ft3. The k-value may be used to extrapolate to find pressure losses at other flow conditions. A plot of pressure loss vs. flow rate is included at the end of this report.

Flow Distribution:

The low head mixer was originally designed as a flow conditioner. As such, it addresses mal-distribution by inducing a small amount of pressure loss, and turning the flow "inside-out" so that momentum is fully exchanged across the flow stream. The flow conditioner is intended to take any incoming flow distribution, and create a fully developed flow profile with minimal swirl within a short distance downstream. Due to the flow disturbance caused by the flow conditioner, the initial deviation from a fully developed profile is greater with the mixer than without, but by less than 6D downstream, the flow profile is better with the mixer than without.

Mixing:

The mixing capability of Westfall's low-head mixer was tested using four injection lances at the upstream edge of the mixer (L/D = 0). The end of the lances were placed on the area centers of the four quadrants of the pipe's cross-sectional area. Two lance orientations were tested:

- Area centered offset from tabs: Lances were placed in between each of the four mixer tabs.
- Area centered in front of tabs: Lances were placed directly upstream of each of the four mixer tabs.

Additionally, a control case was tested with four injection lances without a mixer to test the benefit of having the mixer installed.

Both injection locations with the mixer performed significantly better than without the mixer. Of the two injection locations with the mixer, injecting the solution directly in front of the tabs proved more effective at distances of more that 4D downstream of the injection location, and achieved a CV of less than 0.03 by 10D downstream of the injection point (CV with no mixer was 0.18 at 10D).

Cavitation:

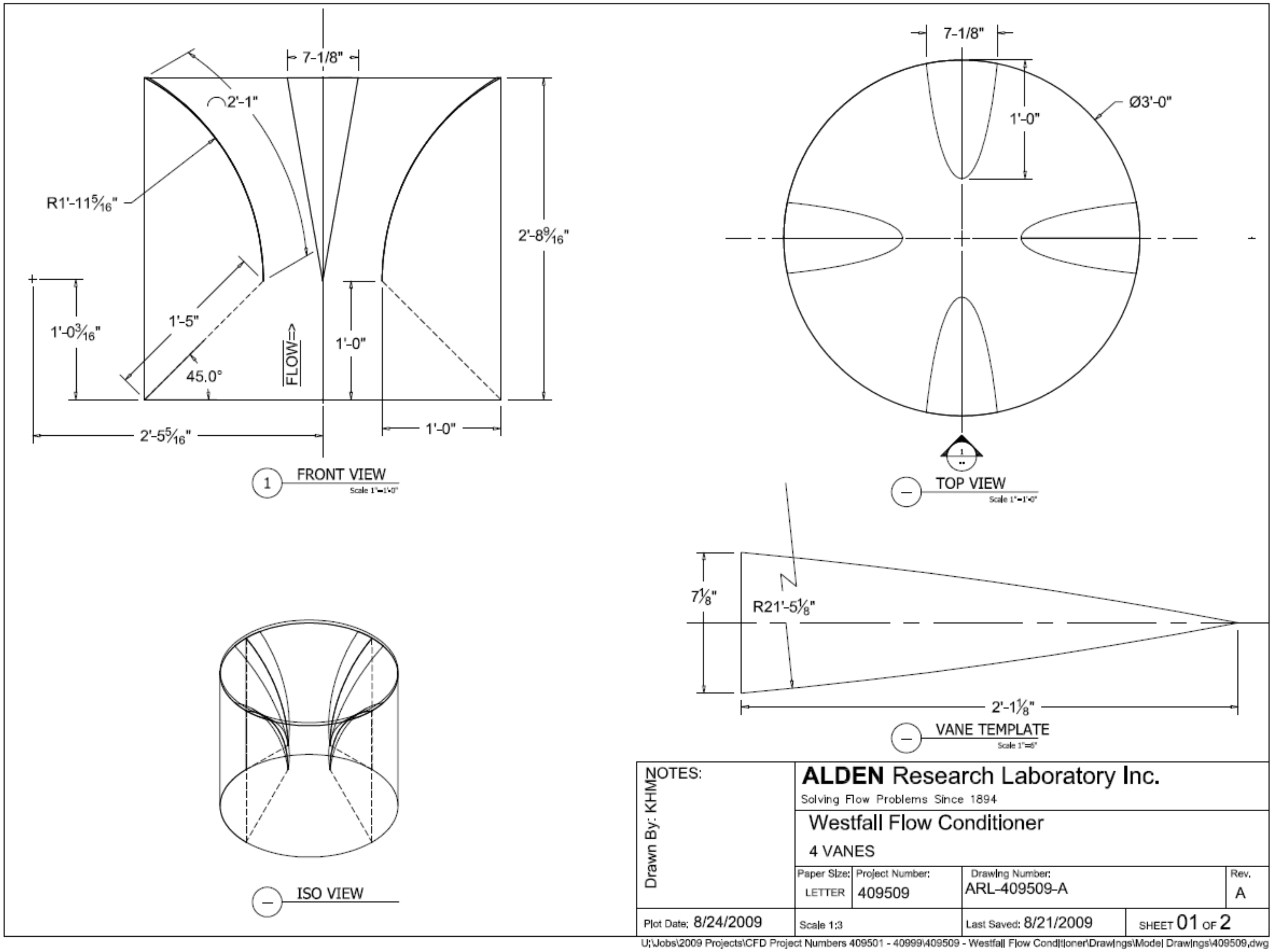
Cavitation can occur in separated flow areas where the velocity of the liquid is high enough that the liquid's momentum creates a low pressure area below the liquid's vapor pressure at that temperature.

At the liquid velocity tested (average pipe velocity = 7.0-ft/s), the lowest pressure caused by the mixer was 1.3 psi (36-inwg) below the average pressure in the pipe at that location, or 13.4 psia if the flow is at atmospheric pressure. This is not a very severe flow condition, and does not pose significant risk to cavitation unless: the liquid temperature is close to its boiling point, there is very little net positive suction head available (NPSH), or there is a significant amount of gas present in the flow.

CONCLUSIONS

With the injection locations shown, the flow conditioner design works quite well as a low-head mixer provided there are a few pipe diameters available for the flow to mix fully. Since the device was originally designed as a flow conditioner, it is very effective at mitigating any swirling flow that is created upstream, and creating a fully developed flow profile. The low pressure loss characteristics are very desirable for pressure limited operation, and the raked angles prevent fouling.

It is recommended that four injection points be used, placed directly upstream of each of the four leading tab mixing vanes, at a penetration depth of 7.2" from the wall in a 36" ID pipe.



7-1/8"
2'-1"
R1'-11 5/16"
2'-8 9/16"
1'-0 3/16"
1'-5"
45.0°
FLOW=>
1'-0"
2'-5 5/16"
1'-0"
FRONT VIEW
Scale 1"=1'-0"
7-1/8"
Ø3'-0"
1'-0"
TOP VIEW
Scale 1"=1'-0"
7 1/8"
R21'-5 1/8"
2'-1 1/8"
VANE TEMPLATE
Scale 1"=6"
ISO VIEW
NOTES:
Drawn By: KHM
ALDEN Research Laboratory Inc.
Solving Flow Problems Since 1894
Westfall Flow Conditioner
4 VANES
Paper Size: LETTER
Project Number: 409509
Drawing Number: ARL-409509-A
Rev. A
Plot Date: 8/24/2009
Scale 1:3
Last Saved: 8/21/2009
SHEET 01 OF 2
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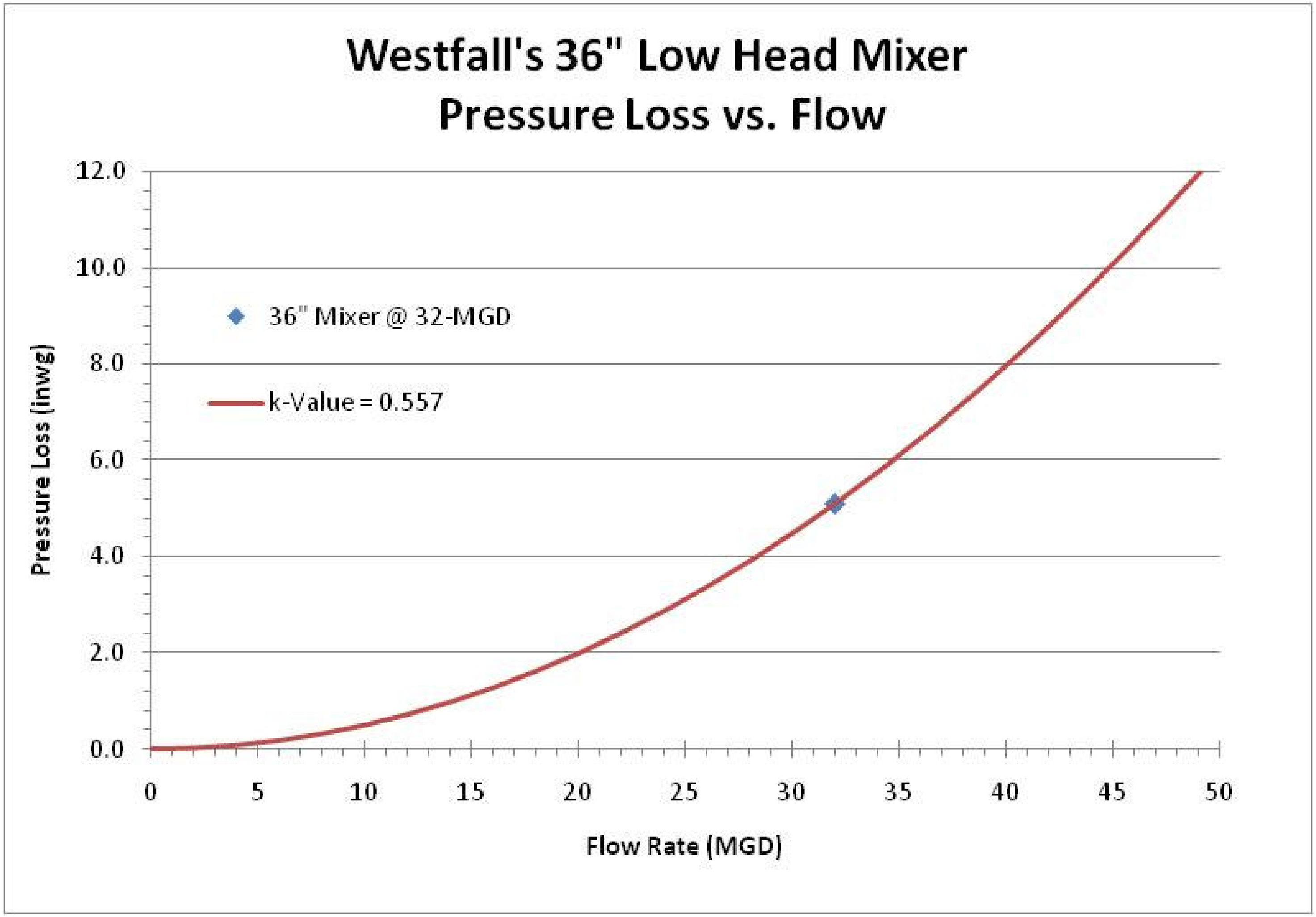
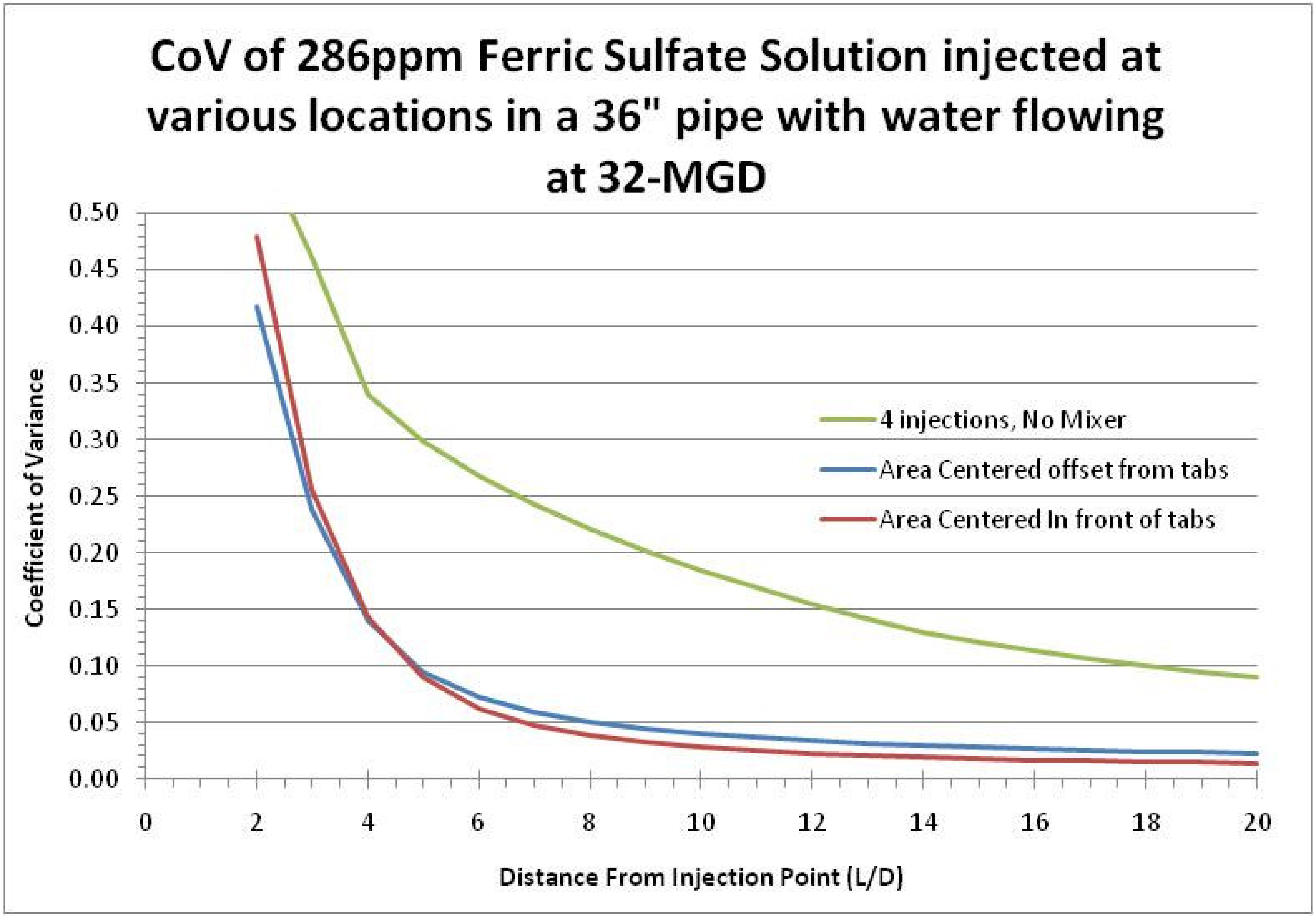
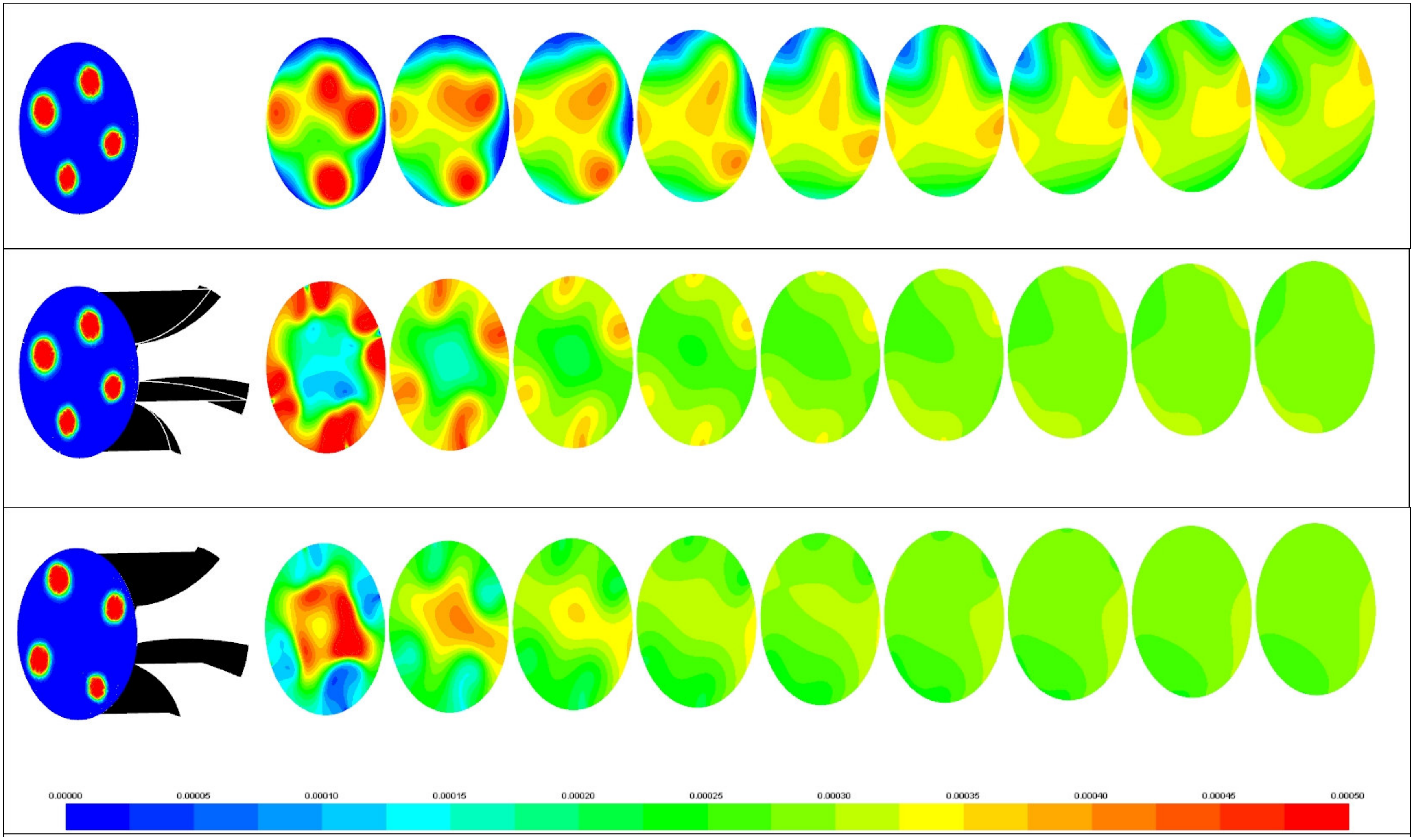


Water flow in a 36-in ID steel pipe, after two out-of-plane 90° bends.

The flow conditioner is installed 4D downstream of the second bend.



32-MGD water flow in a 36-in I.D. steel pipe, after two out-of-plane 90° bends.
The flow conditioner is installed 4D downstream of the second bend.



32-MGD water flow in a 36-in I.D. steel pipe, after two out-of-plane 90° bends.
The flow conditioner is installed 4D downstream of the second bend.
Contours of volume fraction of injected solution at injection point, and for distances 2-10 D downstream:
<u>Top</u> - No mixer; <u>Middle</u> - Mixer with injection directly upstream of vanes; <u>Bottom</u> - Mixer with injection offset from vanes by 45°