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Safety Injection Tank Performance Analysis Using CFD

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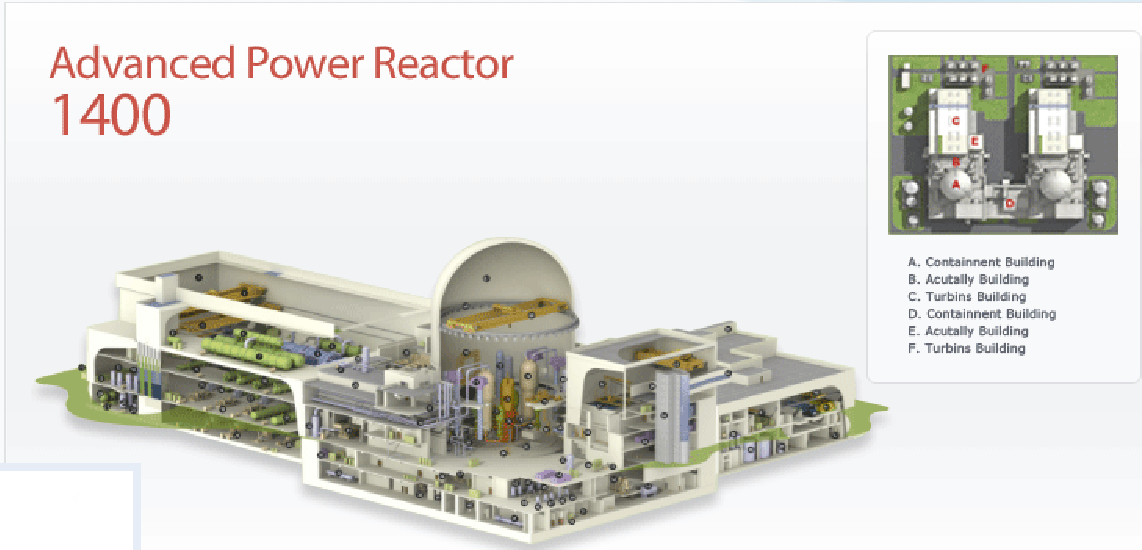
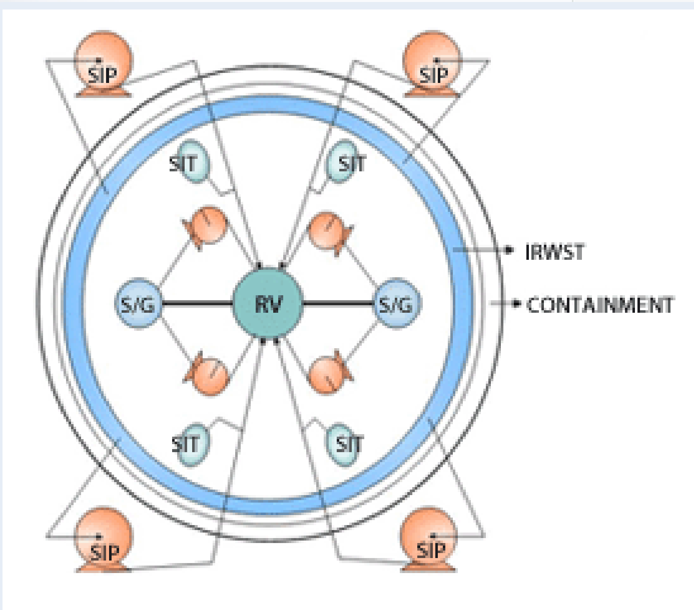
Introduction

The APR 1400 is a large pressurized water reactor (PWR). Just like many other water reactors, it has an **emergency core cooling system (ECCS)**.

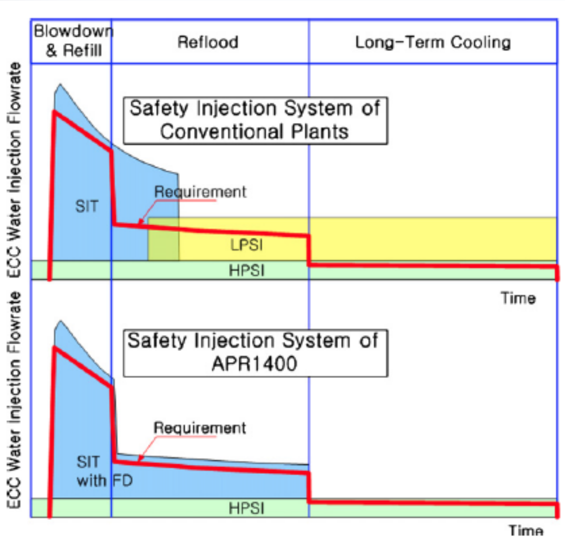


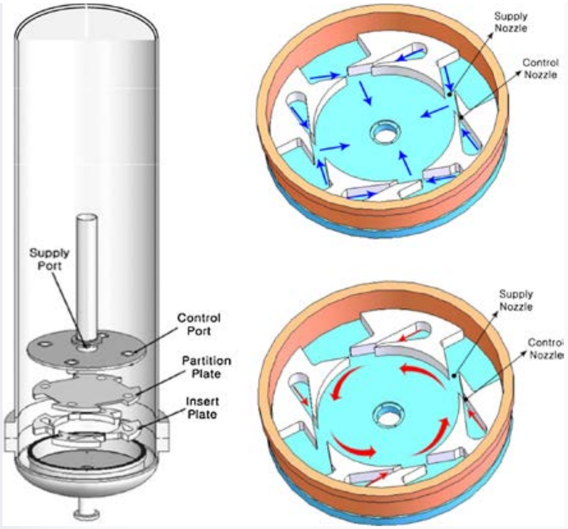


Safety Injection System

- One of the most important components in the ECCS is the **safety injection tank (SIT)**.
- The SIT is designed to provide ECC water in LOCA scenarios.
- The tank is pressurized to a certain level and once the system pressure drops below that level, the check valve opens and water flows into the core.

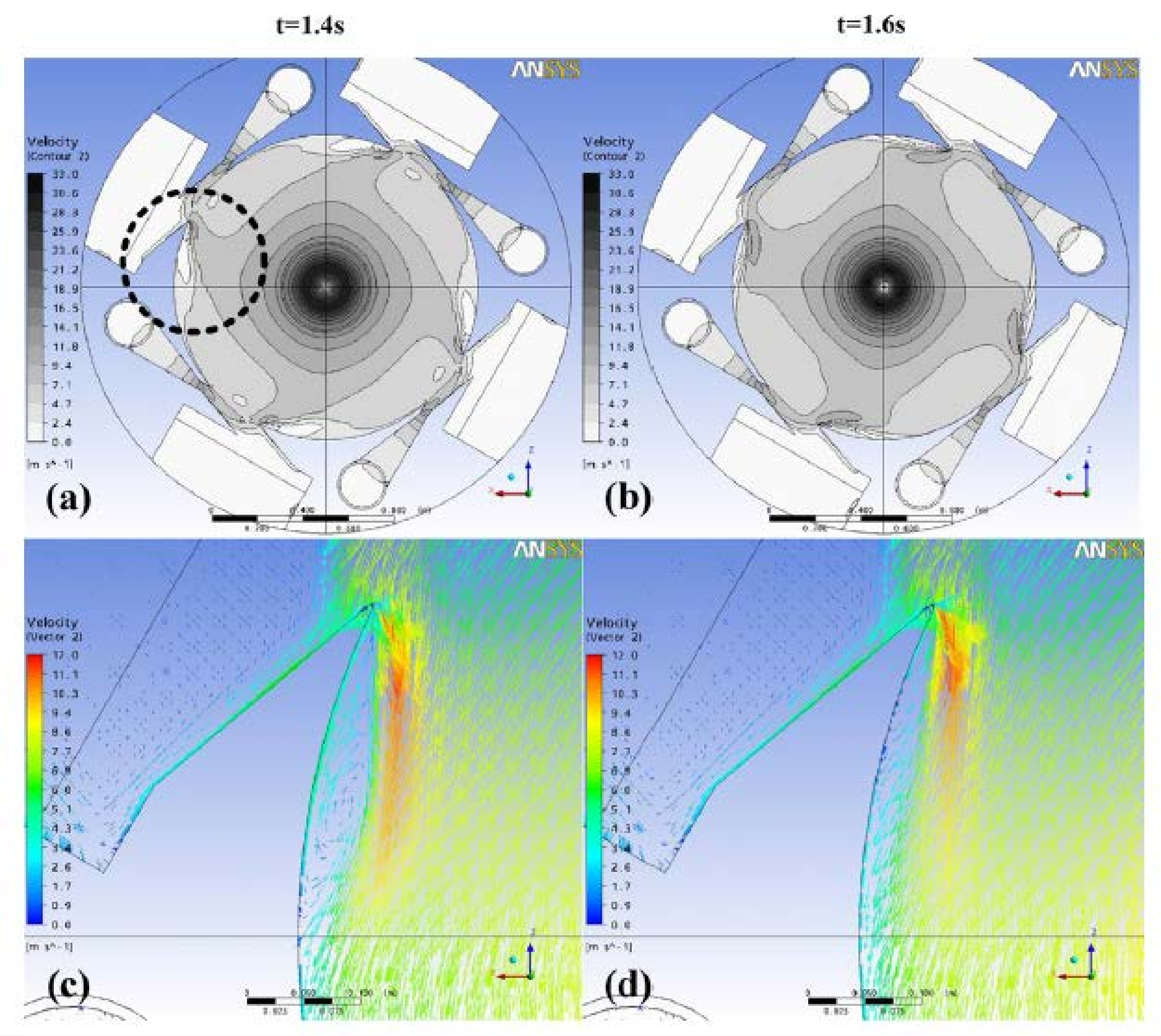
Safety Injection Tank





- Inside the SIT, a **fluidic device** is installed, which passively controls the mass flow of the safety injection and eliminates the need for low pressure safety injection pumps.
- As more passive safety mechanisms are being pursued, it has become more important to understand flow structure and the loss mechanism within the fluidic device.
- Current computational fluid dynamics (CFD) calculations have had limited success in predicting the fluid flow accurately. **This study proposes to find a more exact result using CFD and more realistic modeling.**

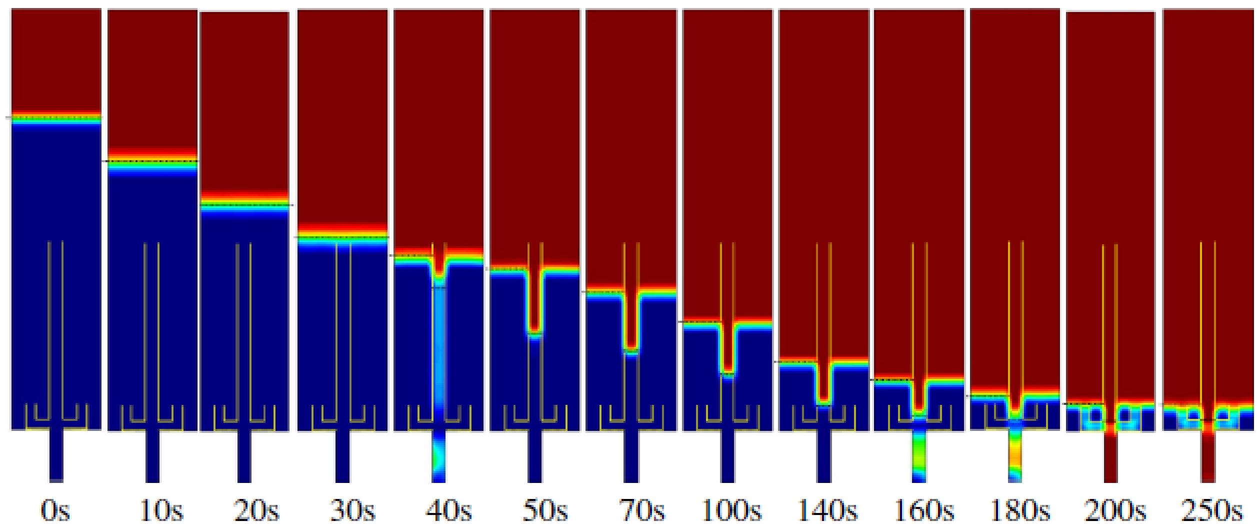
Literature Review

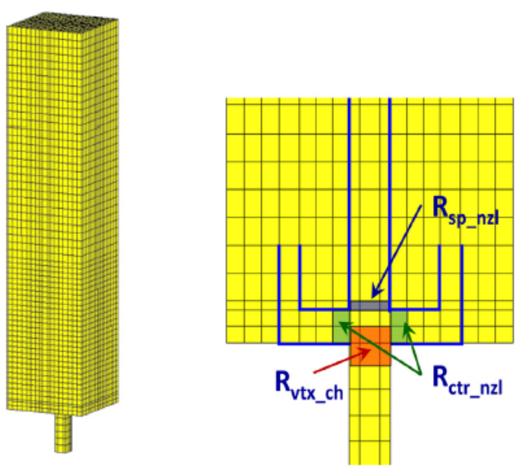


Benchmark and parametric study of a passive flow controller (fluidic device) for the development of optimal designs using a CFD code
- *Korea Hydro & Nuclear Power Company*

- No nitrogen
- Free surface effect neglected

Literature Review





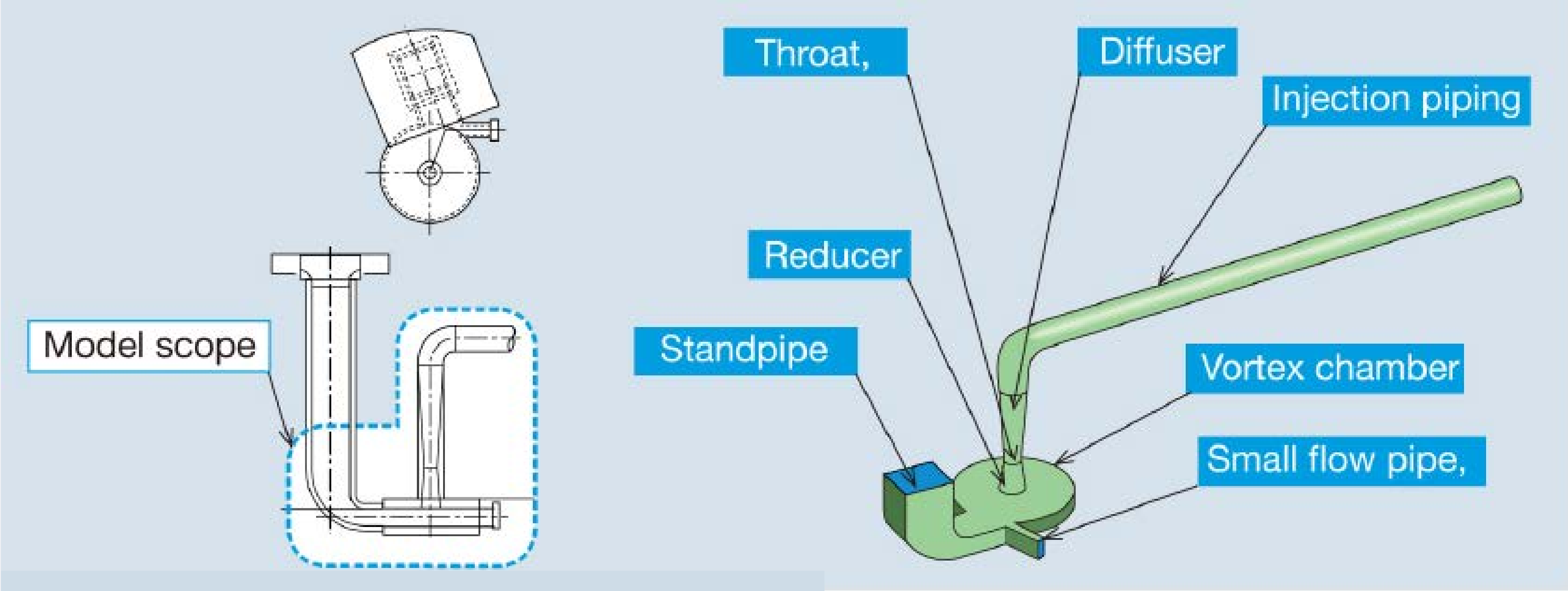
(a) Hexagonal grids for SIT

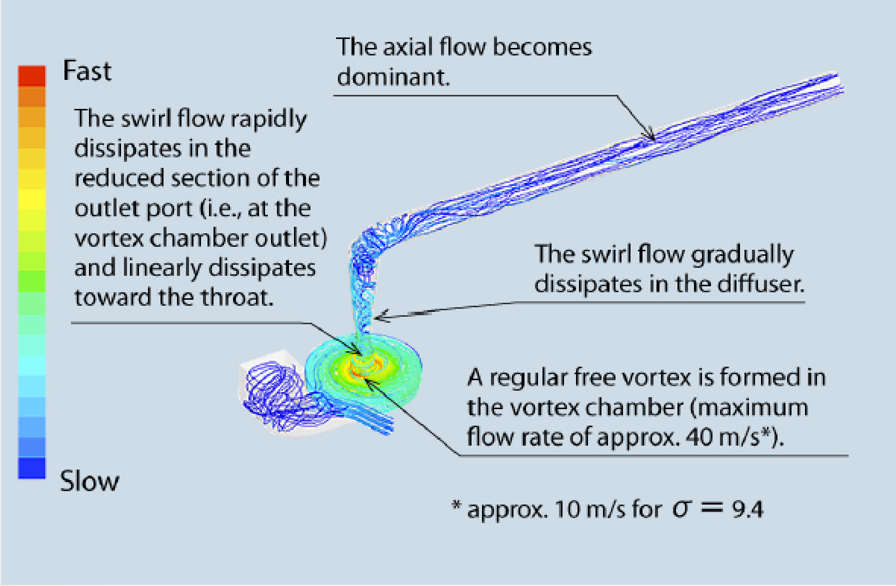
(b) Flow resistance model

A multi-scale analysis of the transient behavior of an advanced safety injection tank - *Korea Atomic Energy Research Institute*

- Geometry simplified
- K-factor given artificially

Literature Review





CFD on Small Flow Injection of Advanced Accumulator in APWR
- *Mitsubishi Heavy Industries*

- FD only
- Steady-state

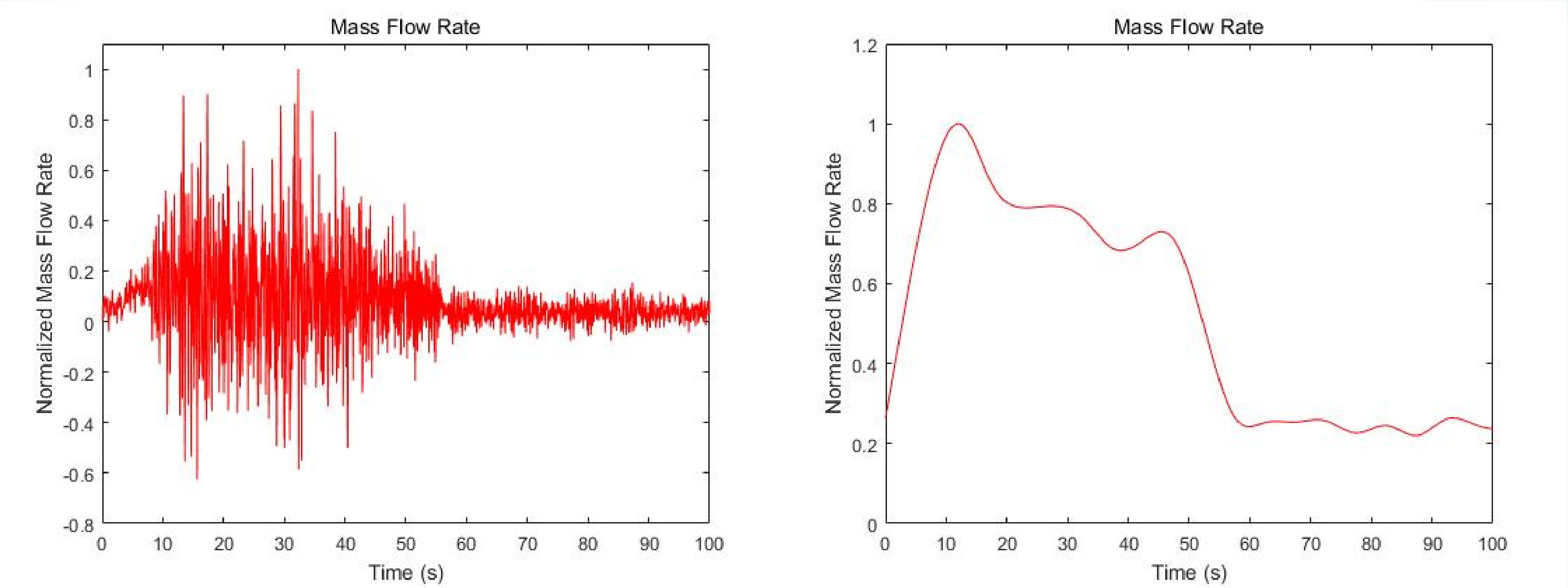
Research Uniqueness

	Nitrogen	Precalculated K factor	Full Geometry	Transient
KHNP	X	X	X	X
KAERI	O	O	Δ	O
MITSUBISHI	X	X	X	X
KAIST	O	X	O	O

Proposed Work

- With Nitrogen
- Without Precalculated K-factor
- Full Geometry
- Transient

Preliminary Results

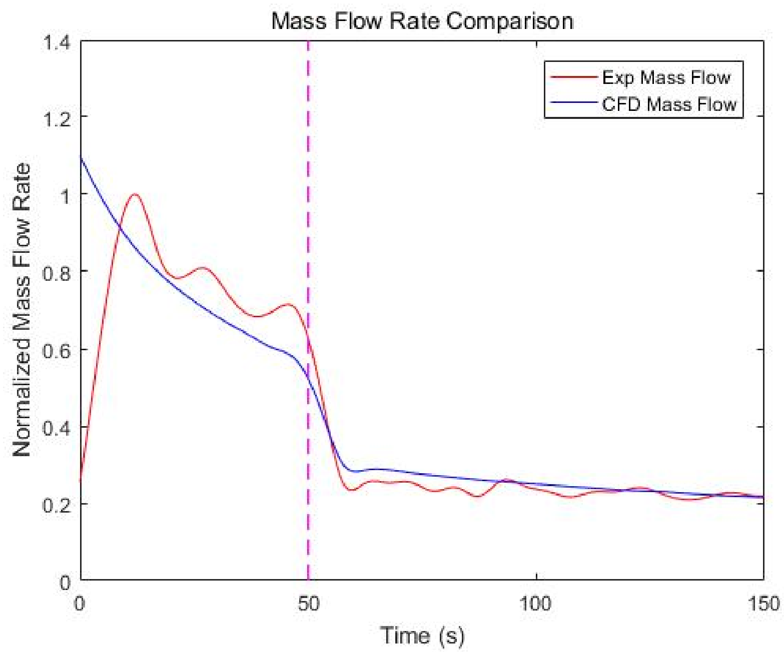


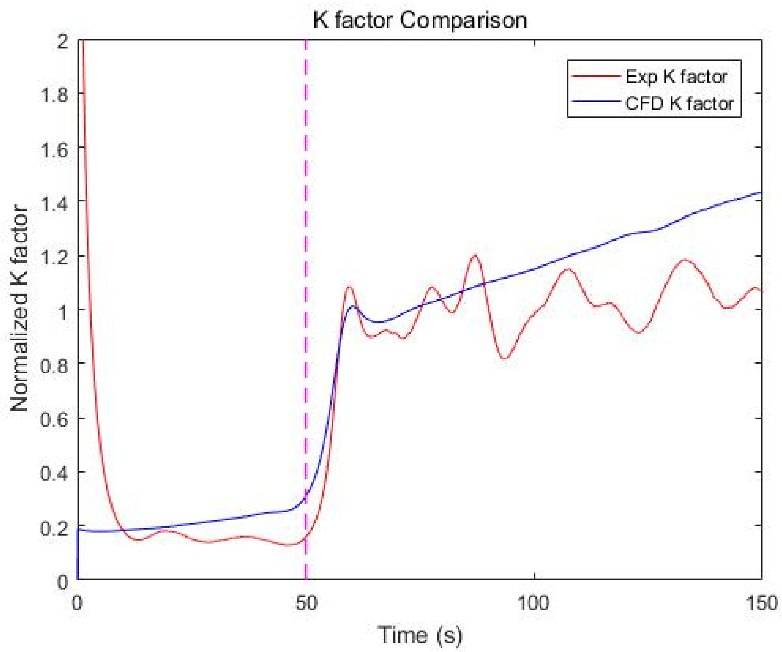
- Mass Flow Rate was retrieved by differentiating the water level.
- However fluctuation in water level was too violent.
- To get a meaningful result, the water level every 5 seconds was used for calculation.

Preliminary Calculation Conditions

- The realizable **K-epsilon model** was used for the turbulence model.
- Eulerian multiphase model with **Volume Of Fluid** (VOF) was used.
- **Polyhedral meshes** were used.
- The tank was given a **constant thermal resistance** and **constant ambient temperature** with **convective boundary condition** on the tank wall.
- Lastly, a **pressure boundary of 1 bar** was given at the end of the discharge pipe.

Preliminary Results





- The CFD mass flow rate matches quite well with the experimental result.
- The total k factor(form loss factor) was calculated in the discharge pipe using the equation below.
- $K = \frac{2 * Pressure * Density * Area^2}{MassFlowRate^2}$

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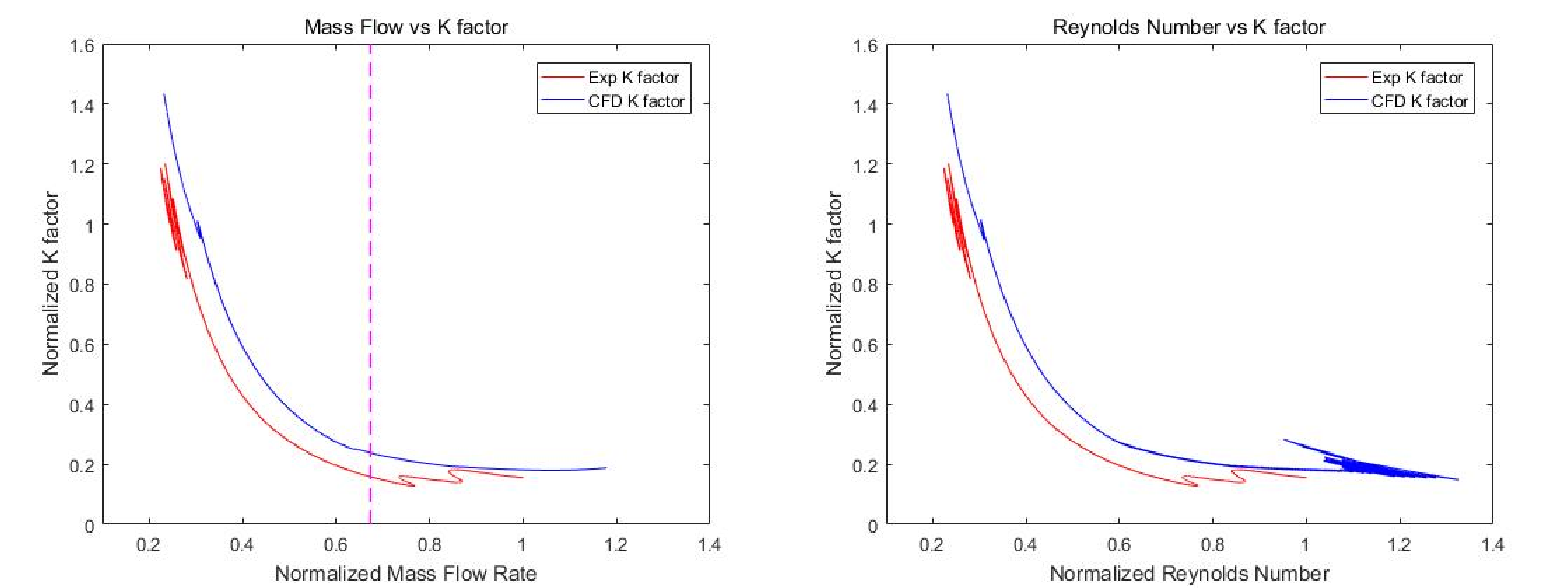
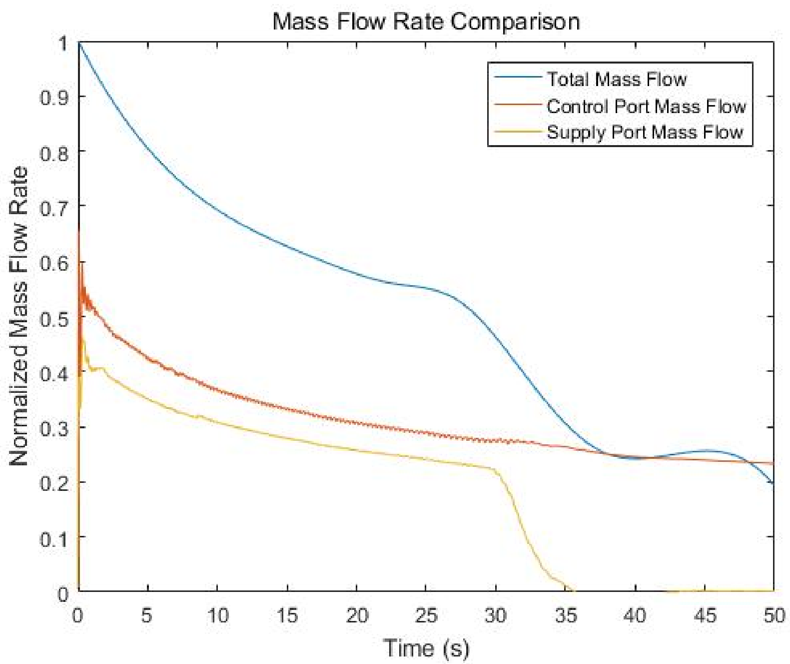
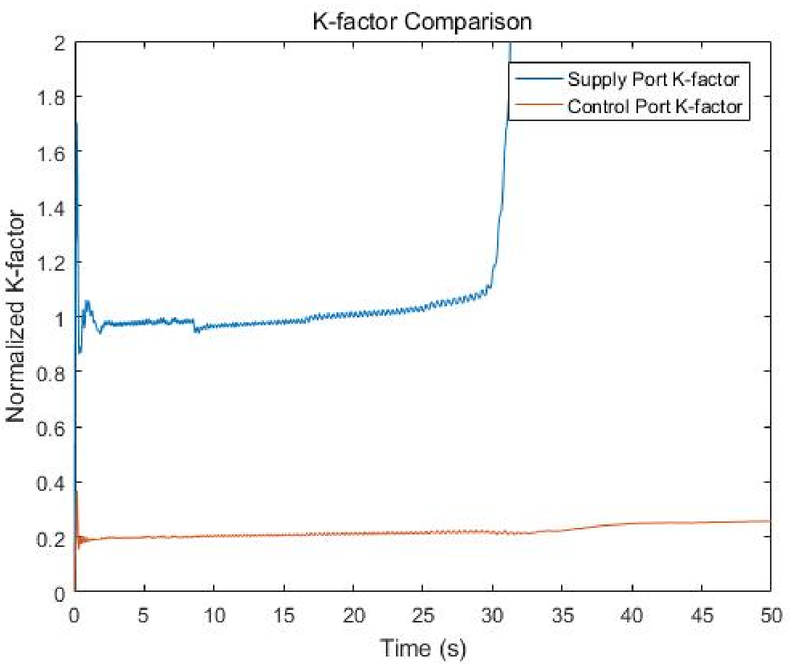
Preliminary Results



❖ The K factor plotted against mass flow rate and Reynold number.

Preliminary Results



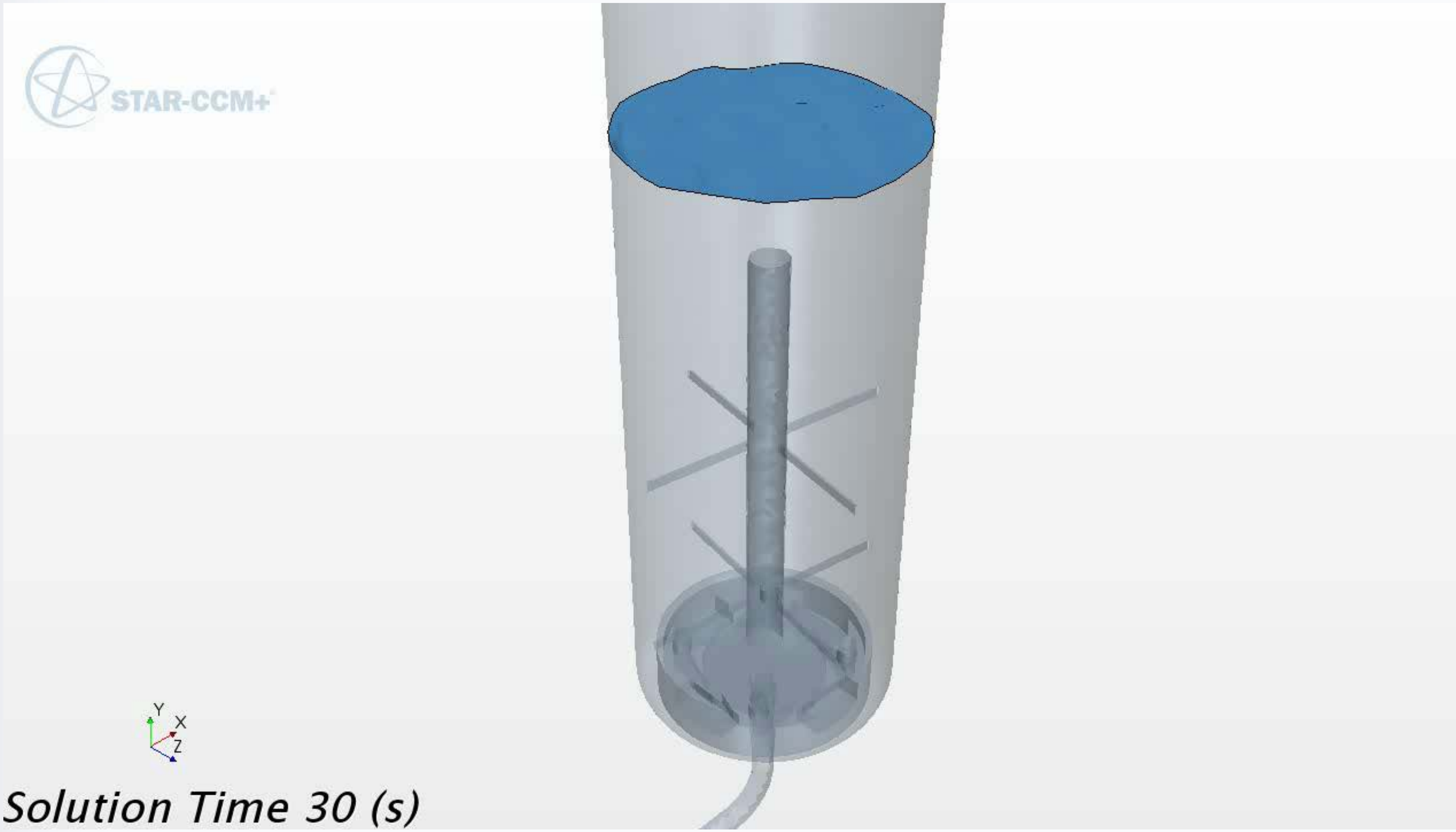


- The mass flow from the Control Port and Supply Port(Stand pipe) were compared.

- The K-factor of the Control Port and Supply Port(Stand pipe) were compared.

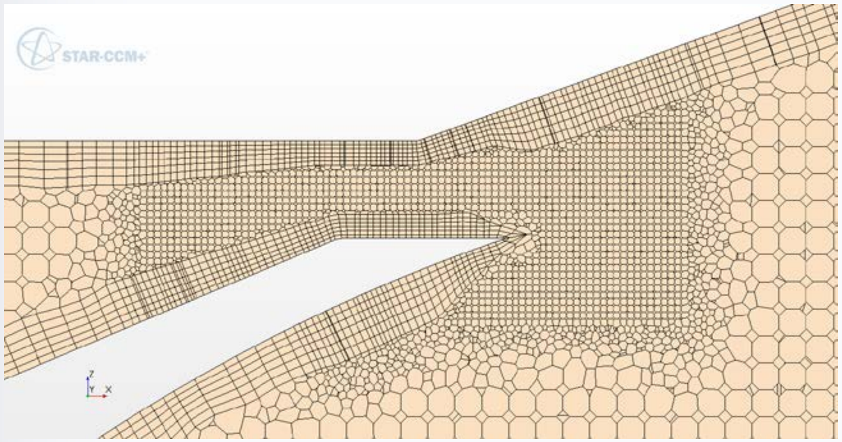
- Control Port K-factor remained near constant while Supply Port K-factor remained so too until 30s.

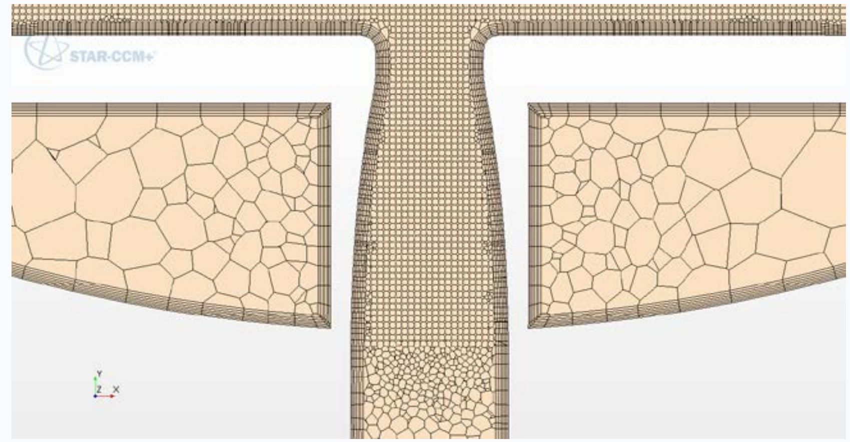
Animation



Liquid Volume Fraction 0.8 Isosurface

Comprehensive Analysis





Updated Mesh

\# of cells: 4 million
Tank Base size: 10cm
FD Base size: 0.25~1cm
Prism Layer: 6
Stretching Factor: 1.08
Growth Factor: 0.1

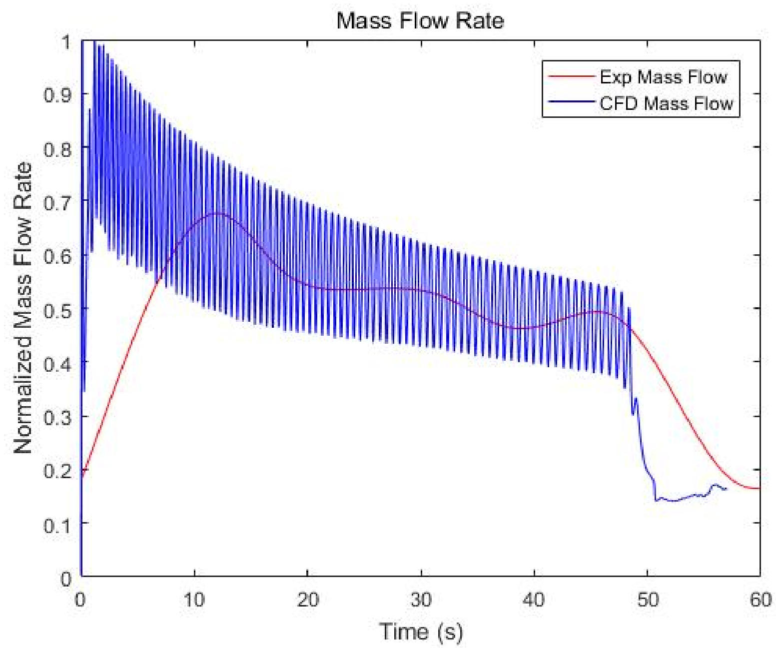
IBM High Performance Computer II HIG

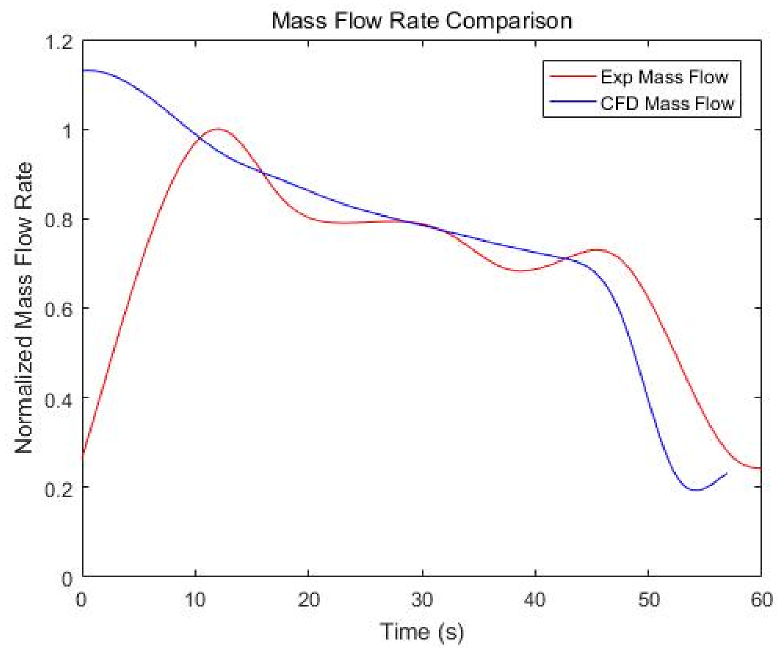
. 11.520 Giga flops for computing.
. 25 Compute node
. 1 Master node
. 1 Login node
. IBM system x3775 M3
. CPU AMD Opteron 6174 12C *4, 256 GB RAM per node
. Infiniband by Qlogic
. 24TB Storage

Applications

- Fluent	- RELAP5
- CFX	- SCDAP
- Star-CD	- SNAP
- Star-CCM	- TRACE
- CONTAIN	- TRAC-P
- MELCOR	- WIMS

Comprehensive Calculation Results

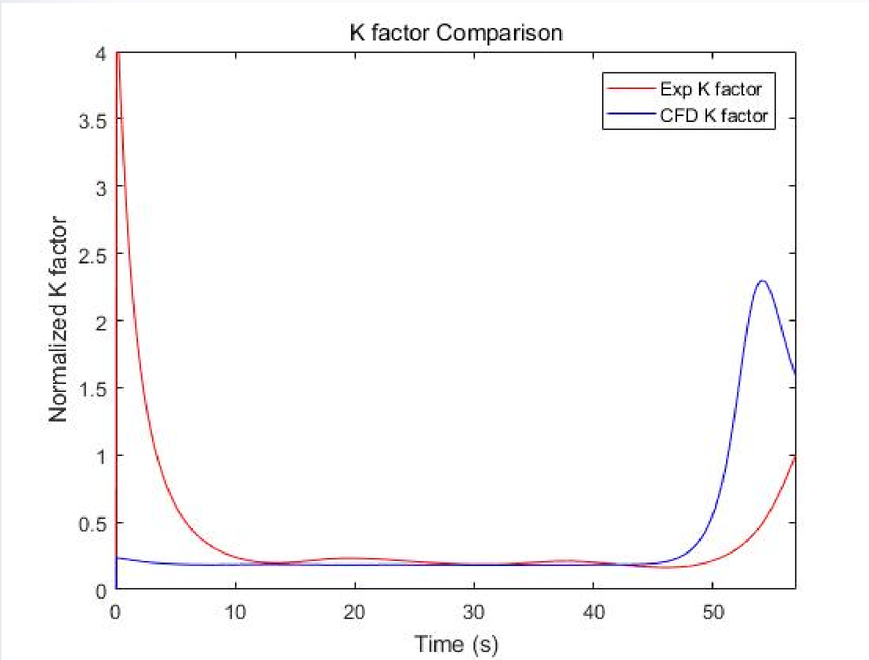


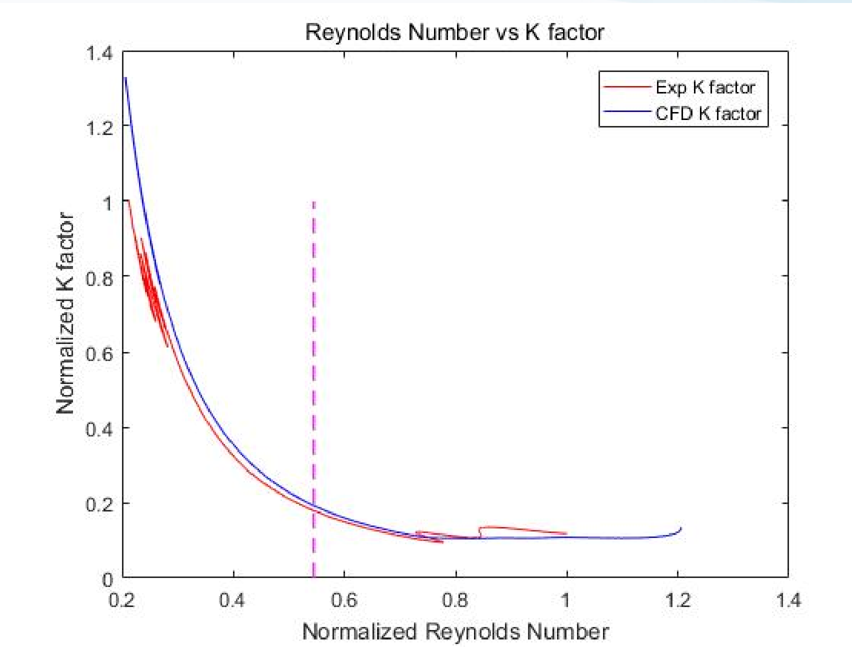


- Original CFD Mass Flow with averaged Experiment Mass Flow
- Averaged Mass Flow of CFD and Experiment

- Results were averaged every 5 seconds for comparison.

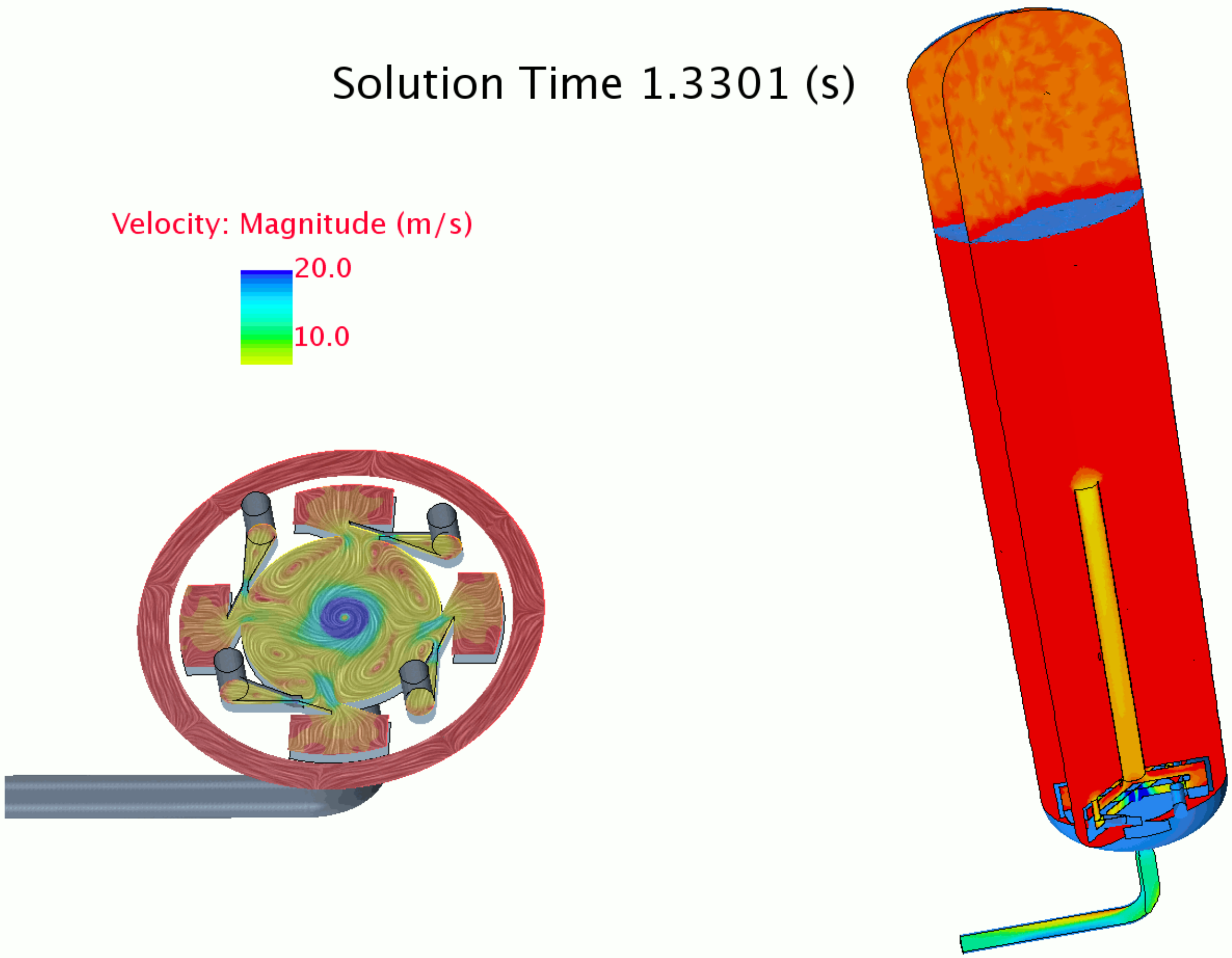
Comprehensive Calculation Results



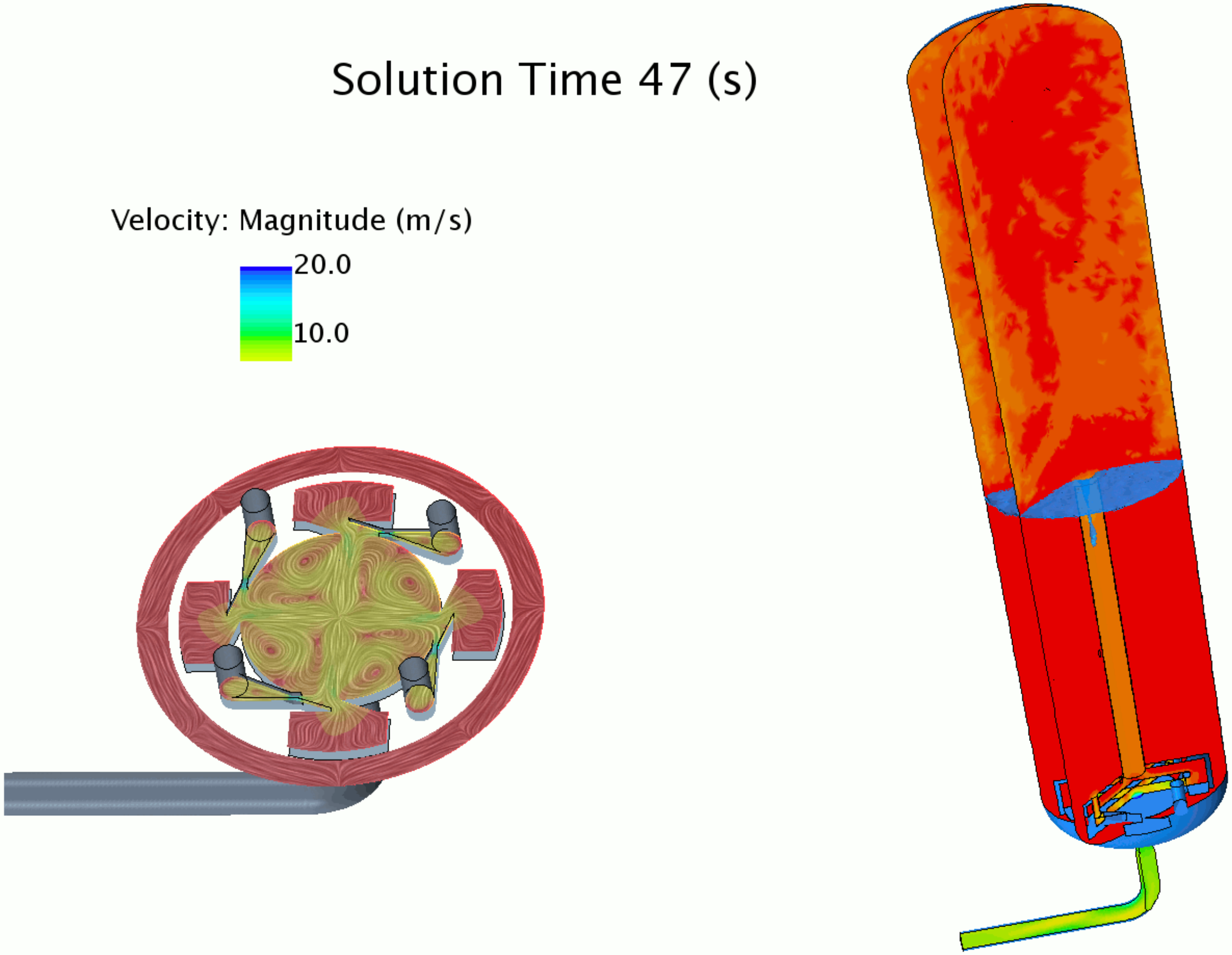


- Time vs K-factor
- Reynolds vs K-factor

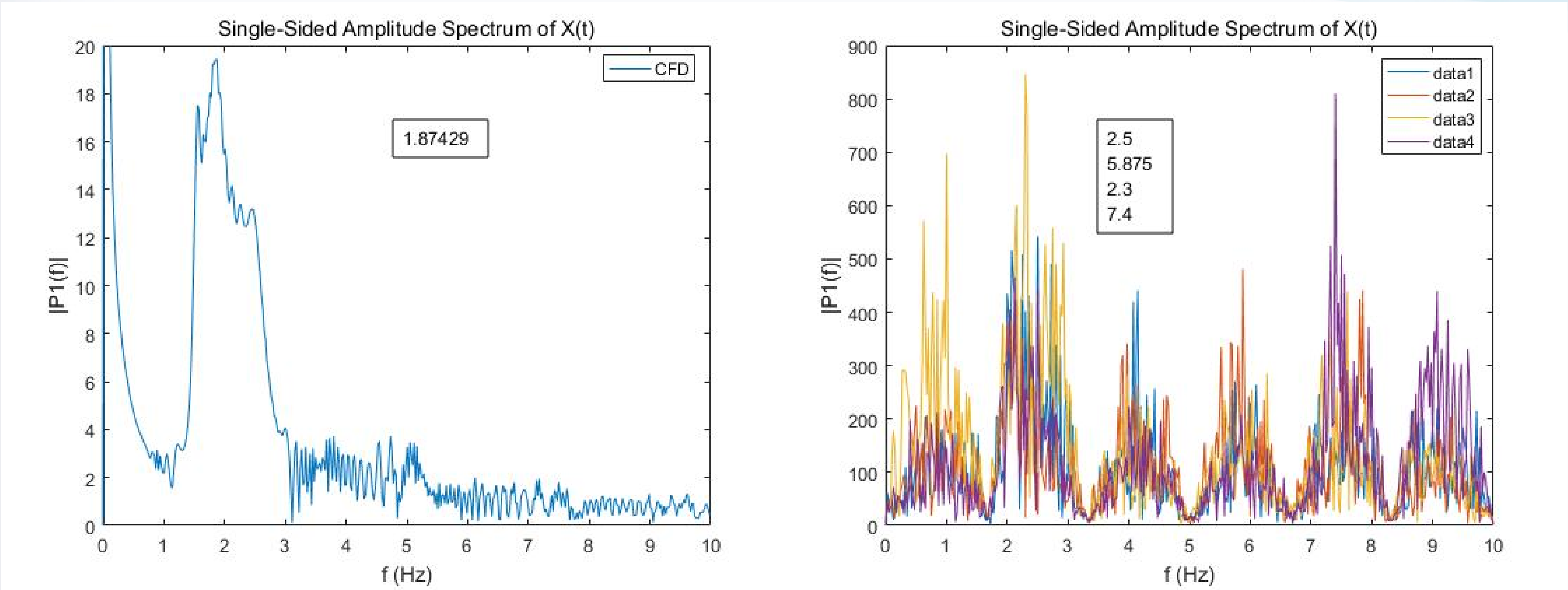
Comprehensive Calculation Results



Comprehensive Calculation Results



Comprehensive Calculation Results



- FFT of CFD calculation

- FFT of Experiment results
- 4 Cases were examined

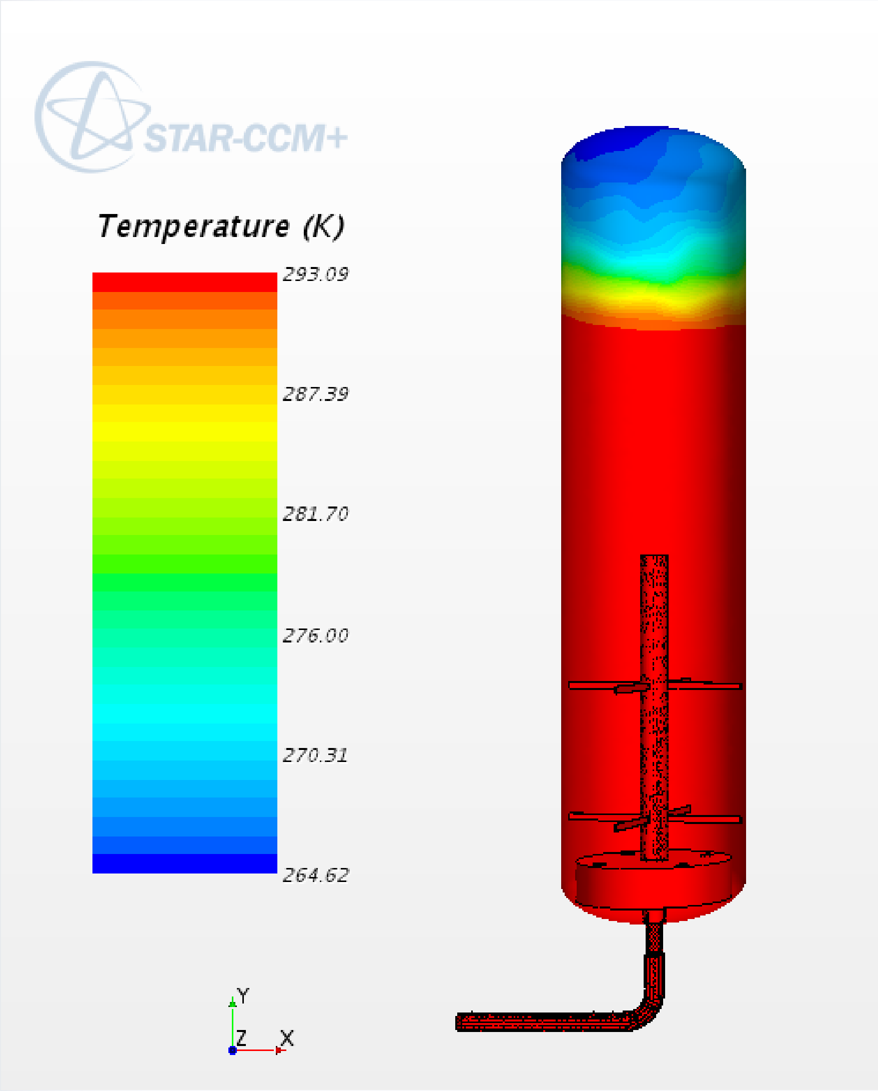
- The numbers in the boxes show the peak frequency of each case.

Summary & Future Works

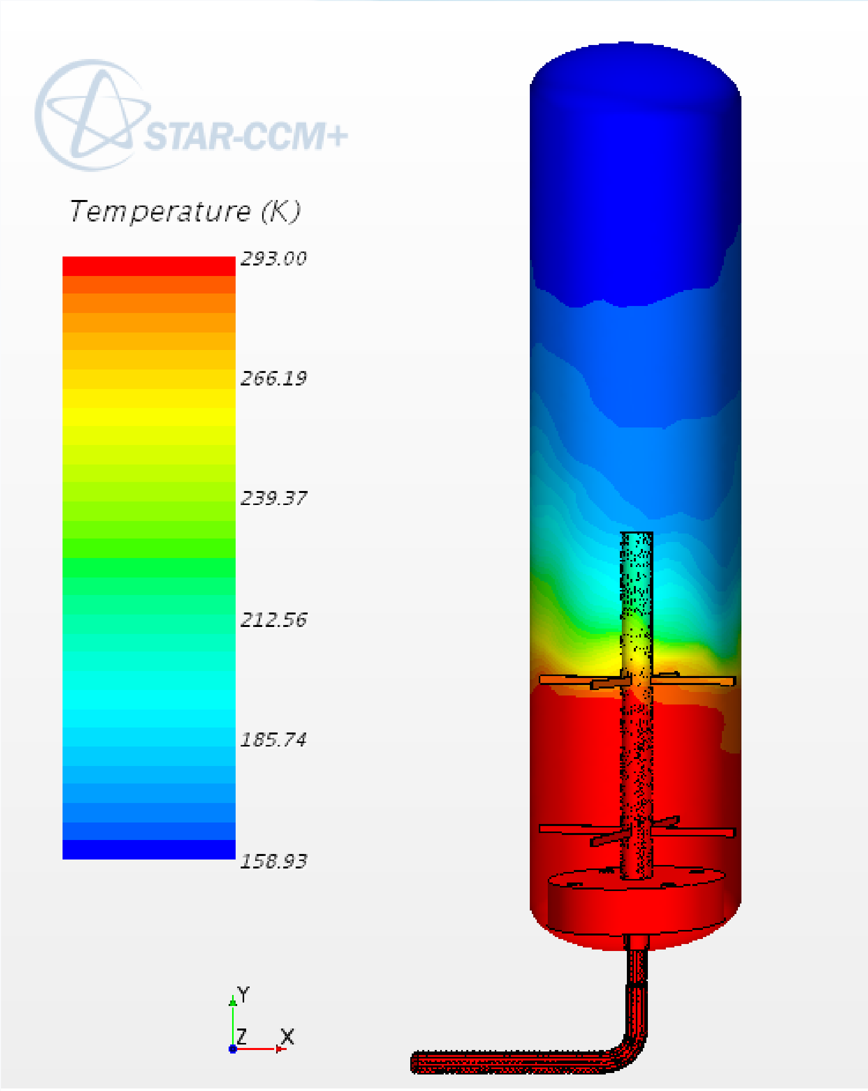
- The SIT of APR1400 was analyzed using CFD.
- Calculation using CFD was performed to compare with experiment.
- A coarse grid calculation was performed along with a fine grid calculation.
- Overall, the curve trend of CFD result followed the experimental result well.
- K-factors of SP and CP remained nearly constant.
- FFT Analysis was done to check for oscillating behavior within Fluidic Device.
- After thorough investigation of flow structure in the Fluidic Device, optimization can be performed.

THANK YOU

Temperature Distribution

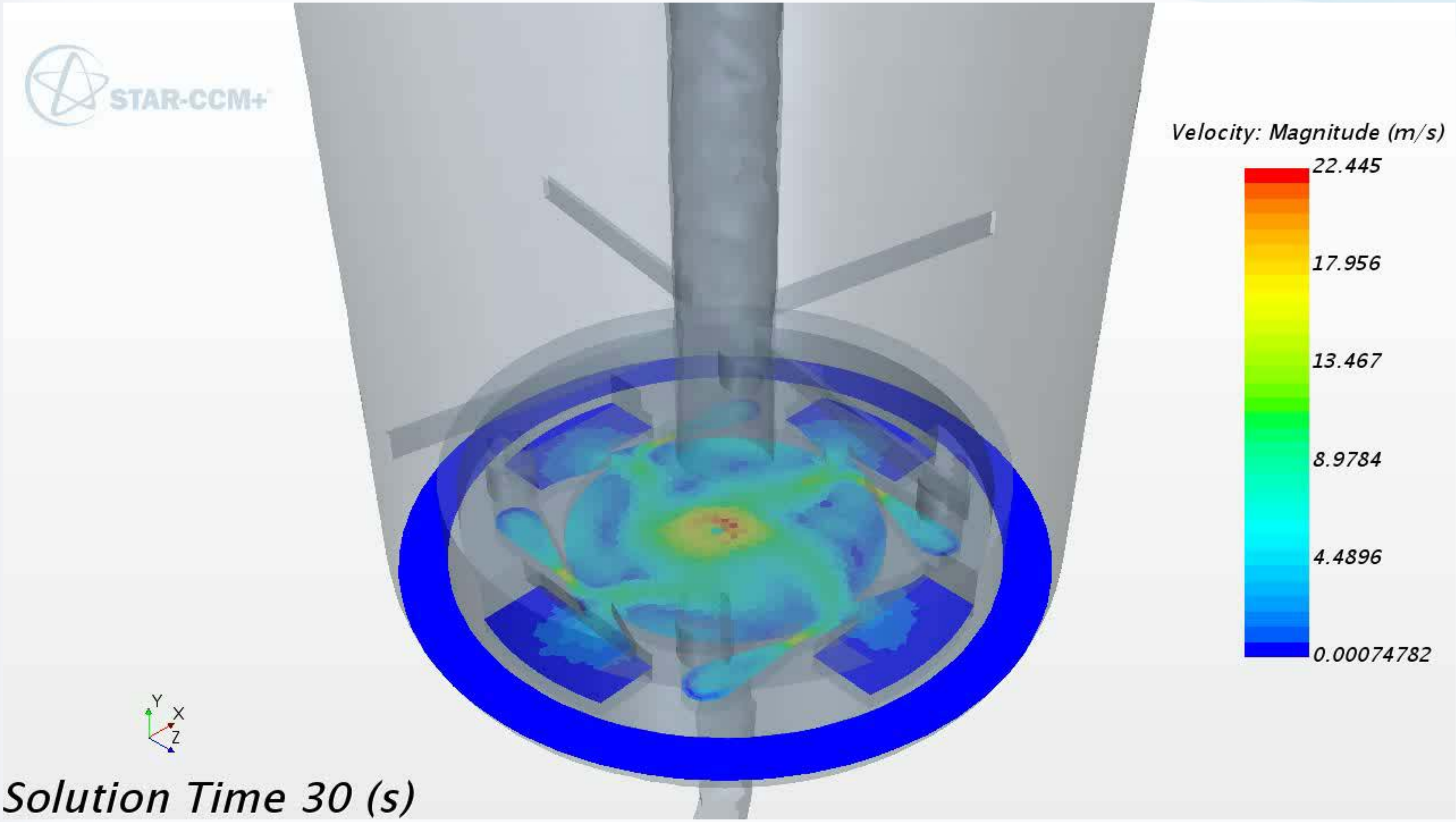


- High Flow Mode



- Low Flow Mode

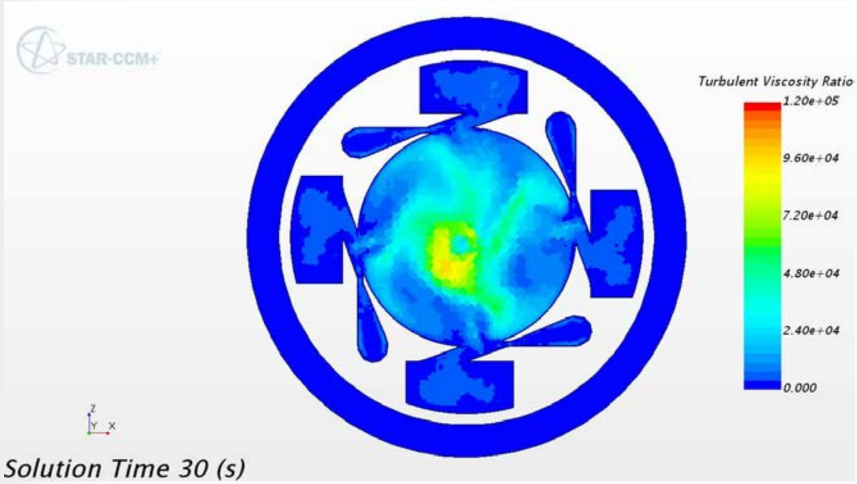
Animation



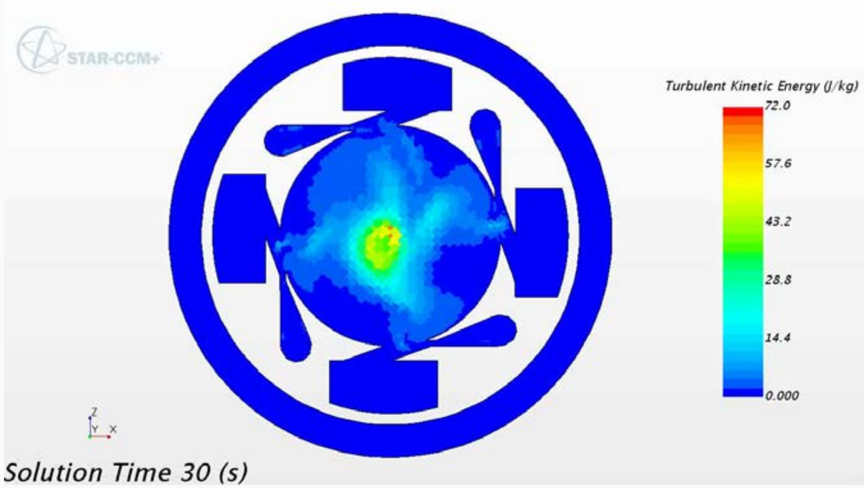
Velocity in Fluidic Device

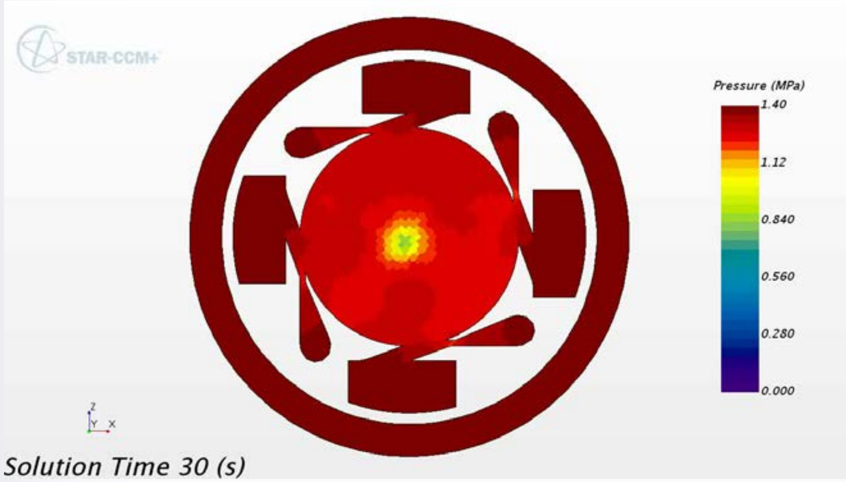
Animation

Turbulent Viscosity Ratio

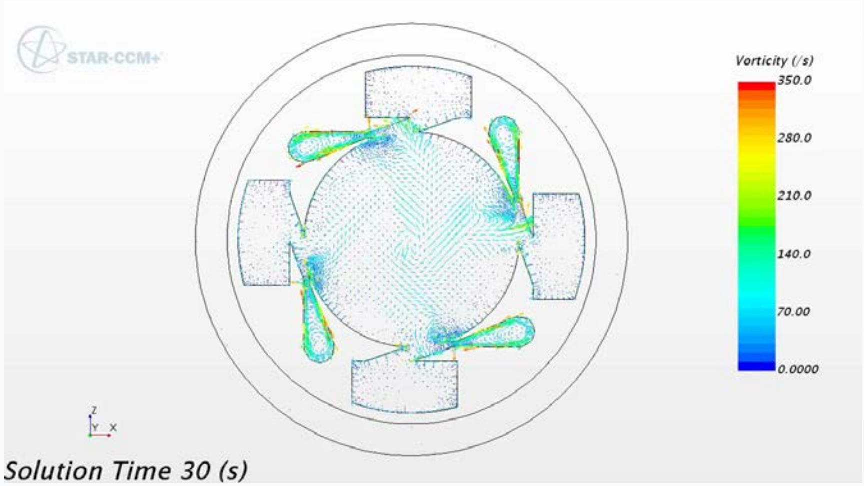


Turbulent Kinetic Energy





Pressure



Vorticity