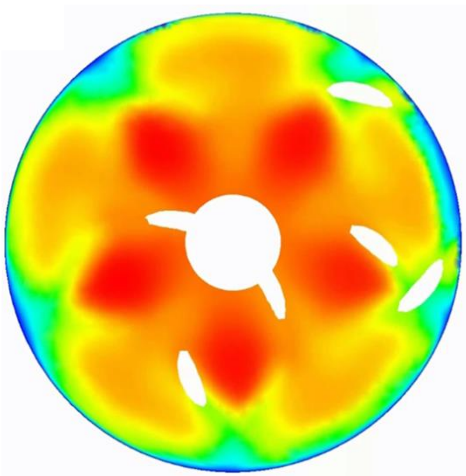
The Practical Uses of Computational Fluid Dynamics – Not Just a Pretty Picture



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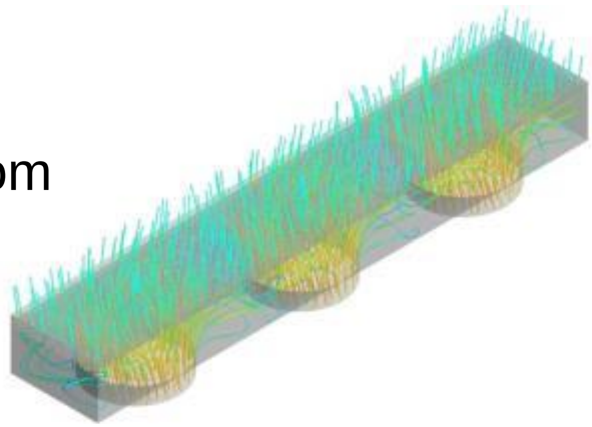

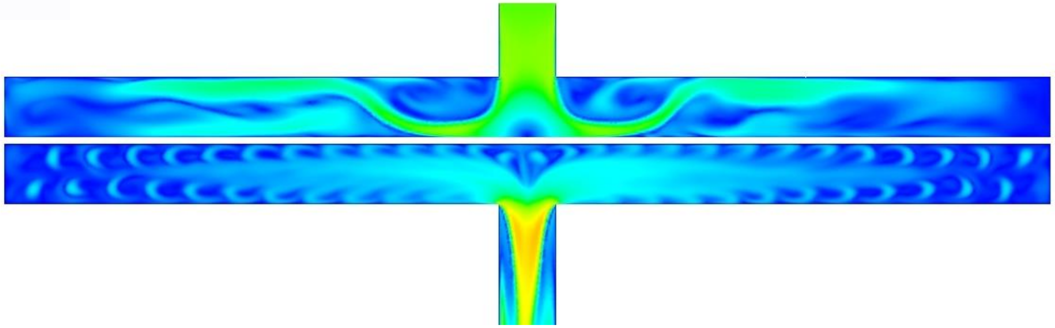

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- **Case Study 5:** Temperature Pinch
- **Conclusion**

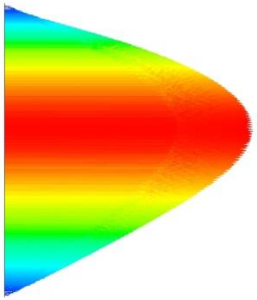
Introduction

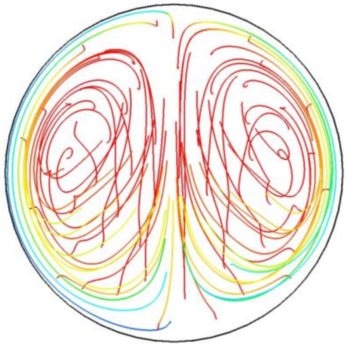
- **Software used:**
  - CFD: ANSYS CFX
  - Geometry: ANSYS DesignModeler

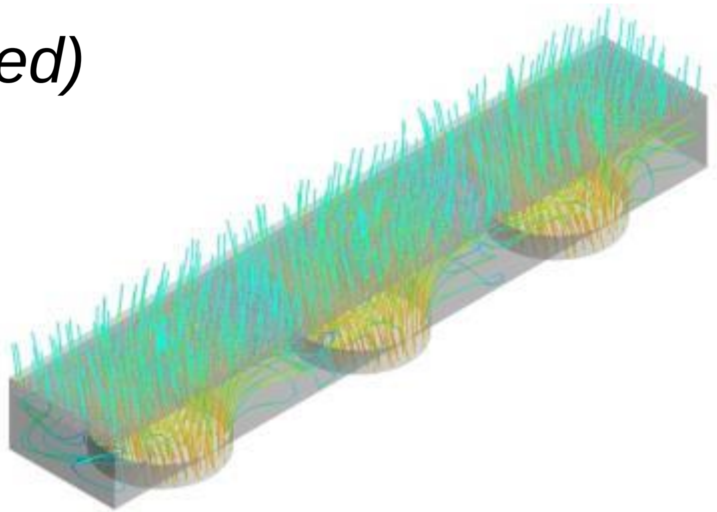
- **Heat Transfer:** Heating and Cooling Investigated

- **Reynolds range:** Laminar and *Turbulent*

- **Turbulence Model***: k-ε (when needed)*







Case Study 1:

Air Cooled Heat Exchanger (ACHE)

Problems related to bypass and flow distribution

Why use Computational Fluid Dynamics to Investigate Air coolers?

- **Air coolers are designed using empirical correlations that use assumptions such as:**
  - ➢ **all** the liquid entering the header subsequently flows through tubes
  - ➢ **perfect** air distribution over the bundle

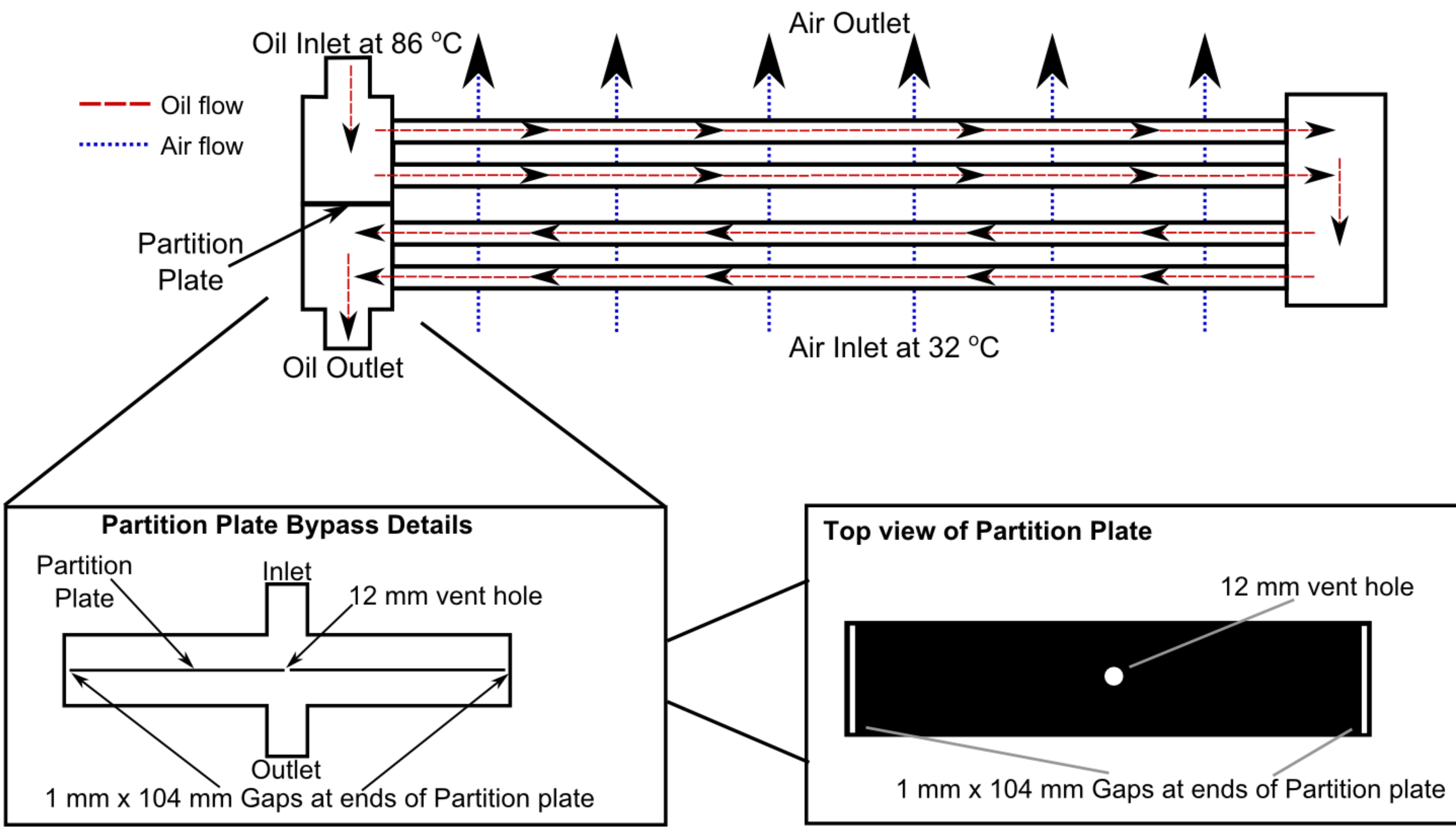
- **When built, the mechanical design and build quality / tolerances can have a profound effect on such assumptions**

- **CFD can be used to investigate those shortcomings and the effects on performance**

Bypass Problem Description

- User of lube oil Air Cooled Heat Exchanger reports significant underperformance
- Measured 50% less pressure drop than design calculations
- Lower than expected tube side pressure indicates bypass around tube bundle
- Possible causes:
  - Vent hole in partition plate
  - Missing / broken welds between partition plate and header walls

Air Cooled Heat Exchanger Geometry

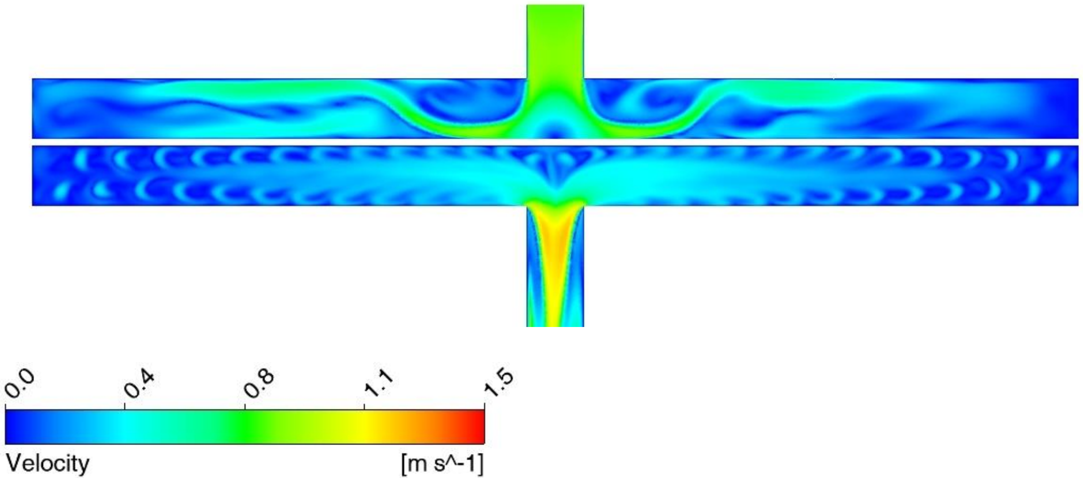


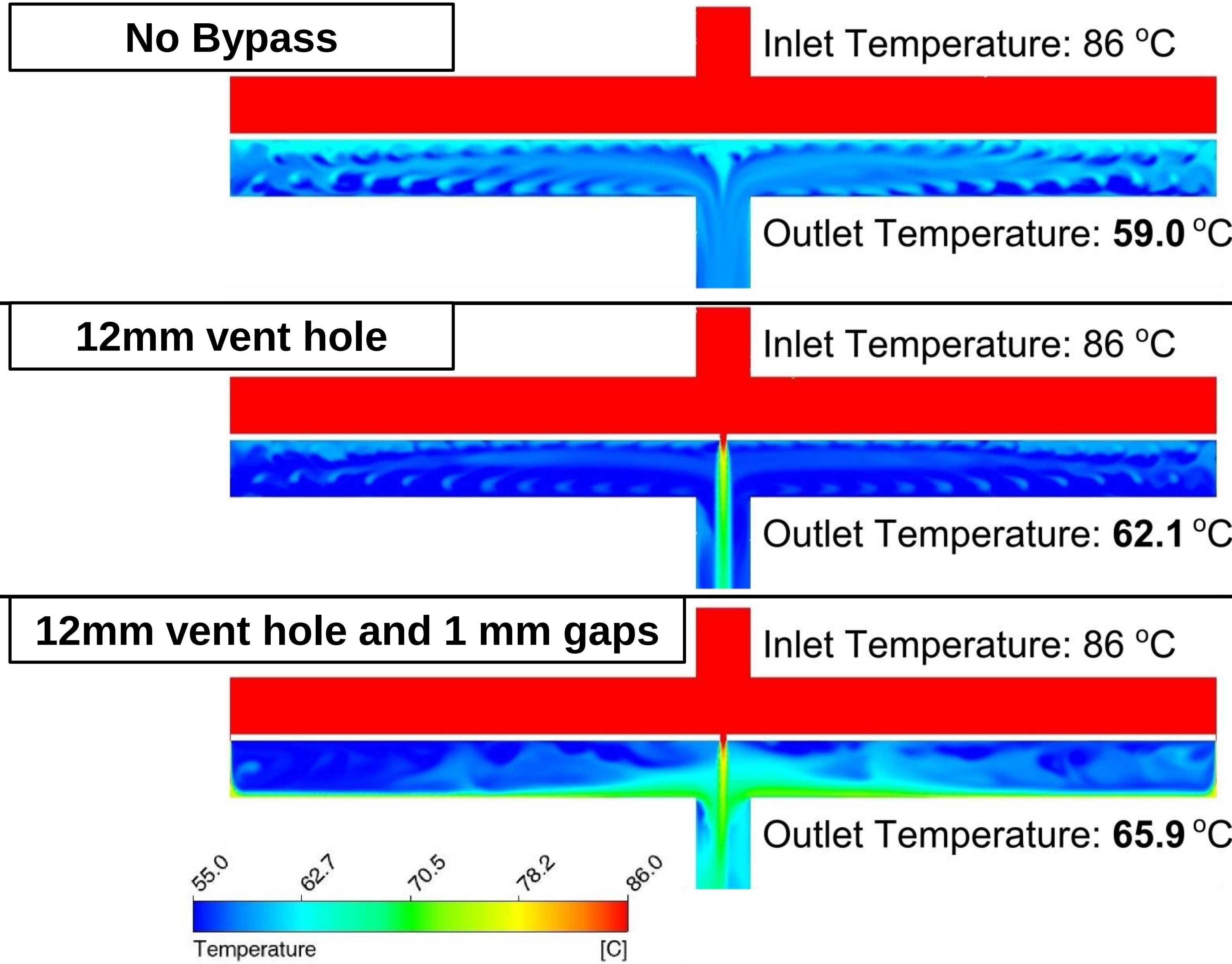
1. No Bypass, 2. 12mm vent hole and 3. 12mm vent hole and side gaps

Verification of CFD simulations

- By comparing the no bypass geometry with: tube side pressure drop (nozzles, header and tubes) results with heat exchanger design software

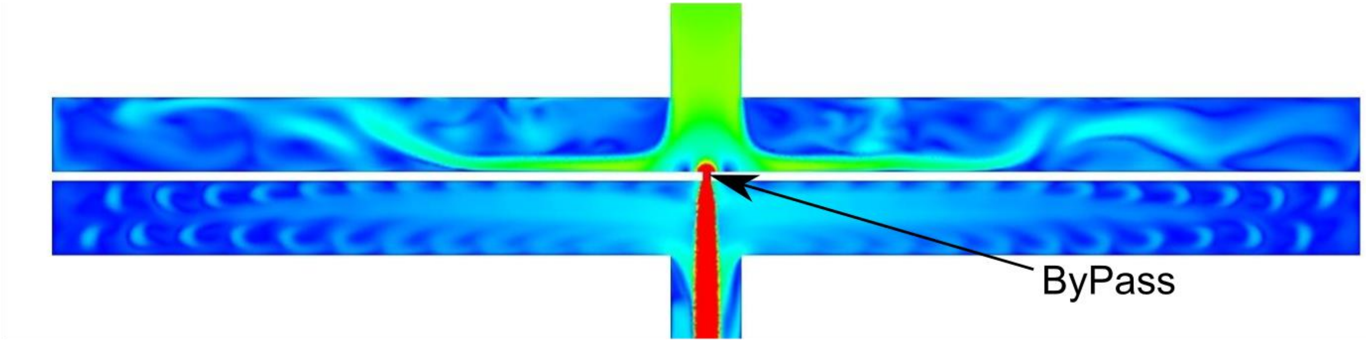
- CFD simulation results within 8% of calculated pressure drop from heat exchanger design software




No Bypass
Inlet Temperature: 86 °C
Outlet Temperature: 59.0 °C
12mm vent hole
Inlet Temperature: 86 °C
Outlet Temperature: 62.1 °C
12mm vent hole and 1 mm gaps
Inlet Temperature: 86 °C
Outlet Temperature: 65.9 °C
55.0
62.7
70.5
78.2
86.0
Temperature
[C]

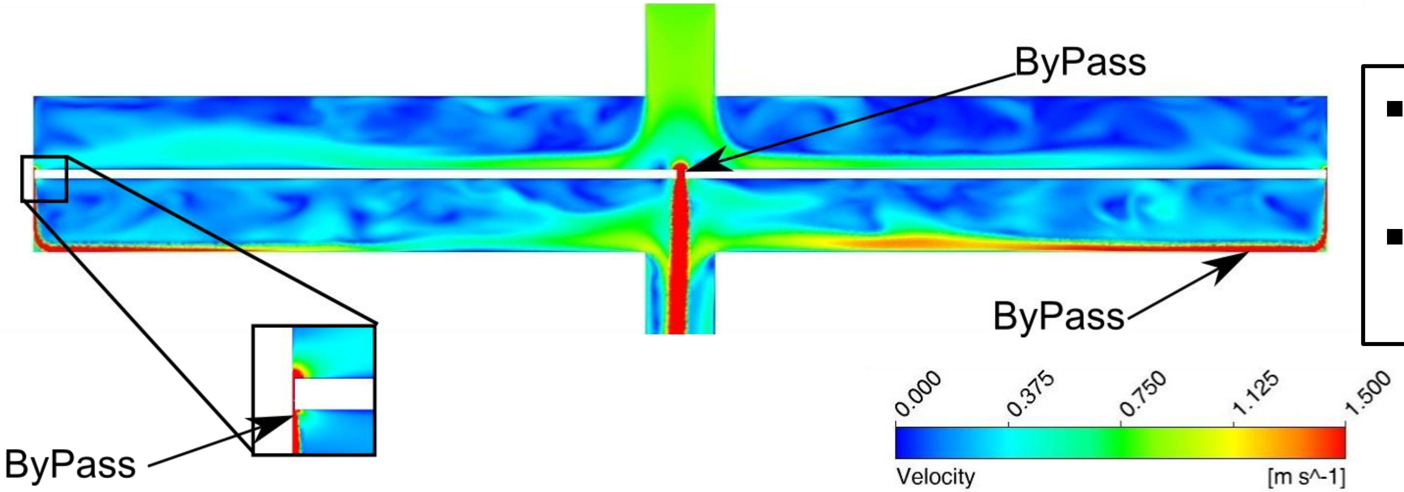
Results

- **12 mm vent hole = 20% mass flow bypass**

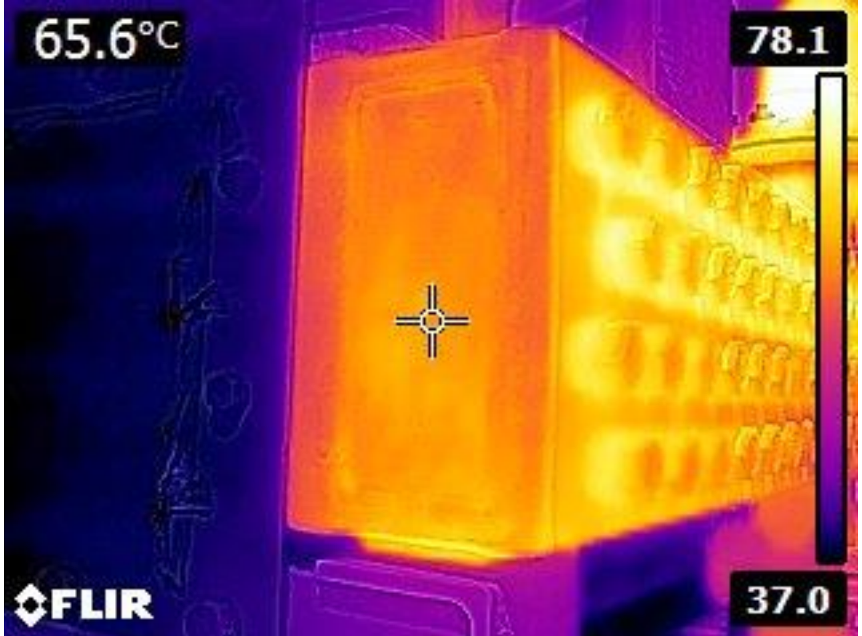
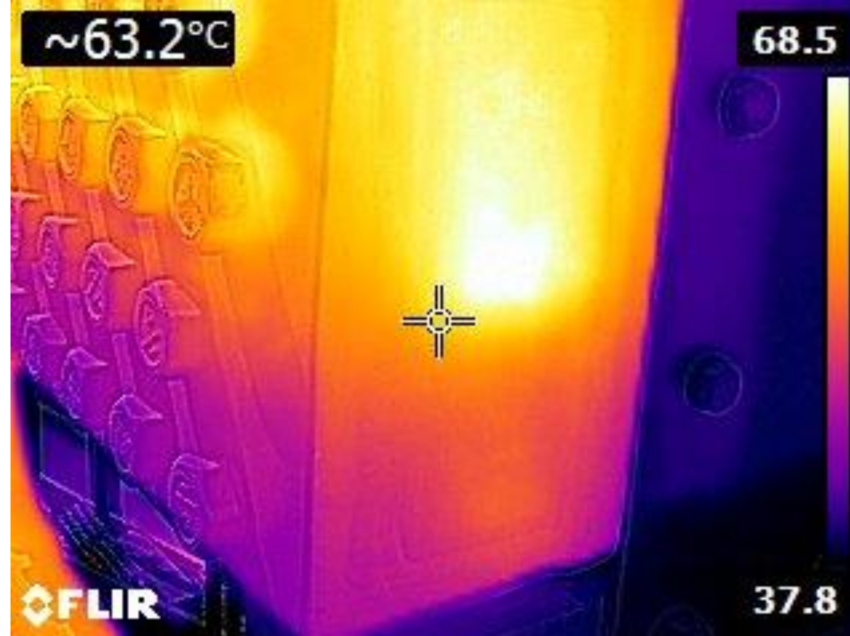
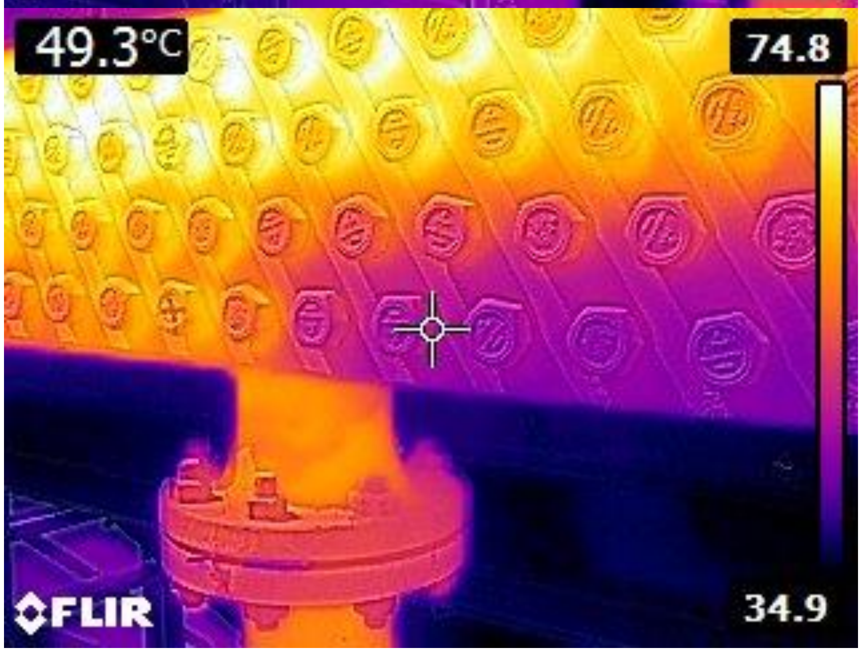


- **35% reduction in pressure drop**
- **11% reduction in duty**

- **12mm vent hole and 1mm gaps = 42% mass flow bypass**



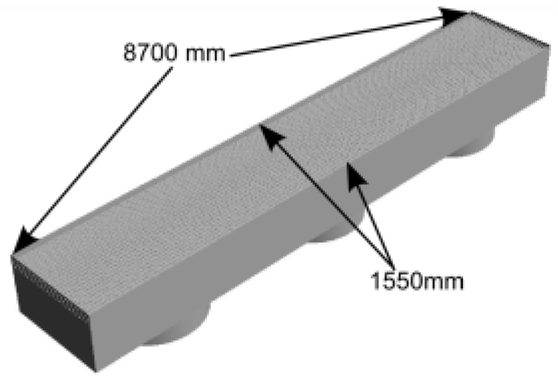
- **64% reduction in pressure drop**
- **27% reduction in duty**

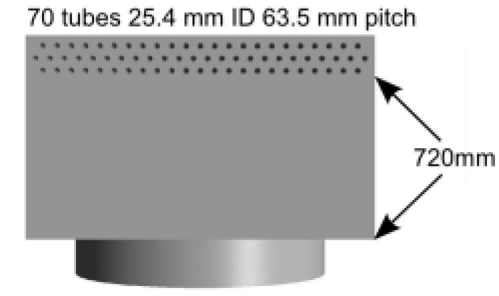

65.6°C
78.1
37.0
FLIR

~63.2°C
68.5
37.8
FLIR

49.3°C
74.8
34.9
FLIR

~55.8°C
76.6
39.3
FLIR

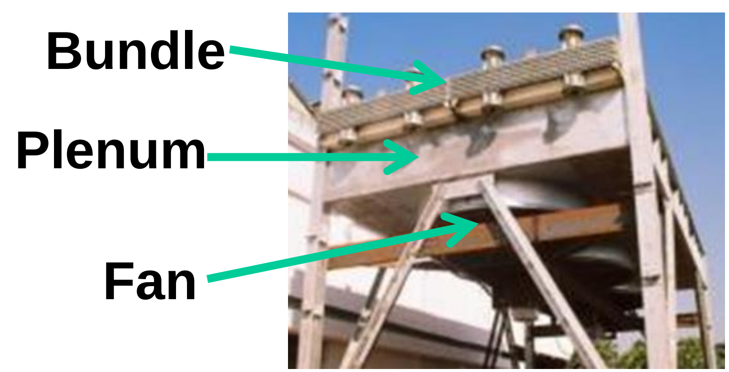
Simulation Scenarios

- **API 661 Recommended 40% fan coverage**





- **Equations used to describe fan air flow**
- **Same total mass-flow for each scenario**
- **Three plenum depths for the three fan layout:**
  - **500mm**
  - **720mm**
  - **1000mm**



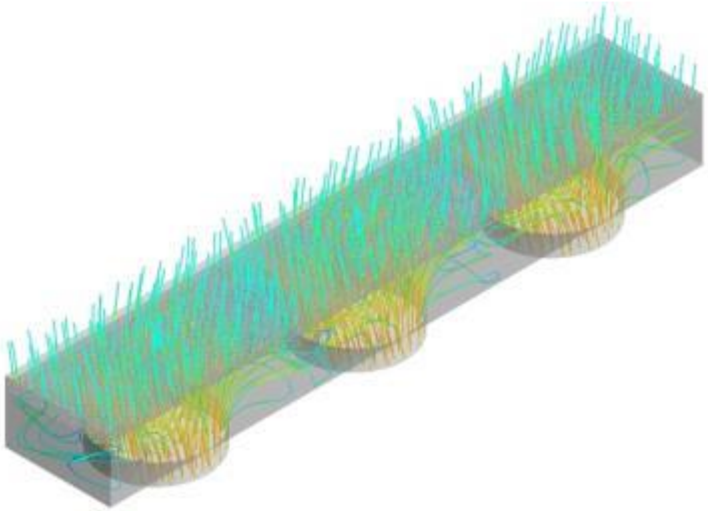
Verification and Results

- **CFD results compared with Equation:**

$$\Delta P_A = \left(2 * f_b * Nr * \left(\rho * V_{max}\right)^2\right) / \rho$$

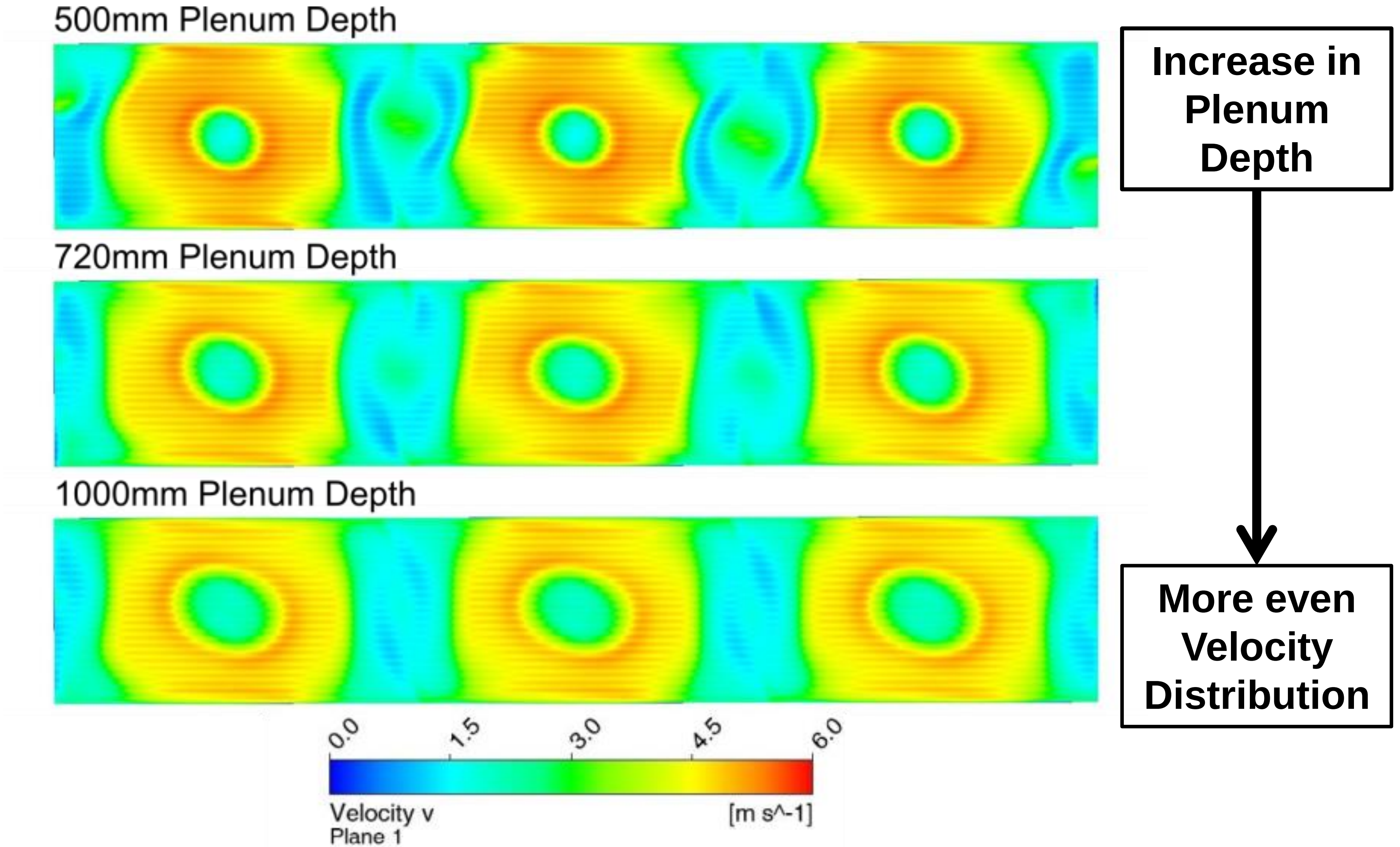
Equation commonly used to calculated cross flow air pressure drop though a tube bundle(Serth and Lestian (2014))

- **Eq 2 gives ΔP_A= 86.4 Pa**
- **CFD gives ΔP_A= 88.4 Pa**
- **CFD model accurately predicts the air flow**

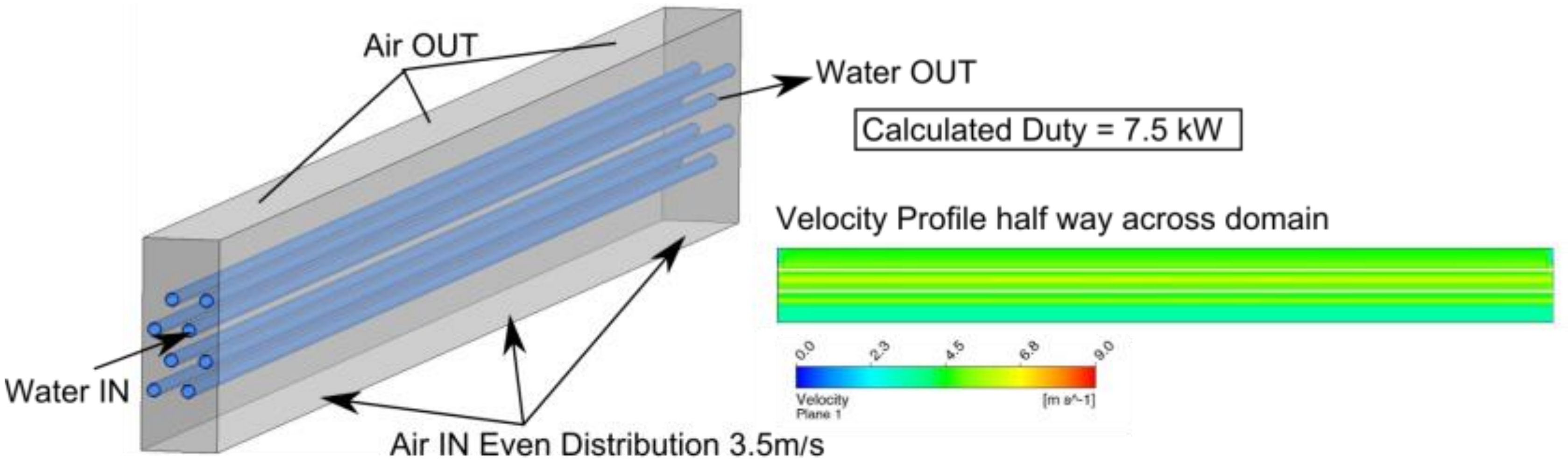


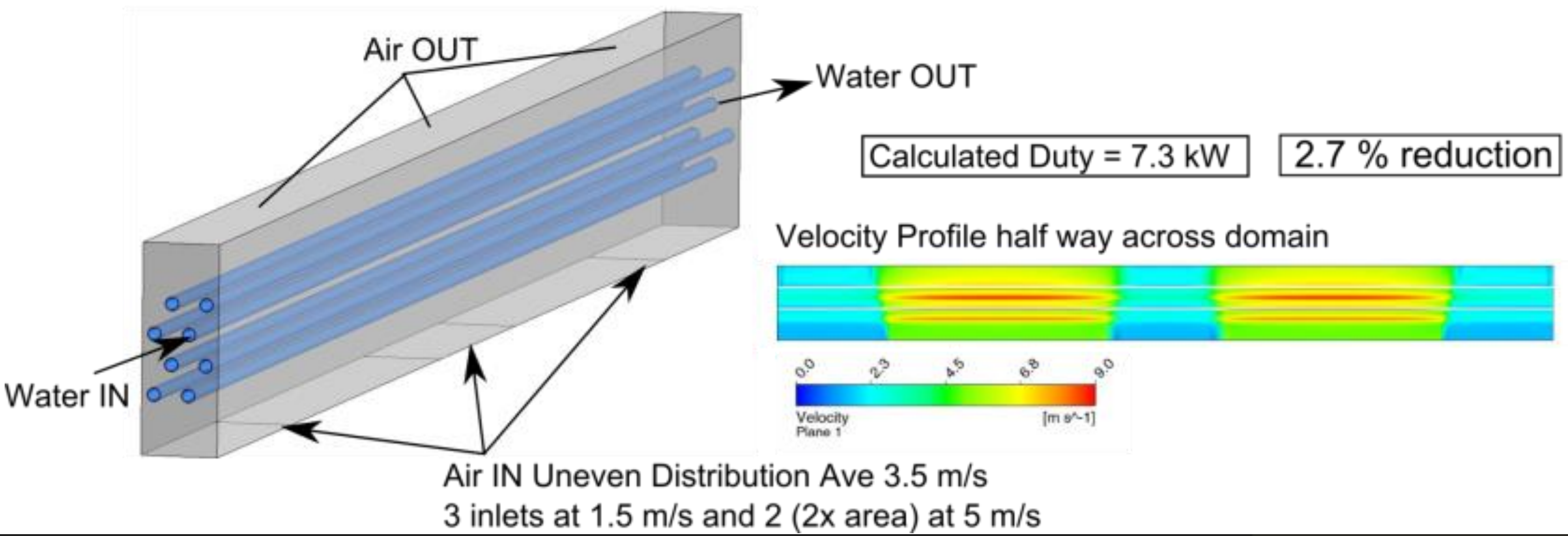
Serth R.W., Lestian T., 2014, Process Heat Transfer (2nd Edition), Academic Press, Elsevier.

Effect of Increased Plenum Depth



Effects of Maldistribution on Heat Transfer





Conclusions

- **Care should be taken in sizing vent holes and pass partition welds to avoided bypass to ensure correct performance**
- **Increased Plenum depth improved distribution**

Case Study 2:
Shell and Tube Heat Exchanger Maldistribution

Thermal Resistance, %	
Shell	18.96
Tube	58.61
Fouling	20.72
Metal	1.71

Service:

- Heat recovery for hydro treatment reactor

Problem description:

- Calculated performance should be 60% higher
- No spare capacity of fired heater to increase throughput

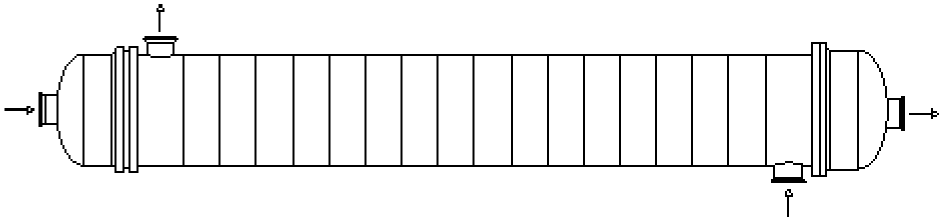
Shells:	TEMA: AES 3 in series; 2 in parallel;
Bundle:	
Tubes:	2521; 1pass 20mm x 1.8mm x 9m
Calculated Exchanger Performance	
Tube side dp calc / allow.	**2.5kPa** / 45 kPa
Shell side HTC	900 W/m^2K
Tube side HTC	**285 W/m^2K**
Duty	Measured 20 MW / real +60%

CFD Simulation of Bundle Maldistribution

Expected severe fluid maldistribution in the bundle on tube side

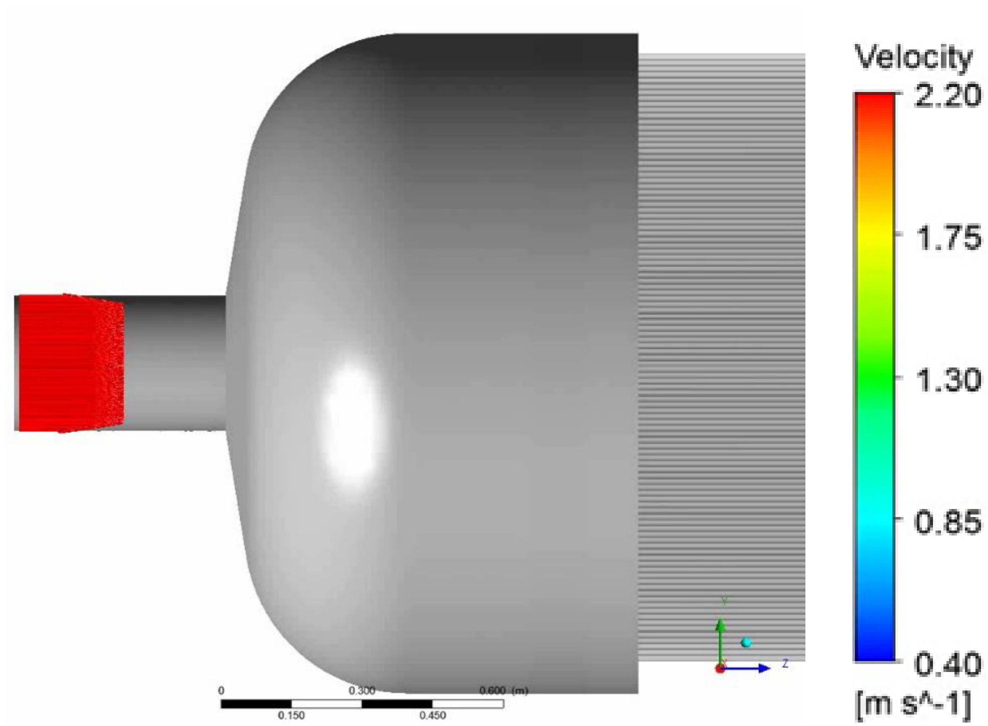
- Tube side pressure drop of 2.5 kPa, this is very low. 85% of which is in the nozzles (allowable tube side pressure drop 45 kPa!)

- Axial Tube side nozzles contribute to maldistribution

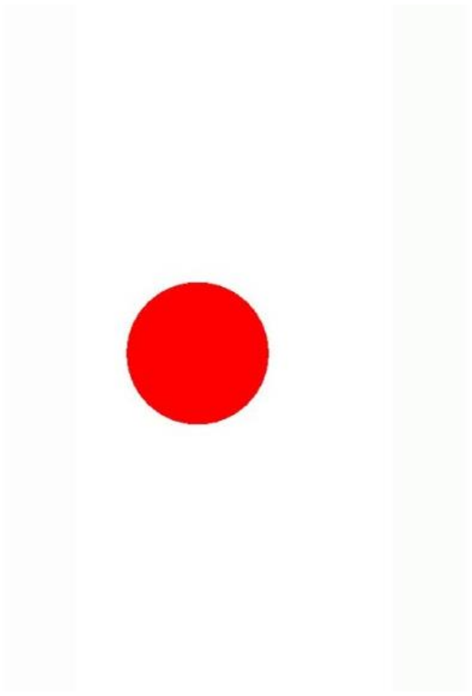


Higher tube side pressure drop would be beneficial

CFD Simulation of Bundle Maldistribution



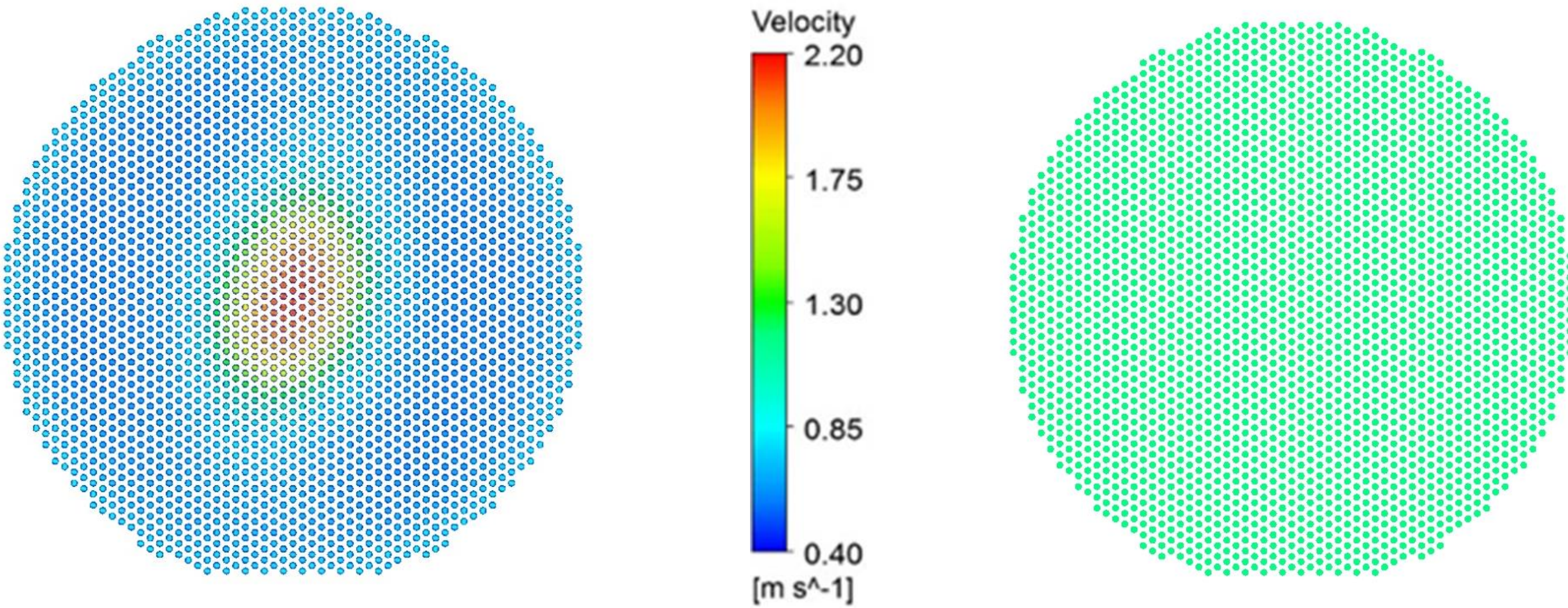
side view



plane

CFD Simulation of Bundle Maldistribution

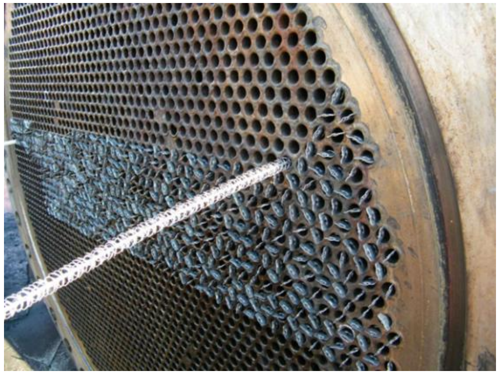
	before (empty)	after (hiTRAN)
Tube pressure drop	2.5 kPa (>85% nozzles)	20 kPa (~10% nozzles)



Plain empty

hiTRAN

hiTRAN installation and benefits

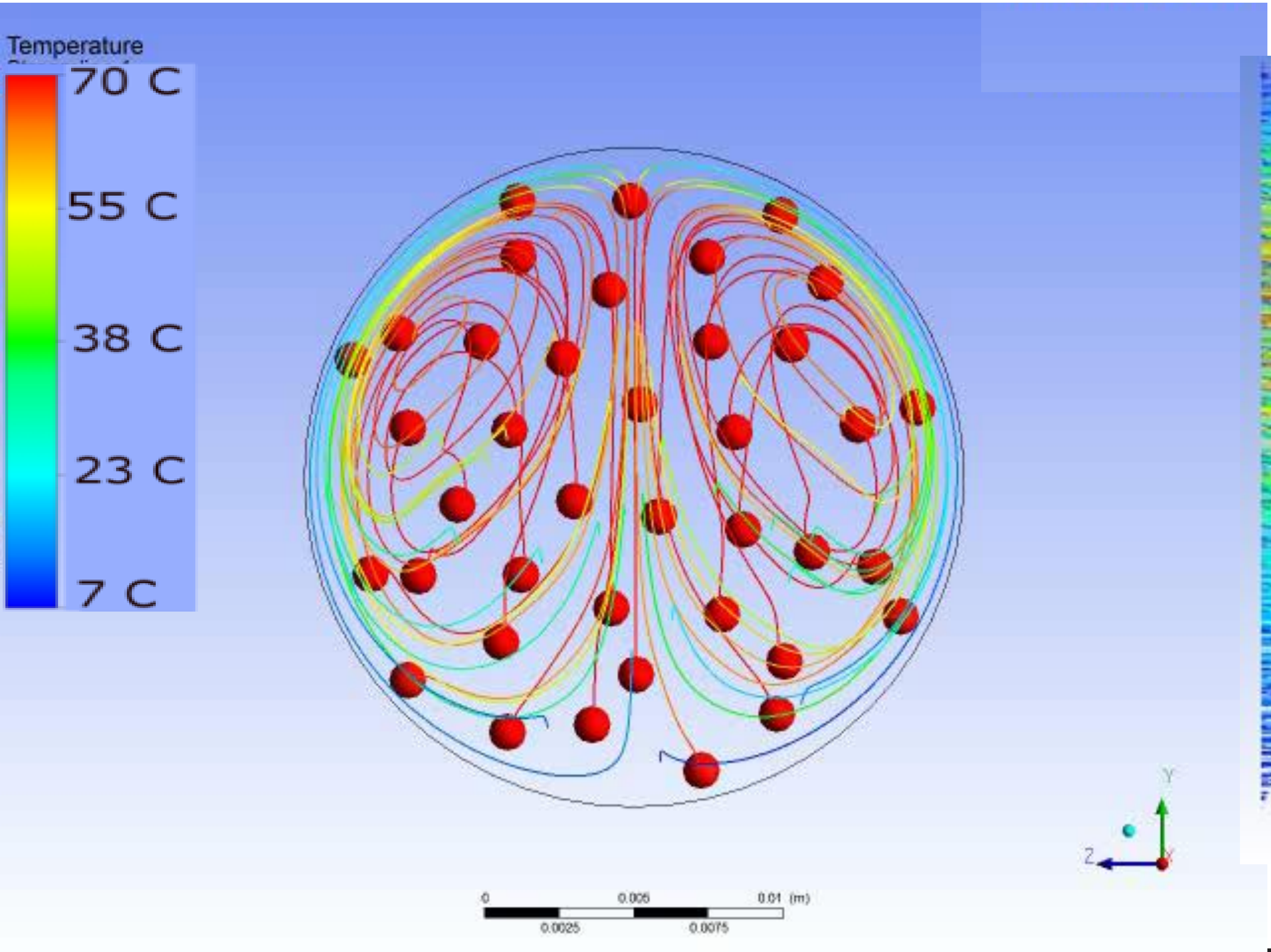


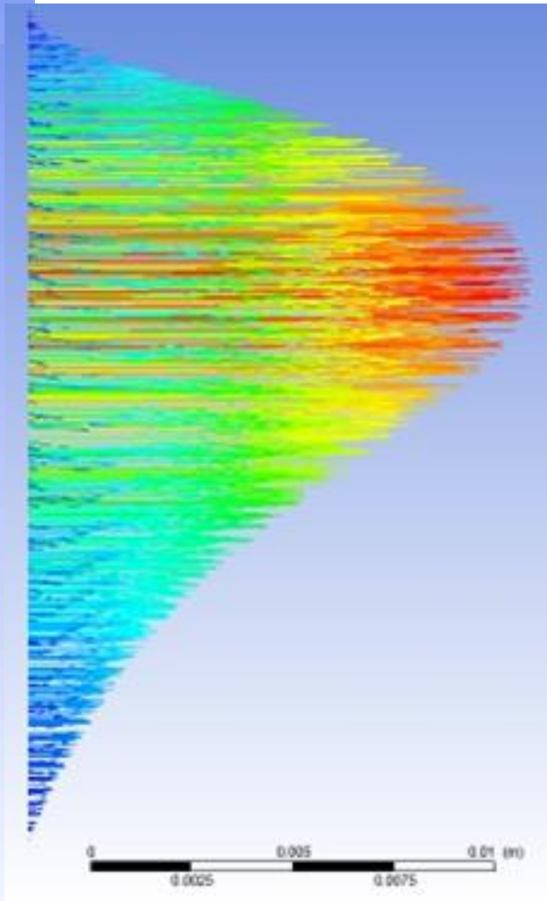
	before (empty)	after (hiTRAN)
Tube pressure drop	25mbar (>85% nozzles)	200mbar (~10% nozzles)
Tube side heat transfer	<285 W/m2K	~980W/m2K
Shell feed outlet temp	240 ℃	314 ℃
Tube effluent outlet	115	82
Mass flow	27kg/sec	**42kg/sec**
Load on fired heater	4.2MW	2MW

Annual energy savings of $ 233000

Case Study 3:
Research and Development

Fluid movement, cooling
Re 253, 70℃ inlet and 7℃ wall

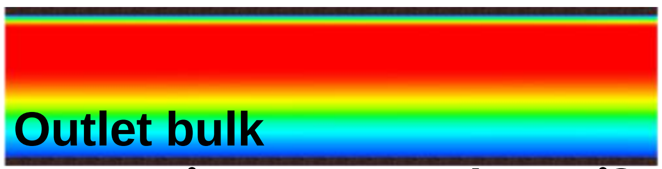


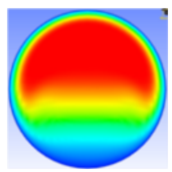


CFD Simulation Plain empty tube

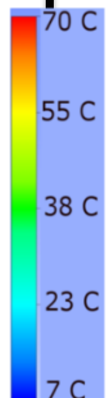
Simulation verified with experimental data for different Reynolds numbers
70 ℃ Inlet temperature; 7 ℃ Wall temperature, 2.5m tube length; Viscosity 12cP

Reynolds 253

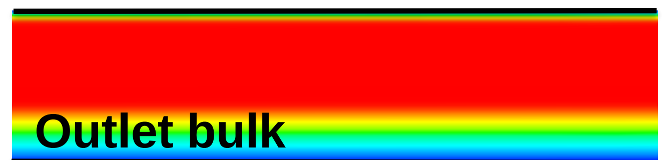


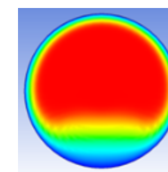


CFD 62 ℃; measured 61.8 ℃

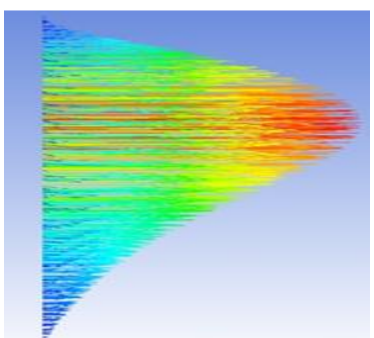


Reynolds 935





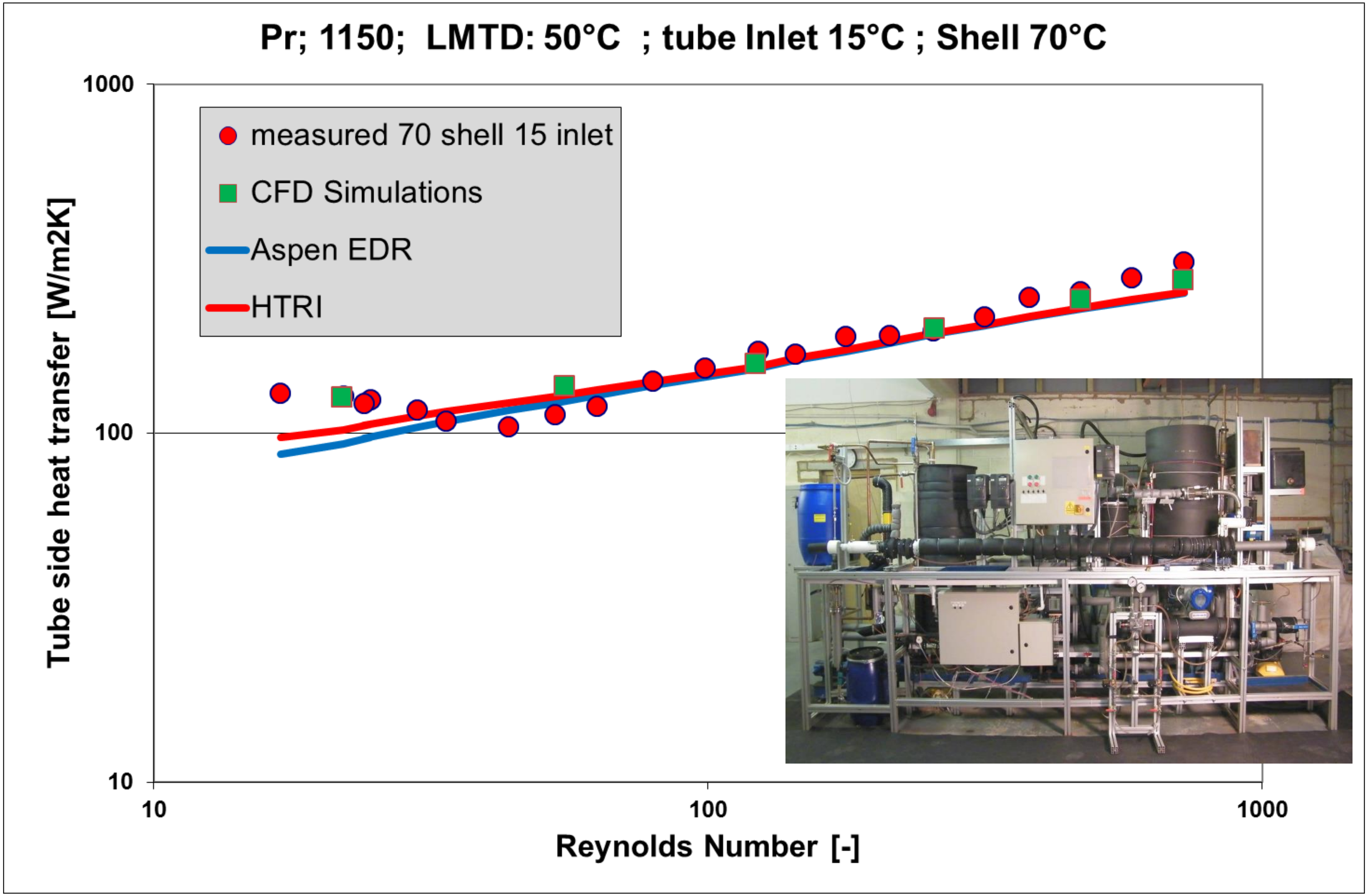
CFD 66.2 ℃; measured 66.2 ℃

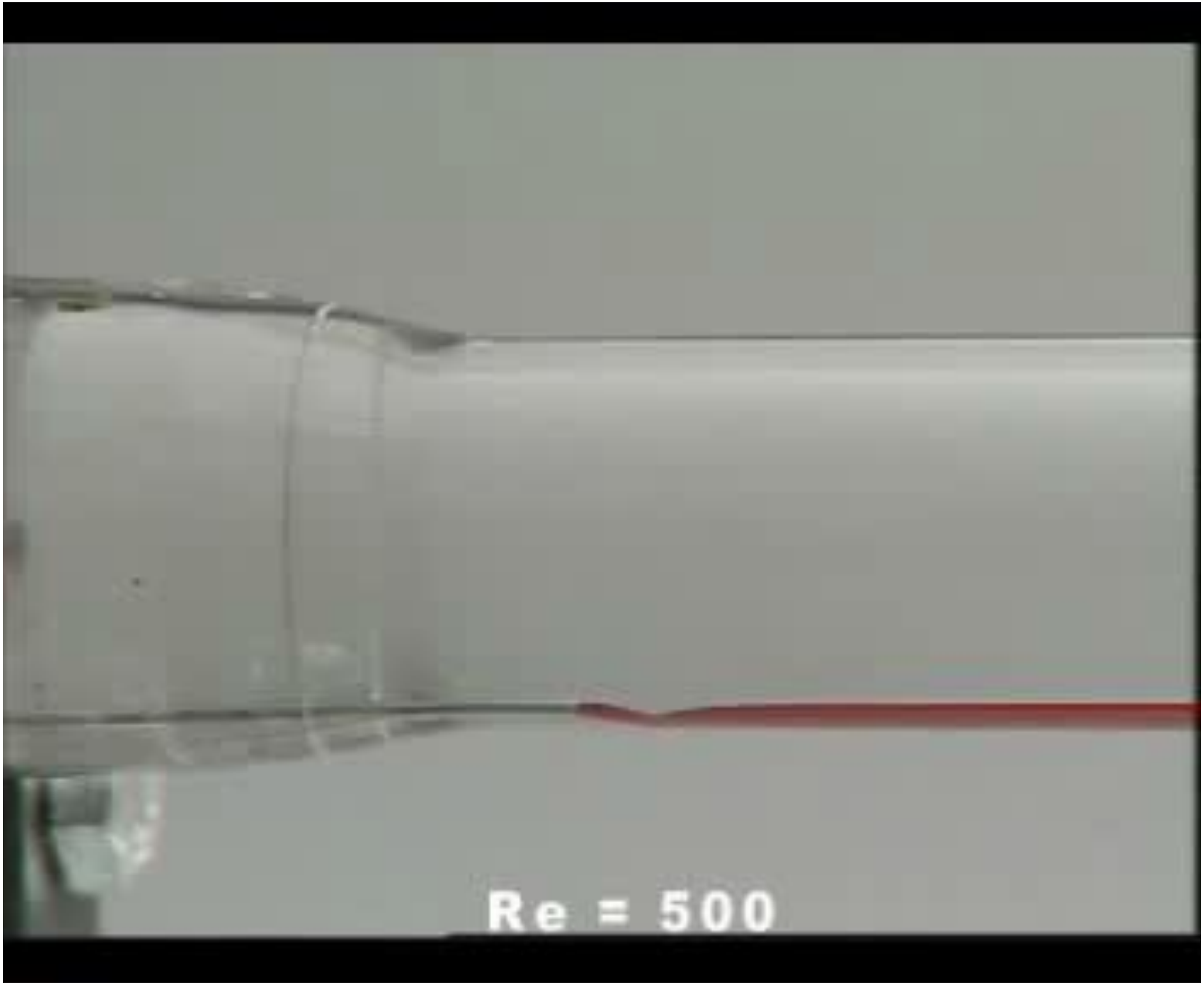


Velocity profile

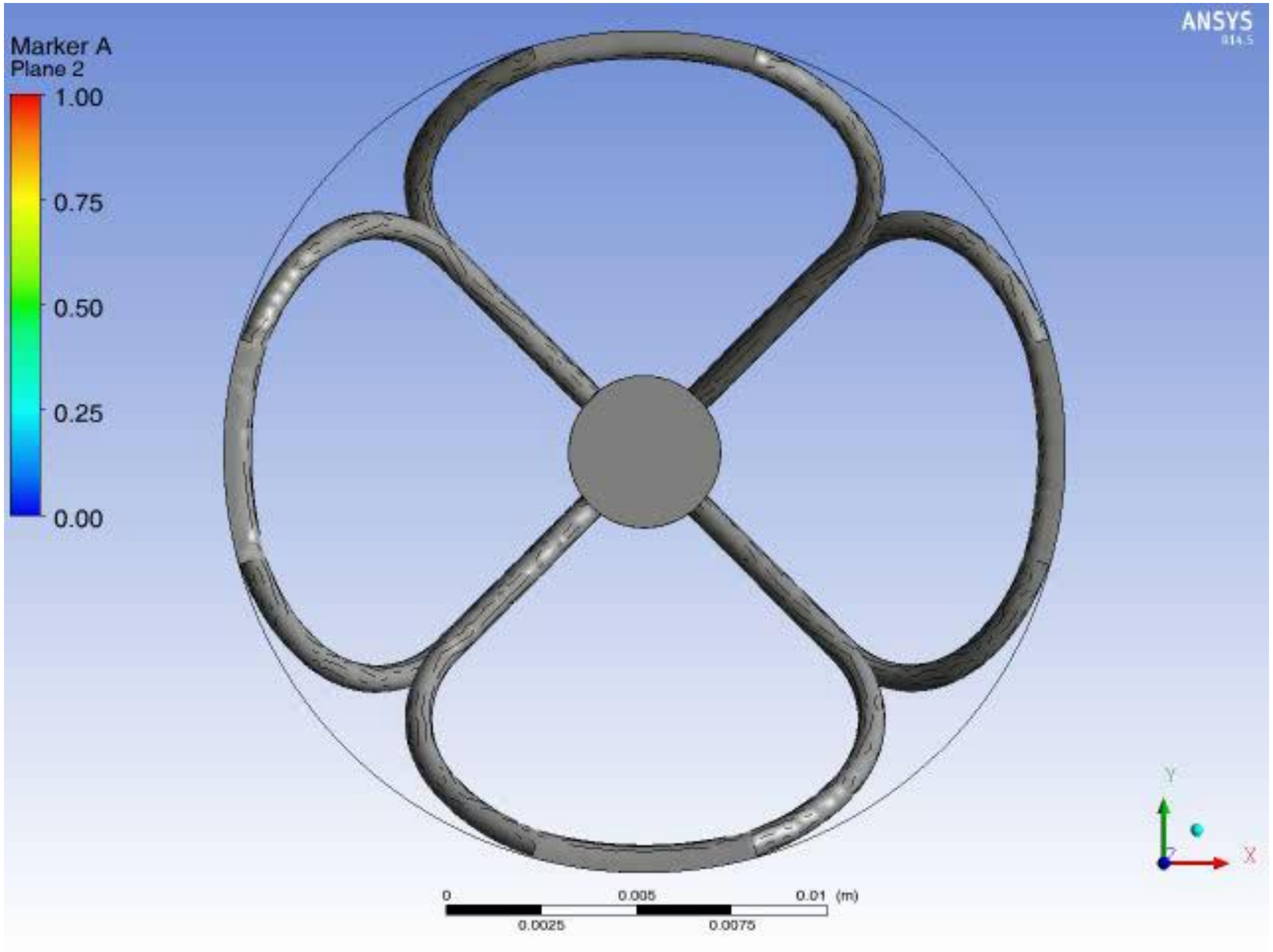
- Stratified flow
- Long residence time
  at bottom of tube
- Low heat transfer

Verifying CFD Simulation results with experiments




Re = 500

Dye Stream hiTRAN



Verifying CFD Simulation results with Cal Gavin heat transfer measurements for hiTRAN

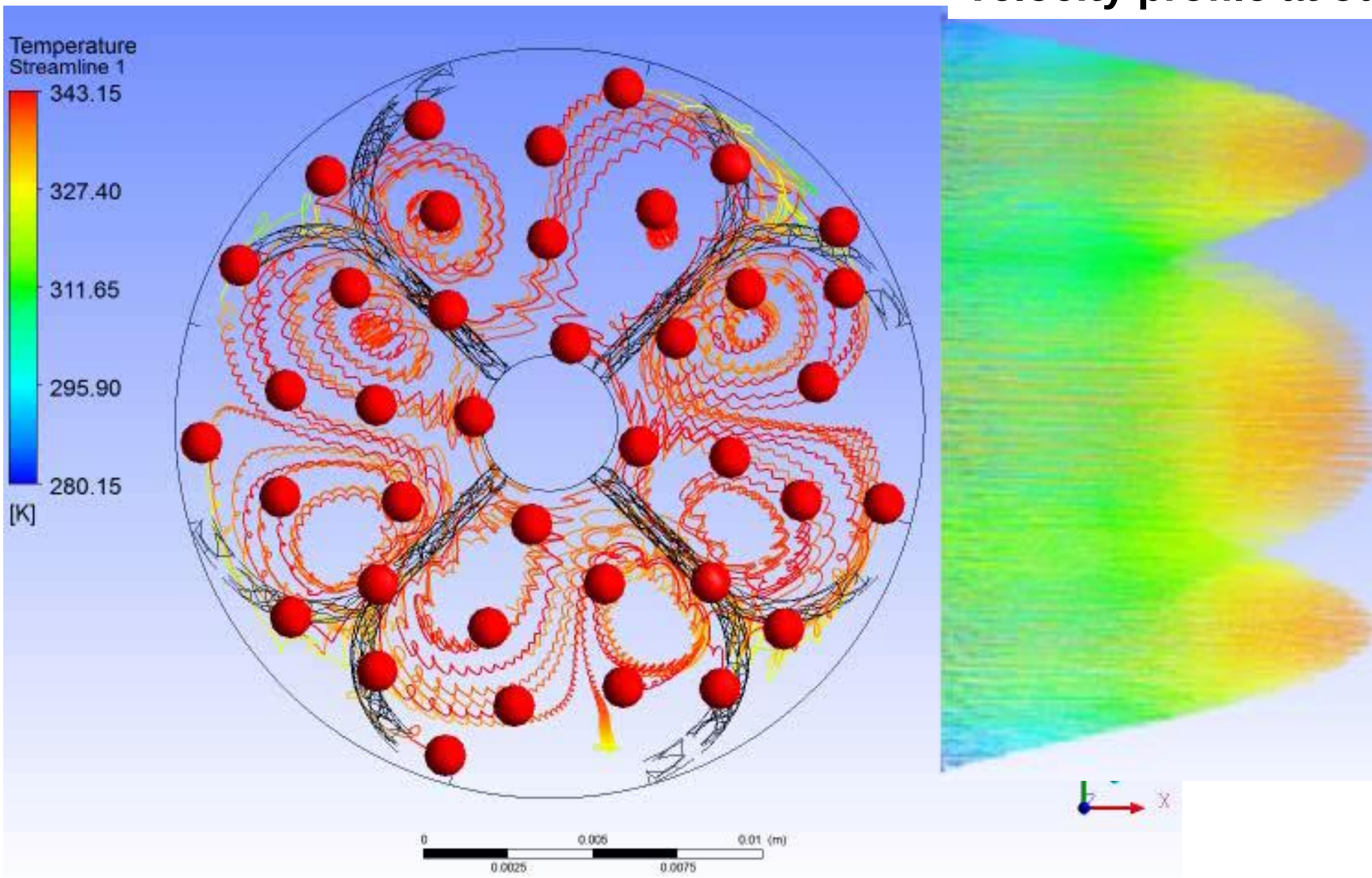
65˚C INLET Temperature, 40˚C Wall temperature, 1000mm test section

	Outlet Temperature (°C)		% dev
Reynolds number	CALGAVIN	CFD	
190	60.98	60.61	0.6
496	62.08	61.94	0.2
1014	62.71	62.61	0.16
1993	63.28	63.17	0.17

Fluid movement hiTRAN

Re 253, 70 ℃ Inlet and 7 ℃ Wall

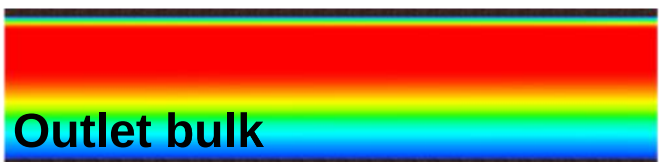
Velocity profile at outlet

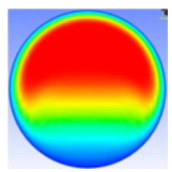


CFD Simulation Plain empty tube compared to enhance hiTRAN flow

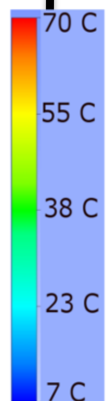
Example Simulation verified with experimental data:
70 ℃ Inlet temperature; 7 ℃ Wall temperature
2.5m tube length; Reynolds number 253; mass flow 195kg/hr; Viscosity 12cP

plain tube

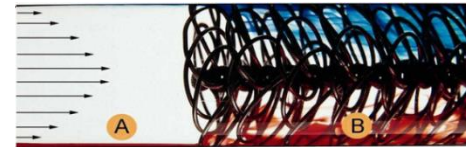


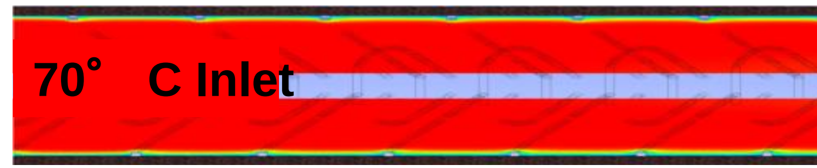


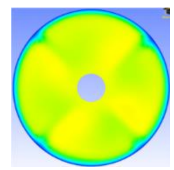
CFD 62 ℃; measured 61.8 ℃

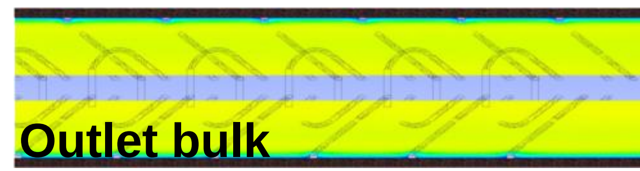


hiTRAN tube

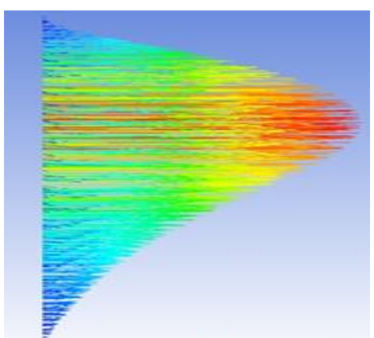






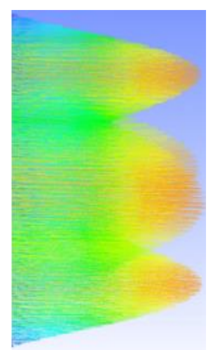


CFD 50.7 ℃; measured 49.9 ℃



- **Stratified flow**
- **Long residence time at bottom of tube**
- **Low heat transfer**

Velocity profile plain



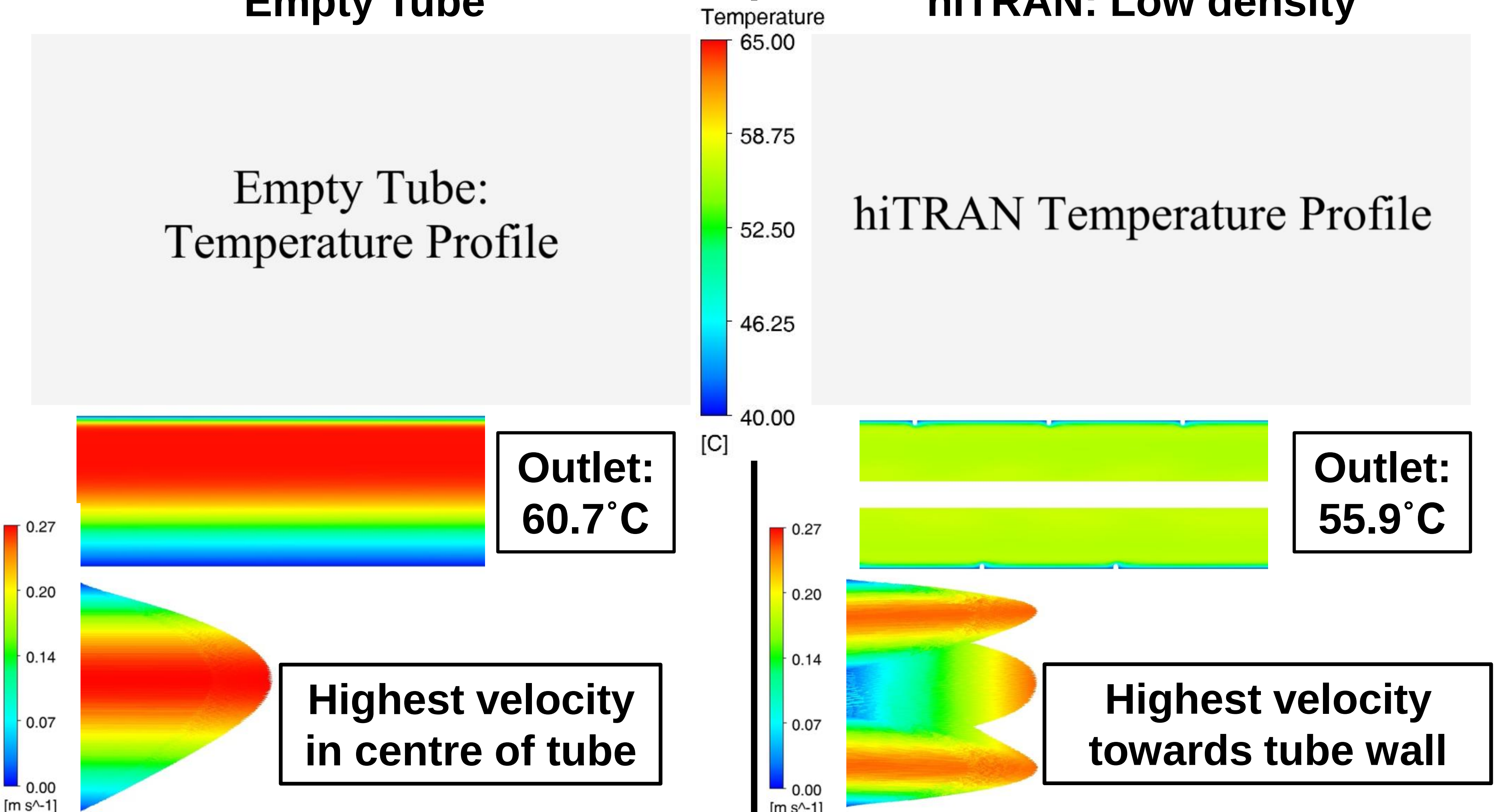
- **Good fluid distribution**
- **High heat transfer with low outlet temperature**

Velocity profile hiTRAN

Flow Stratification

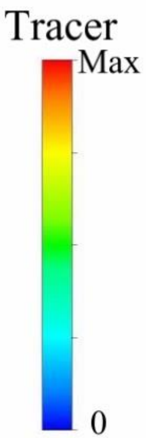
Tube ID: 22 mm, Tube Length: 2500mm, Reynolds number 190, Inlet 65˚C Wall 40˚C

Empty Tube | **hiTRAN: Low density**

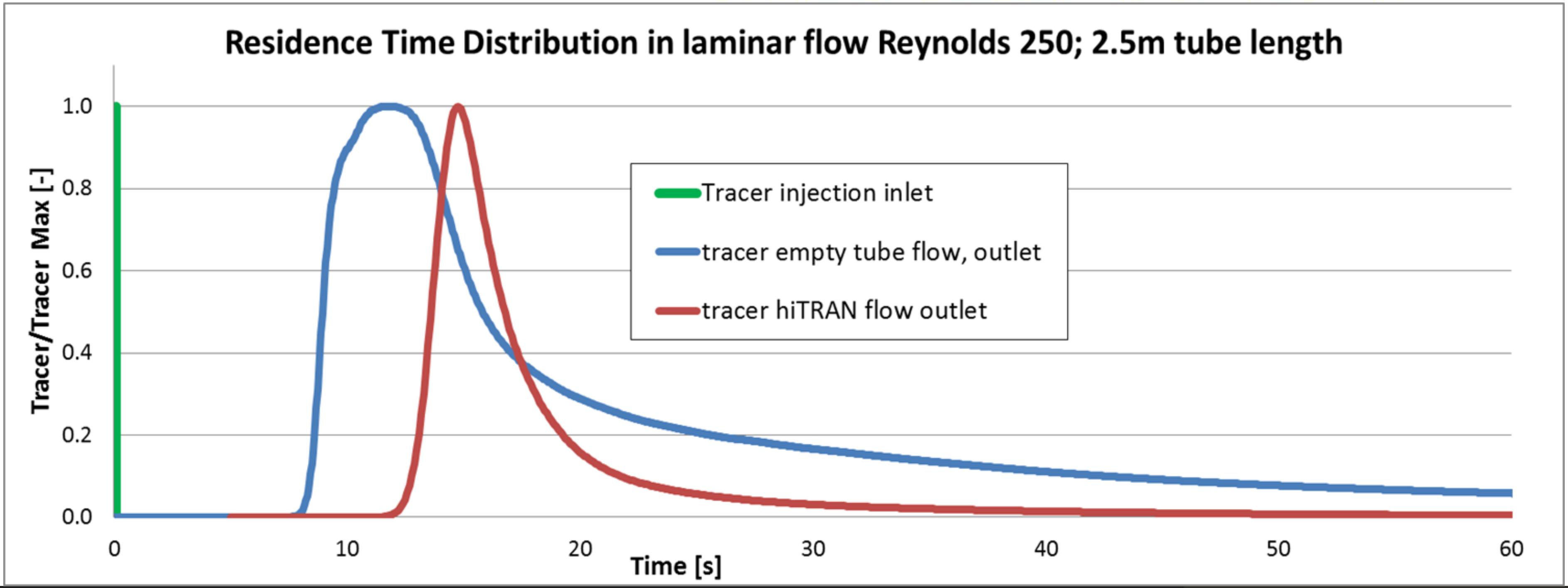


Residence time Distribution

Tracer at tube outlet, plain empty



Tracer at tube outlet, hiTRAN



Static mixer Heat Transfer – Heating Experimental and CFD comparison

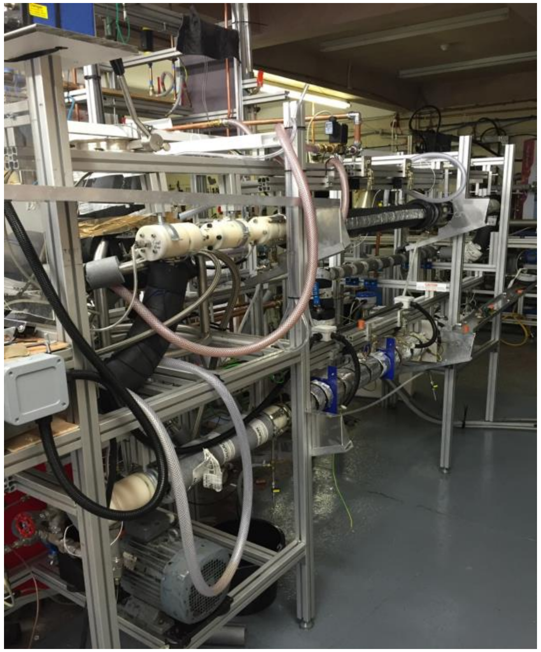
Fluid used: Glycerol

Viscosity: 350 cP at ~35 ˚C

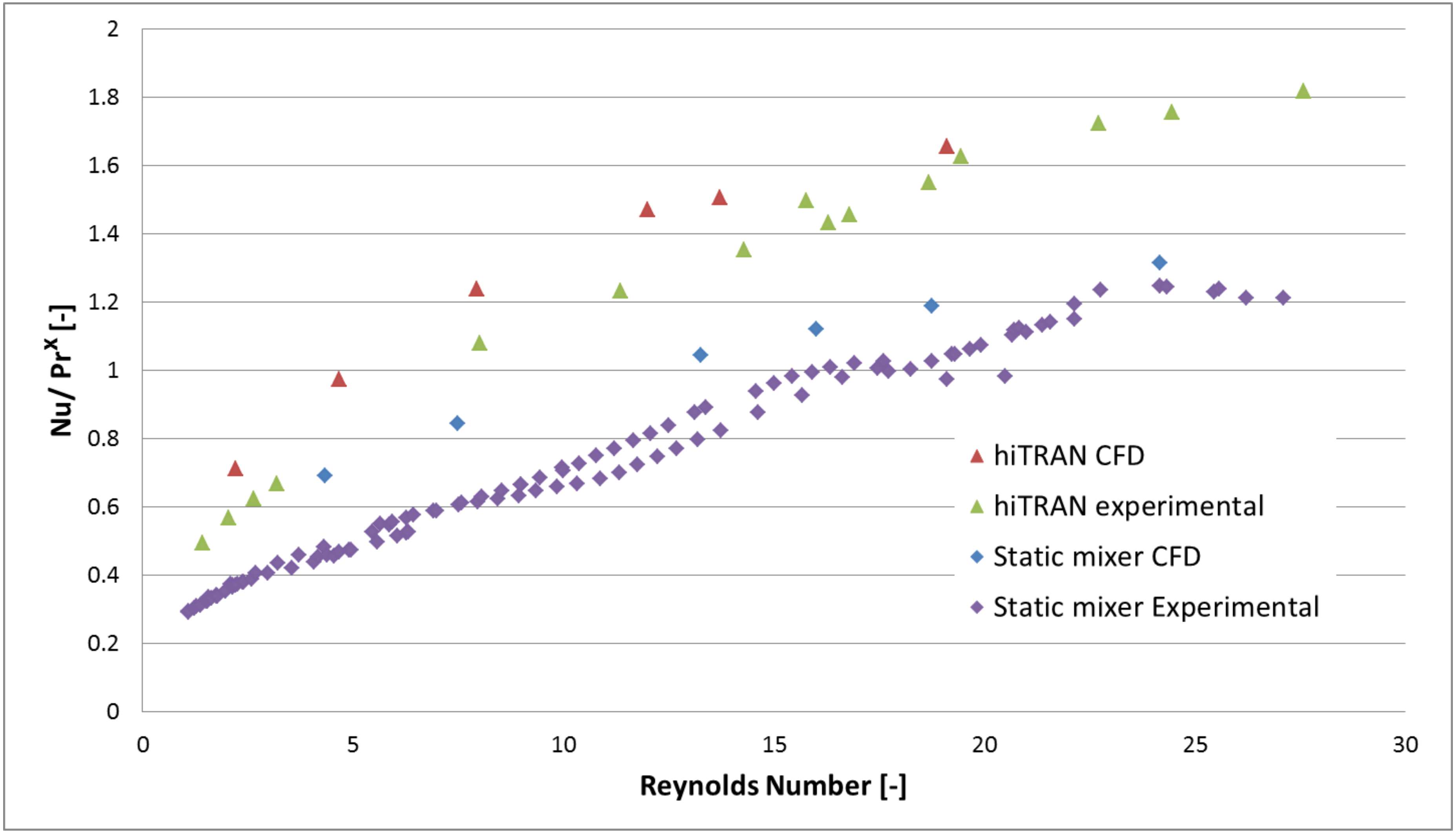
Reynolds number Range: laminar 1 to 28

Inlet Temperature: ~30 ˚C

Wall Temperature: ~64 ˚C

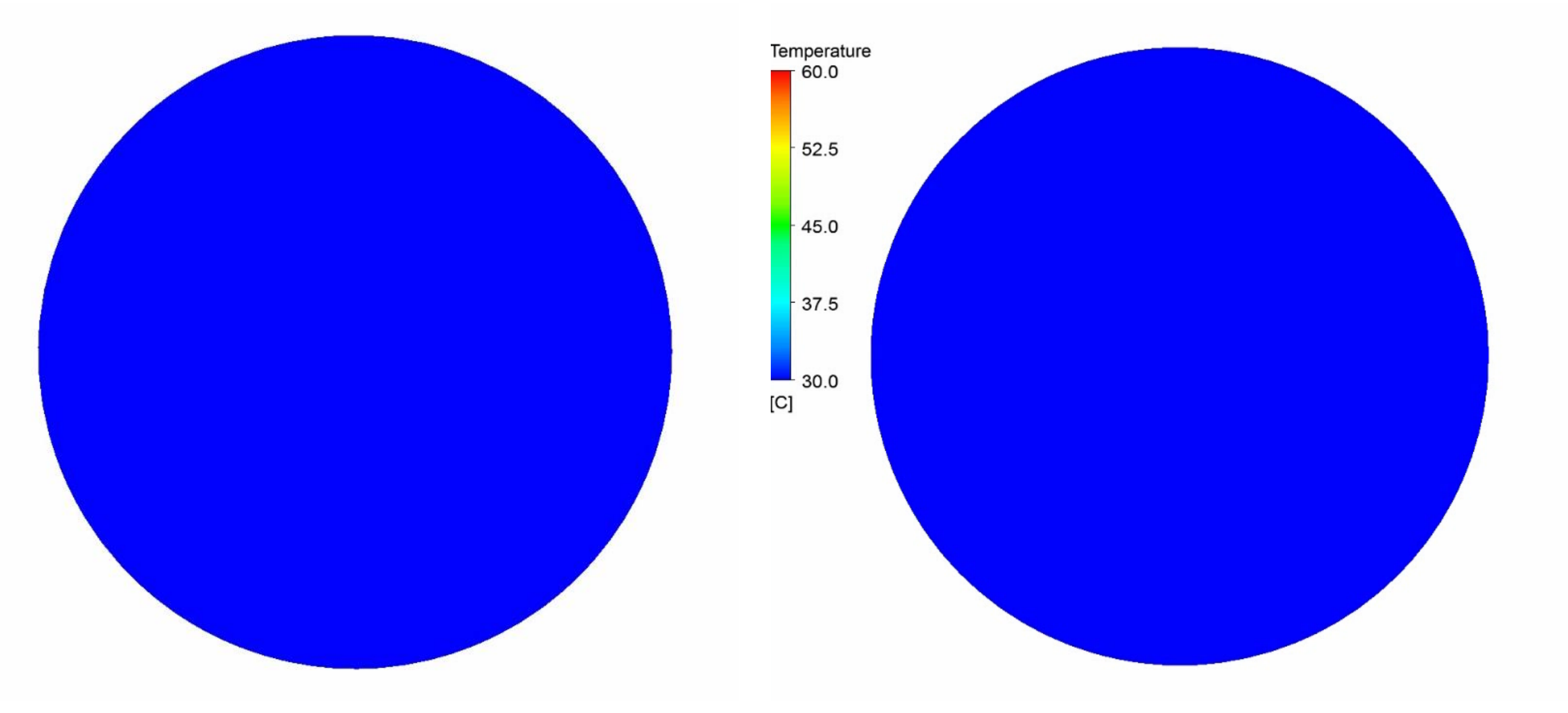


Comparison of Experimental and CFD results



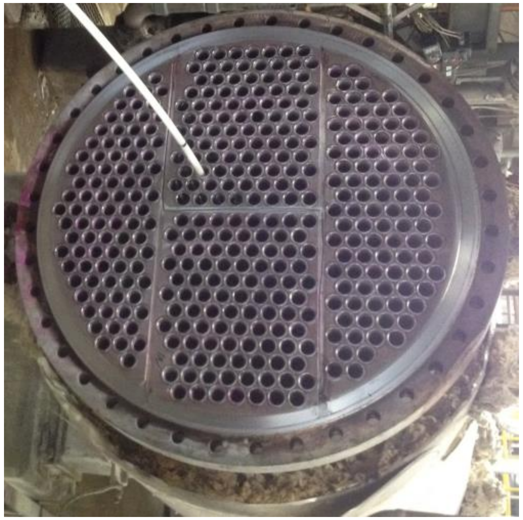
Static Mixer: Re 16, Inlet 30℃ and Wall 60℃

hiTRAN: Re 14, Inlet 30℃ and Wall 51℃

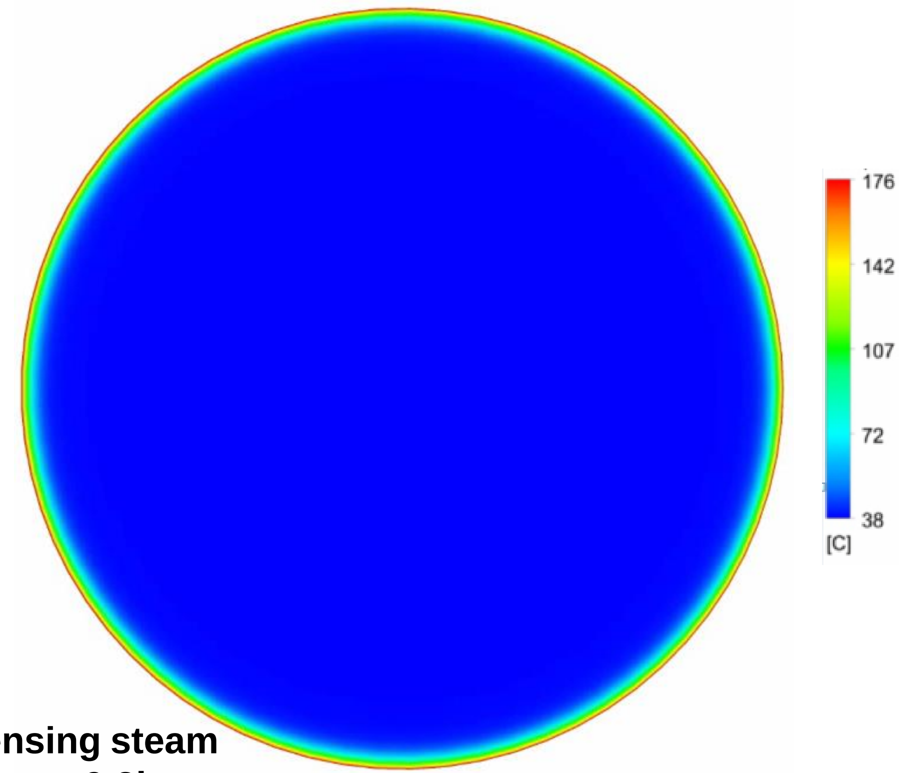


Case Study 4:
Tube-side Flow stratification

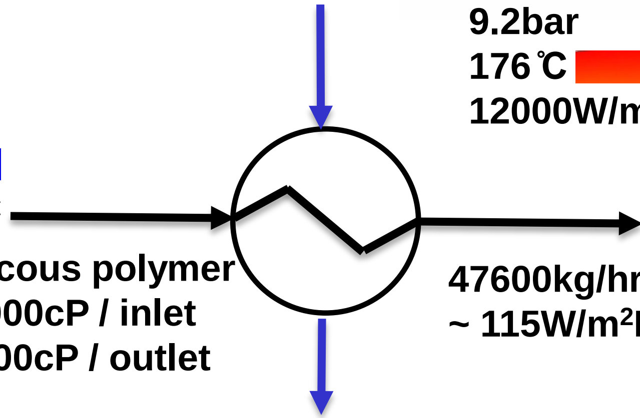
Goal of Revamp is to increase polymer outlet temperauter



AEL 4pass, 372 tubes
25.4mm x 1.65mm x 4000mm



condensing steam
9.2bar
176℃
12000W/m²K



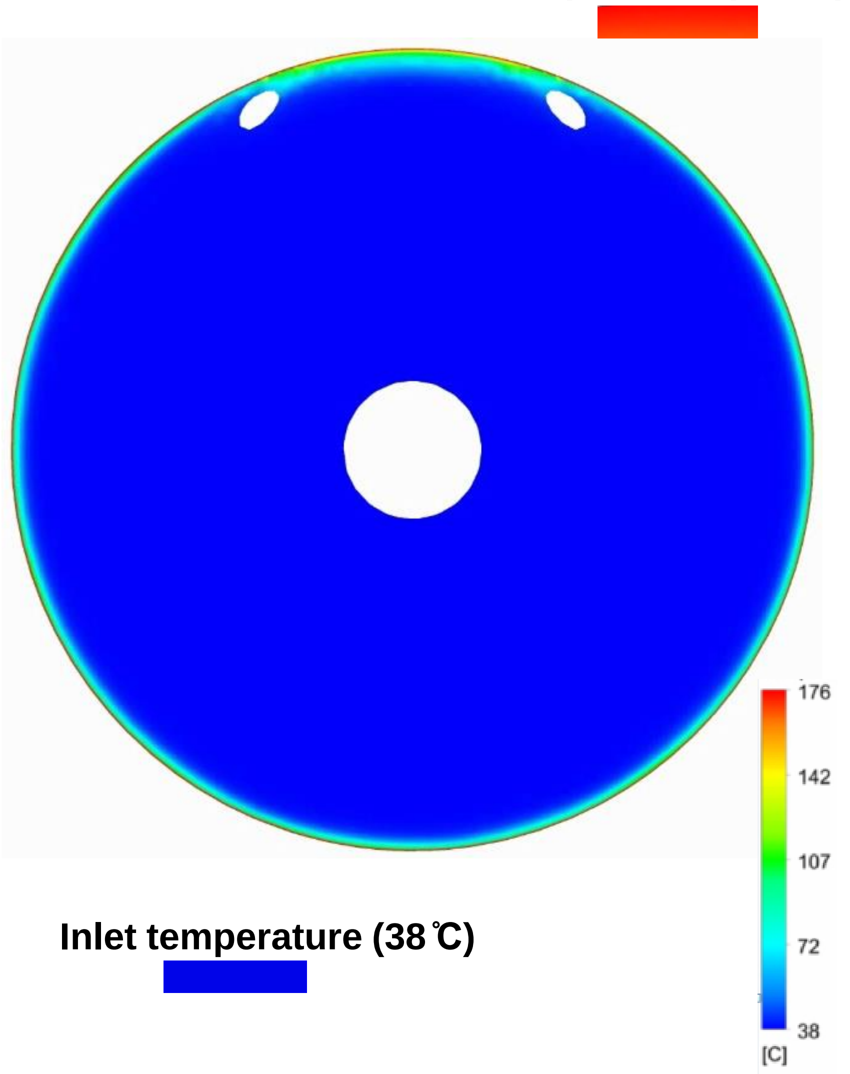
38.2 ℃

Viscous polymer
~2000cP / inlet
~ 800cP / outlet

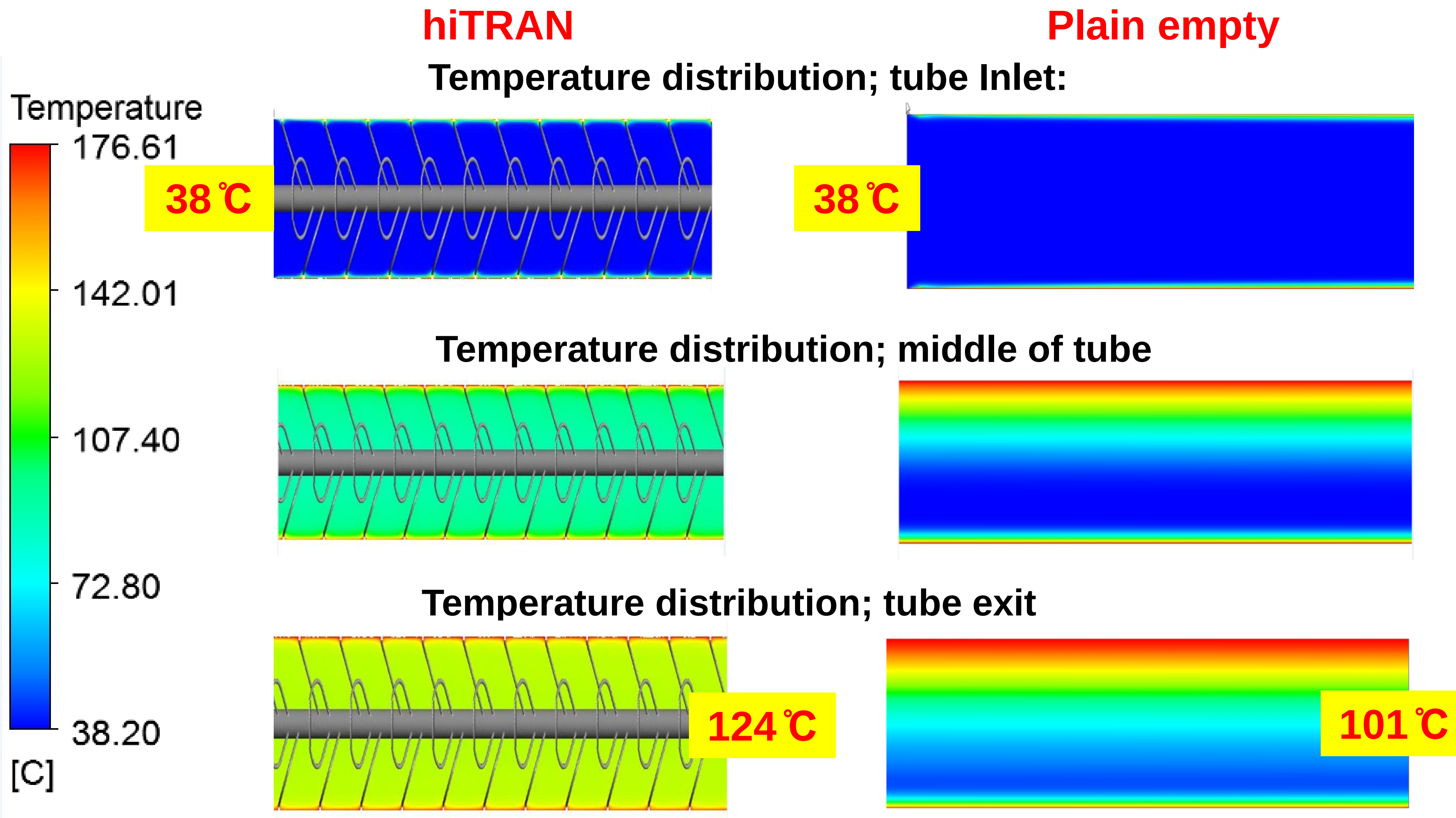
47600kg/hr
~ 115W/m²K

101℃ / dp 2.7bar

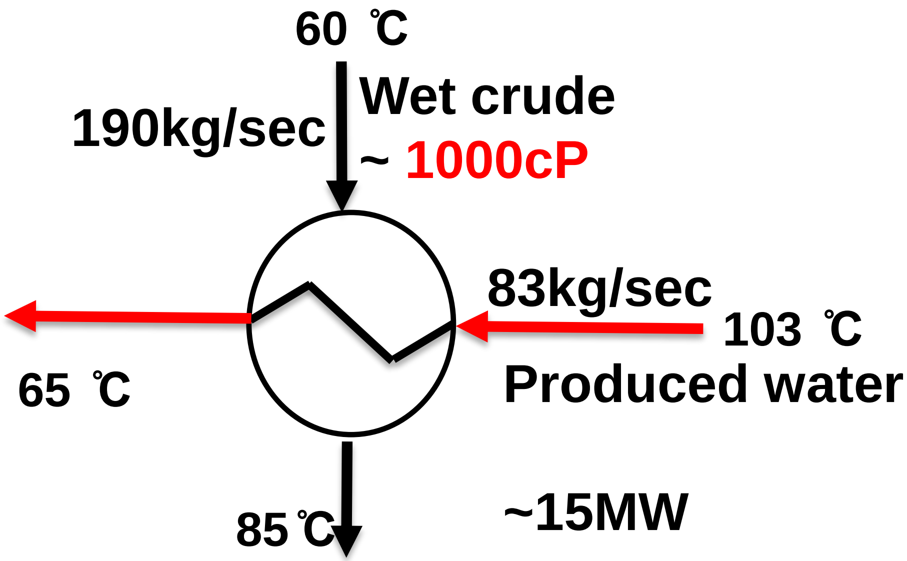
	Plain 9.2bar	hiTRAN 6.3bar
No of passes	4	2
Steam pressure [bar]	9.2	6.3
Steam temp. [C]	176	160
tube side HTC [W/m²K]	100	206
Tube side outlet [C]	101	124
Tube side dp [bar]	2.7	2.9

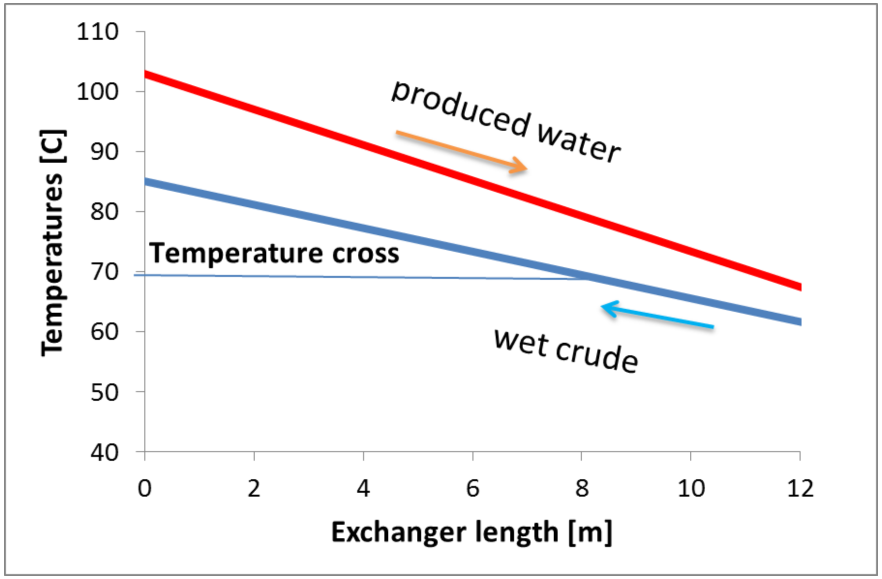


Mixed Convection causes flow stratification



Case Study 5:
Temperature Pinch





Heat transfer	Plain design
Tube side / Reynolds ~ 1800	400 W/m²K
Shell side	300 W/m²K
Overall **U**	**140 W/m²K**
EMTD	**~9℃**

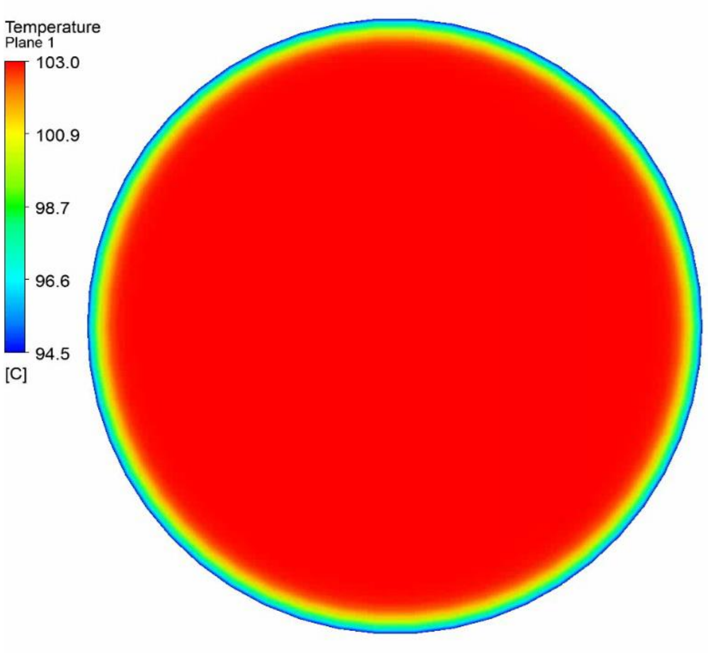
	plain
No of shells [-]	2 parallel
Total tubes [-]	10348 x 12.8m long
Total area [m²]	7821

In tube temperature pinch in conventional design

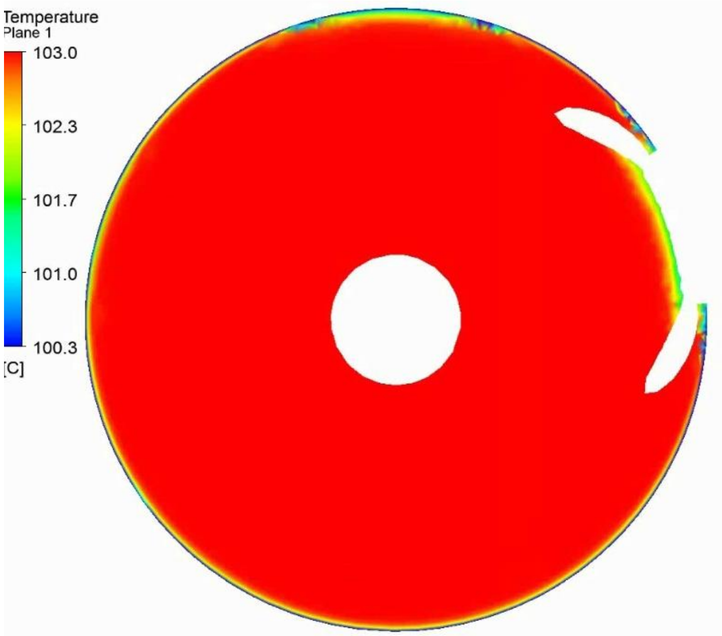
HTRI warning message on plain tube design:

Intube temperature pinch predicted in tubepass 1: The localized temperature pinch could effectively nullify up to 55.6% of the tubeside heat transfer surface area in this tube pass.

Empty tube



hiTRAN



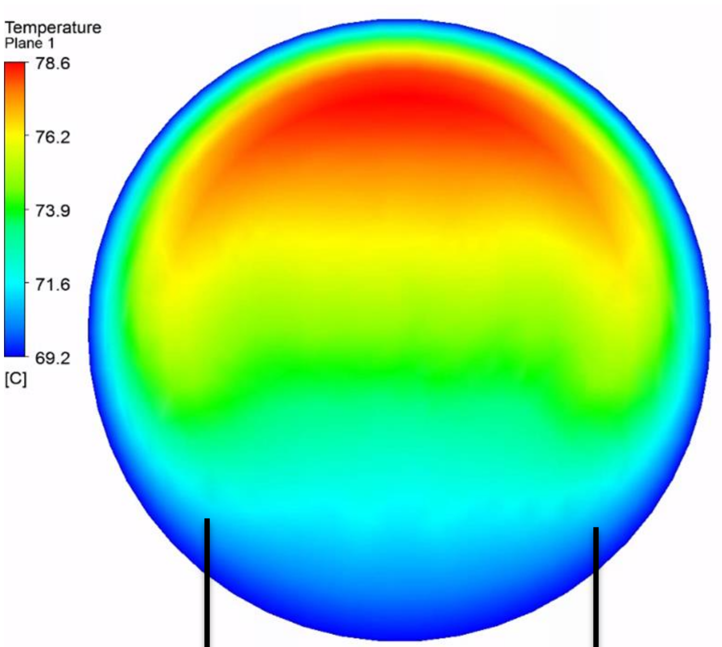
CFD simulation over 10.2m tube length with: water inlet 103℃

In tube temperature pinch in conventional design

Water outlet temp: 74℃
ΔT on tube cross-section ~10℃

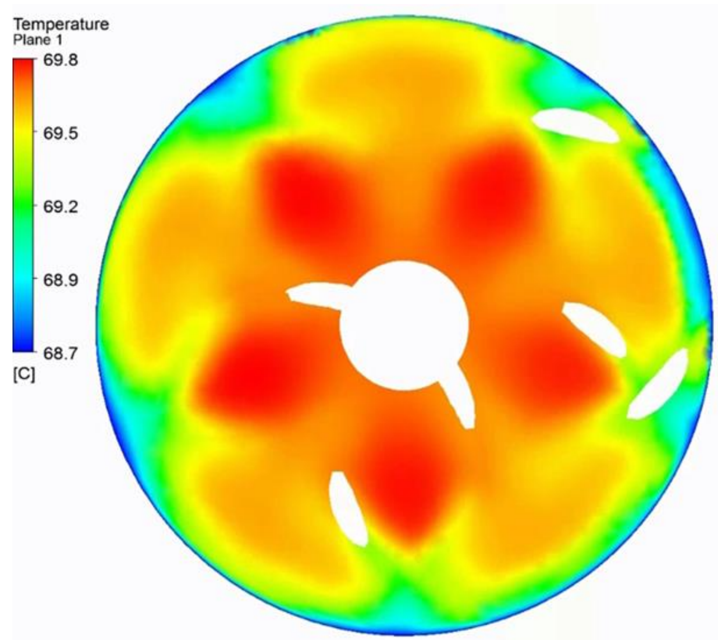
Water outlet temp: 69℃
ΔT on tube cross-section ~2℃

Empty tube



Pinch Area

hiTRAN



No in-tube pinch

Conclusion

- **This presentation has shown a variety of uses for CFD they include:**
  - Identification for the cause of an air cooled heat exchanger underperformance
  - Investigation ACHE air-side flow distribution
  - Shell and tube tube-side maldistribution
  - Identification of flow stratification and temperature pinch
  - Research and development
- **There are many more possibilities to explore using CFD**:
  - New heat transfer enhancement geometries
  - Turbulence flows
  - 2-phase flow

CALGAVIN Limited, UK

Specialist Heat Exchange Engineers

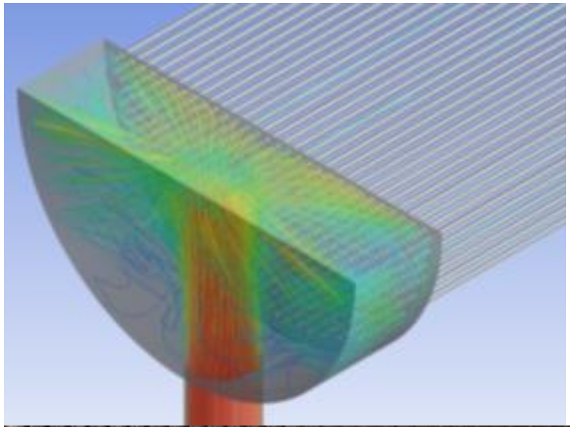
- **What we do?**
  - ➢ Provide thermal engineering solutions to:
  - ➢ Optimize plant production
  - ➢ Solve production limitation problems
  - ➢ Reduce energy costs
  - ➢ Enhancement technology (hiTRAN)

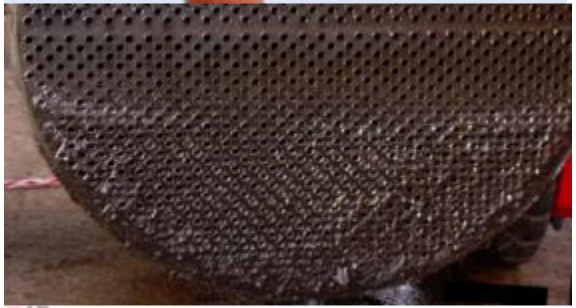
CALGAVIN: Solving Problems, Saving Costs

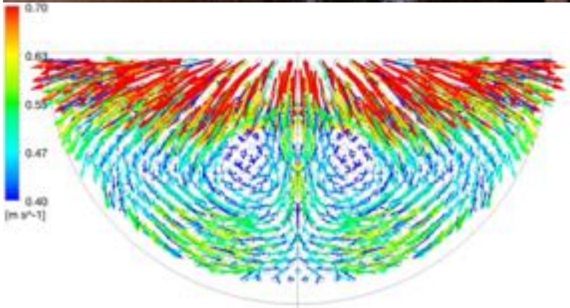
- **Study to revamp operations** - Providing consultancy advice through project engineering to improve plant operations.

- **Design Services** - Enhancing heat exchangers using various software such as HTRI, Aspentech and hiTRAN SP.

- **Analytical engineering services** - Analysing the performance and operation of existing heat exchangers, making comparisons between original designs and enhanced designs for improved efficiency.







Any Questions?

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