HEAT TRANSFER SIMULATIONS FOR A ADDITIVELY MANUFACTURED HEAT EXCHANGER

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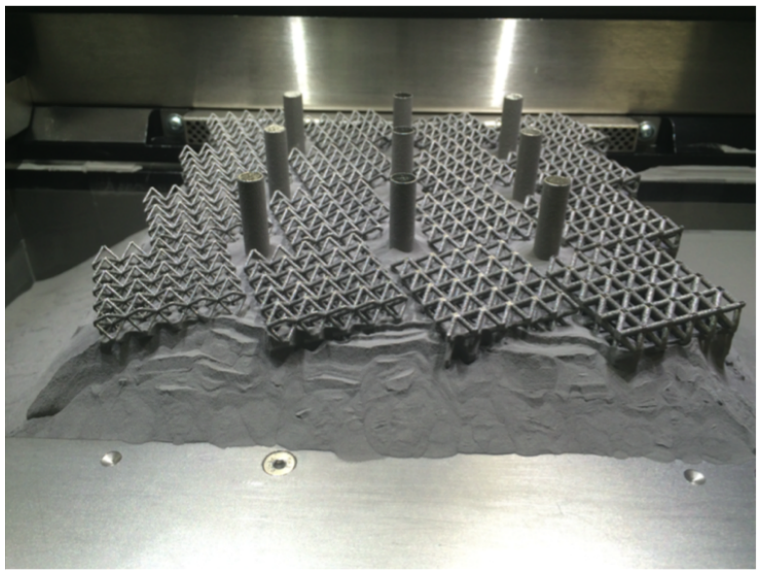
Outline

- Additive manufacturing
- Objectives and challenges of the project
- Brief overview of the experimental set up
- Description of the condensation solver **interExCondPhaseChageFoam**
- Results and discussion
- Conclusion

Additive Manufacturing

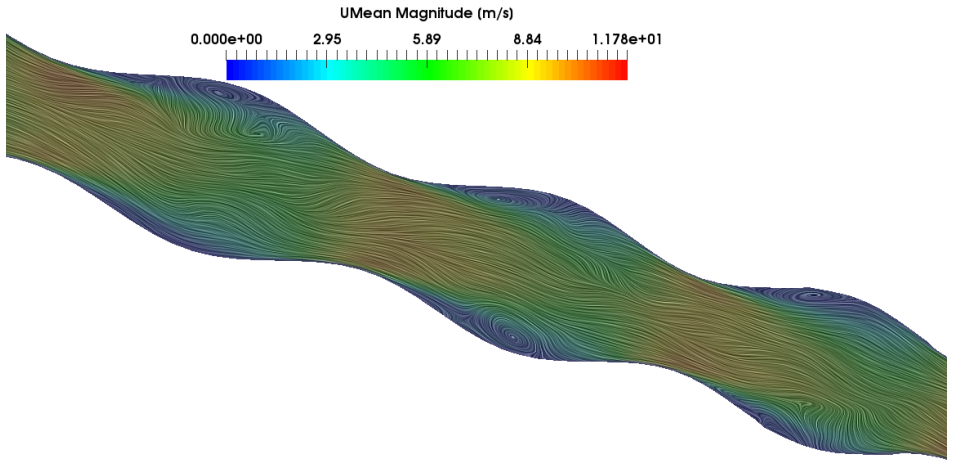


AM

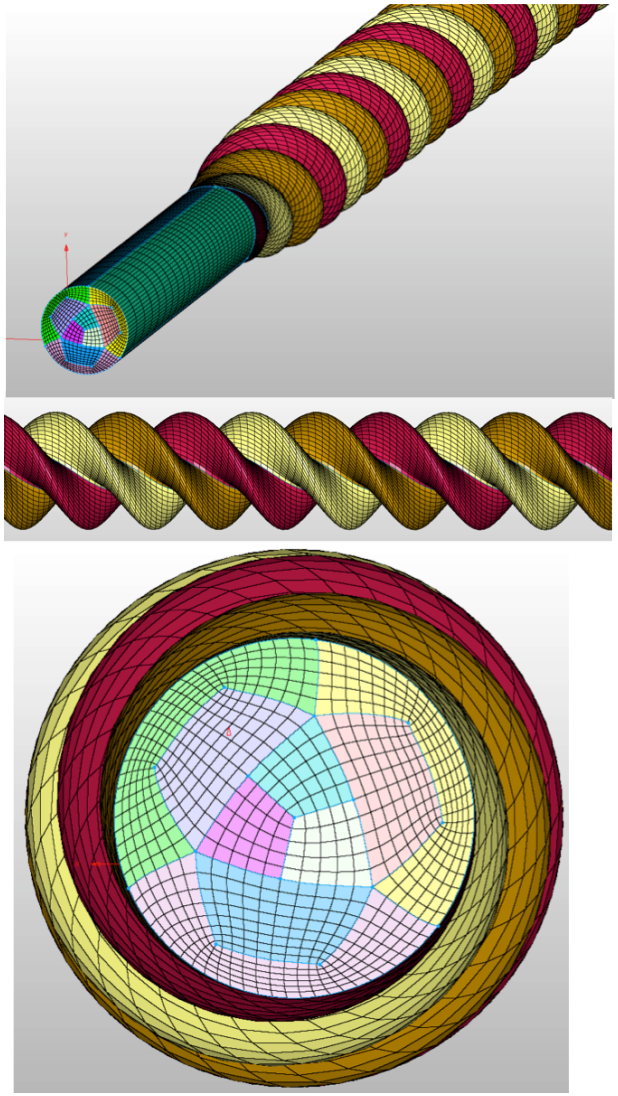
- Known as
  - additive manufacturing
  - additive processes
  - additive techniques
  - additive layer manufacturing
  - freeform fabrication
  - 3D Printing
- Benefits
  - Component integration
  - Increased performance
  - Novel geometries
  - Added functionality
  - Reduced weight
  - Reduced lead time

Objectives of the Project

- Entirely new concept
- It is a condenser for a automotve fuel cell hence the requirements for low volume and weight.
- Compact heat exchanger (HX)
- Existing condensing HX weighs 27.4 kg; not suited for automotive application
- New designed condensing HX weighs 13.16 kg
- Lower price

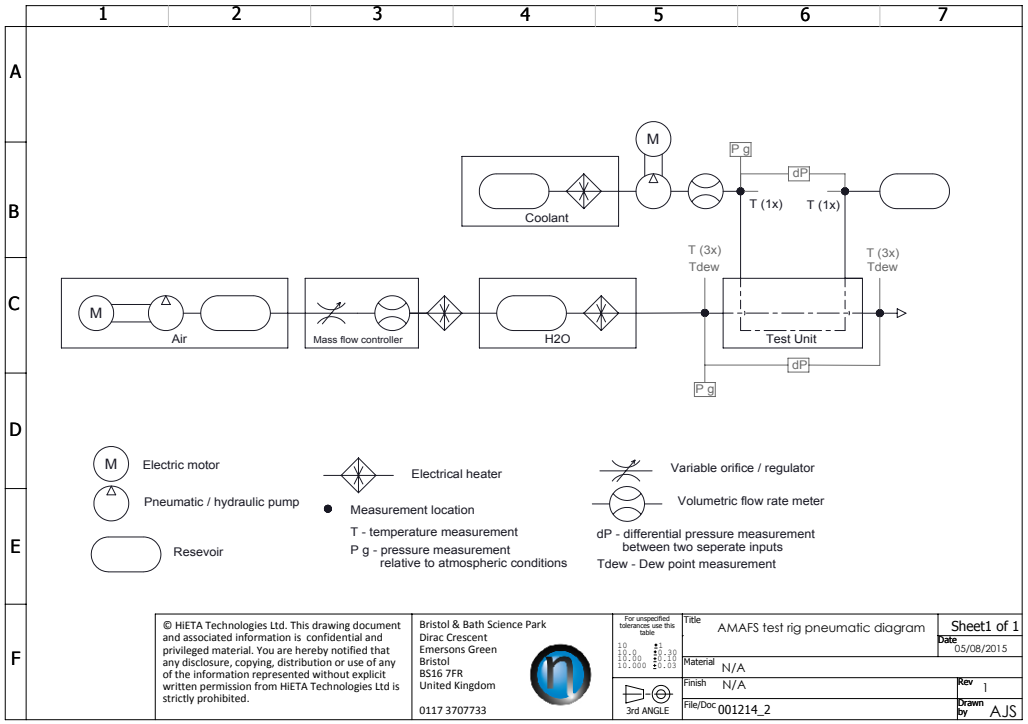


Challenges of the Project



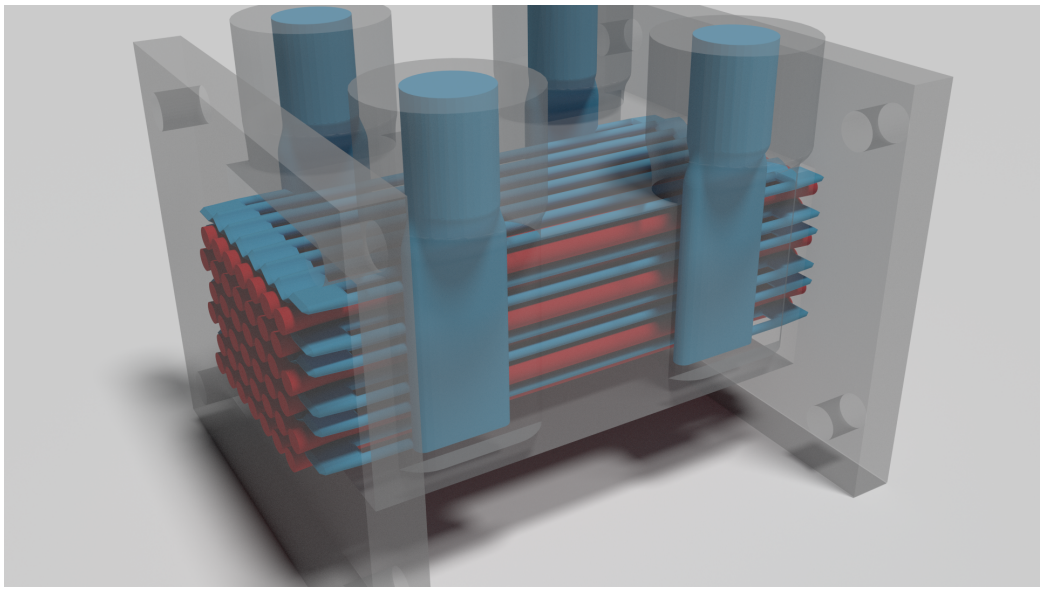
- Consists of 3200 microchannels
- Test unit consists of 42 microchannels and approx 55 million mesh cells
- Complexity of the condensation and heat transfer
- Complexity of the geometry
- Short time

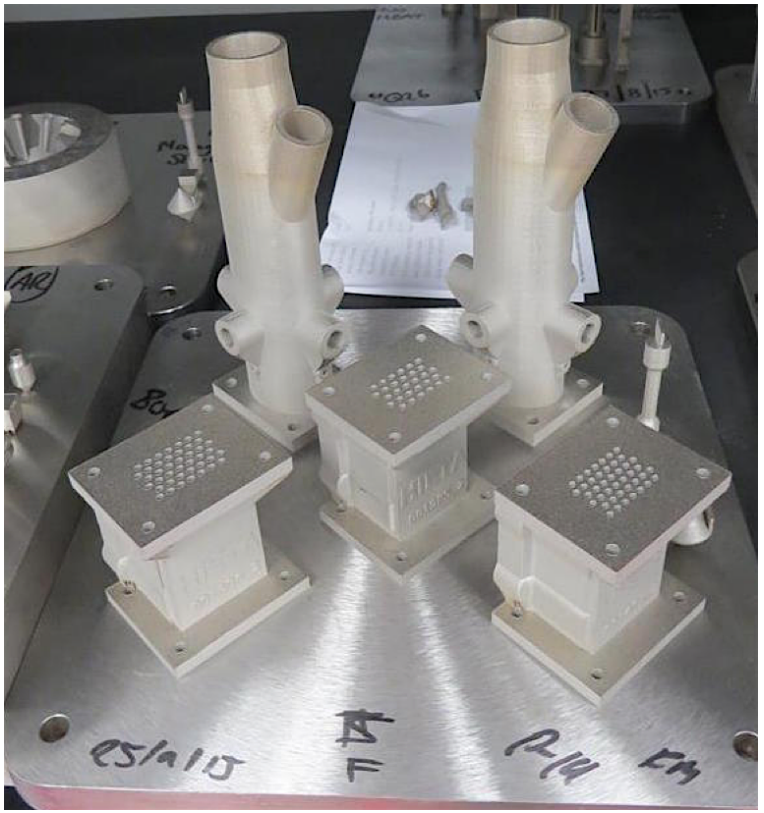
Experimental set-up



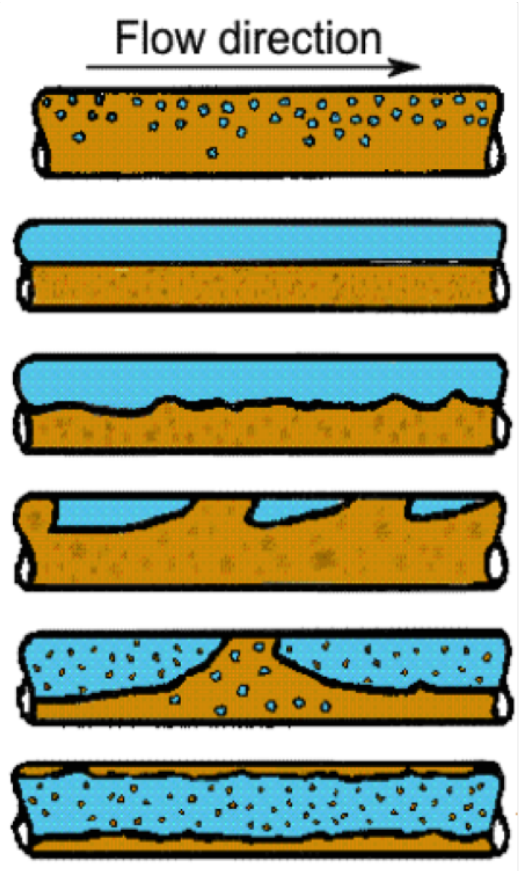
- Test unit consists of 42 microchannels
- Water is collected at the outlet
- Heated air used to keep the desired flow rate
- Heated air is passing through the steamer bath where humidity of air is reaching the saturation point
- Glass tube is integrated before the inlet to make sure water is not going in

Experimental test blocks





Two-Phase Flow Patterns



Flow Patterns

1. Bubbly, Stratified, Wave, Plug and Annular flow
2. Choice of modelling approach
3. Volume of Fluid Method is applied
4. The condensation model is implemented in OpenFOAM interPhaseChangeFoam solver

Condensation Model

Heat flux term

$$(q^{"})_{local,in} = -k_{eff} \times (\nabla T)_{local,in}$$
$$(q^{"})_{local,in} = (m^{"})_{local,in} \times h_{LV}$$

Energy source term

$$S_h = +(S_{\alpha_L})_{local,in} \times h_{LV}$$

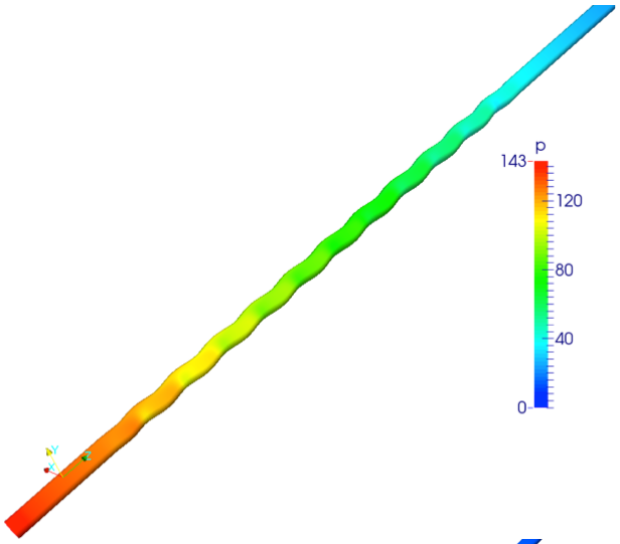
***Ganapathy, H. et al, Int. J. Heat Mass Transfer, 2013**

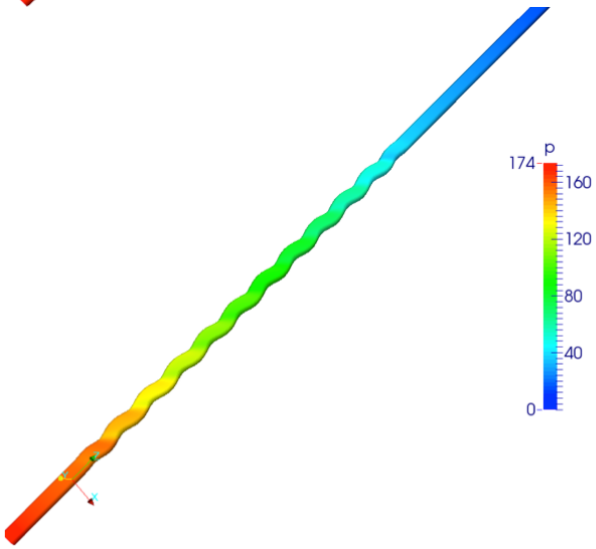
Mass source terms

$$(S_{\alpha_L})_{local,in} = \frac{(q^{"} \cdot \nabla\alpha)_{local,in}}{h_{LV}}$$
$$S_{\alpha_V} = -S_{\alpha_L} = -\frac{(q^{"} \cdot \nabla\alpha)_{local,in}}{h_{LV}}$$

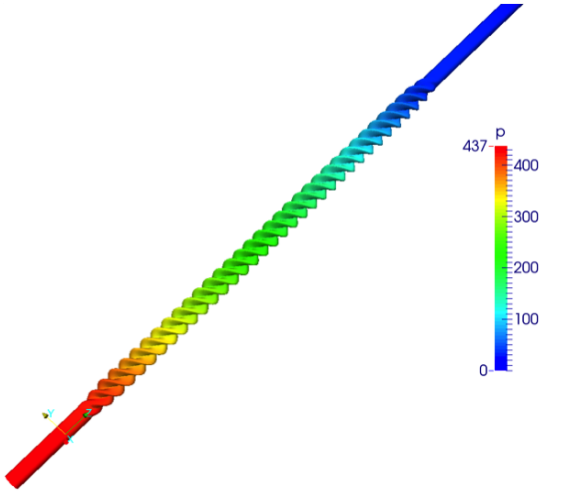
h_{LV} - *latent heat* (J/kg)
k_{eff} - *thermal conductivity* (W/mK)
$q^{"}$ - *heat flux* (W/m^2)
α - *volume fraction* $(-)$
S_α - *mass source term* (kg/m^3s)
S_h - *energy source term* (kg/m^3s)
L - *liquid*
V - *vapour*

Different types of microchannels and pressure drop

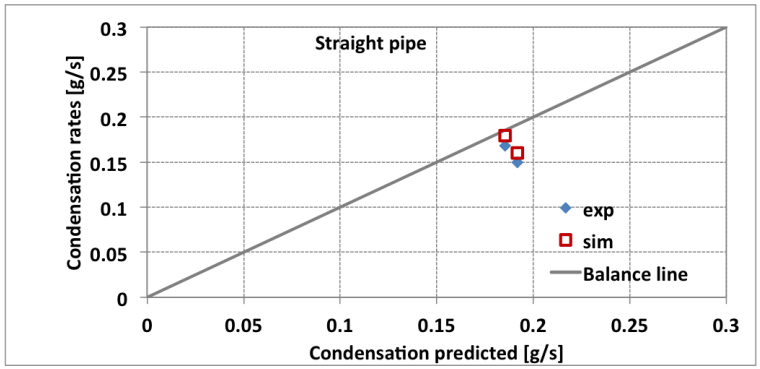




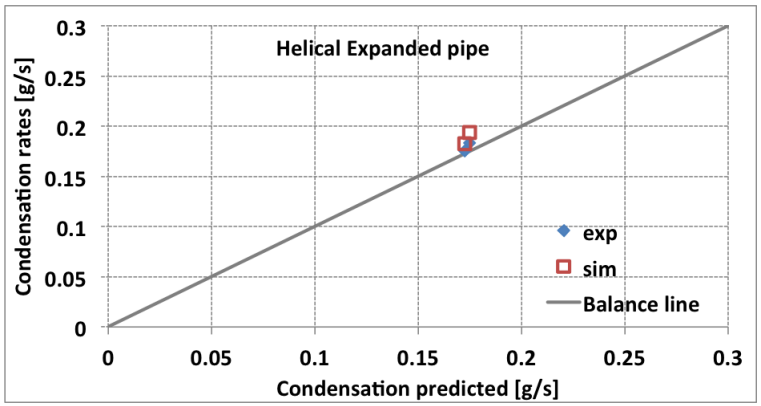
1. Higher pressure loss [Pa] observed in the fusilli case
2. Lowest pressure loss in the sinusoidal case
3. Highest heat tranfer coeff. observed in the fusilli case

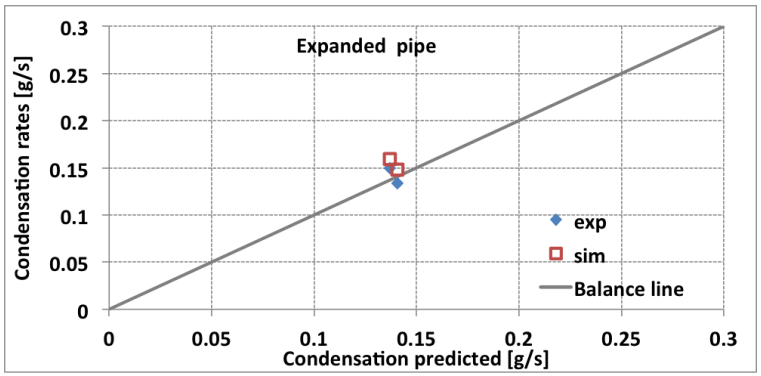


Condensation Rate Comparison

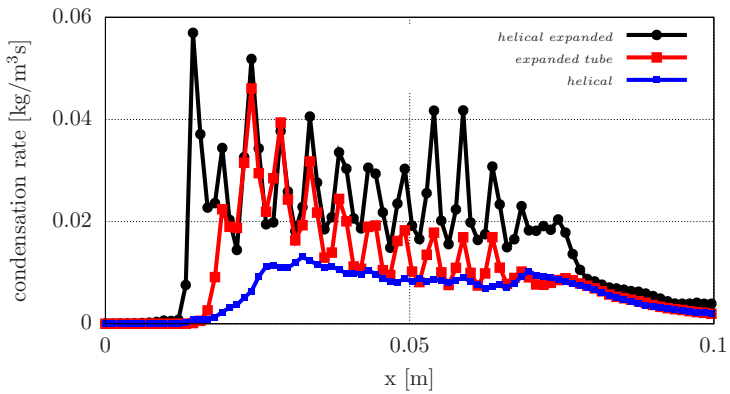


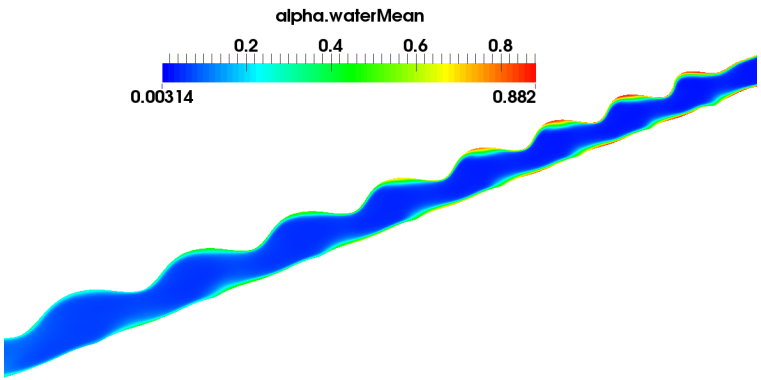
1. Error less than 5%.
2. Very good agreement with experimental results.





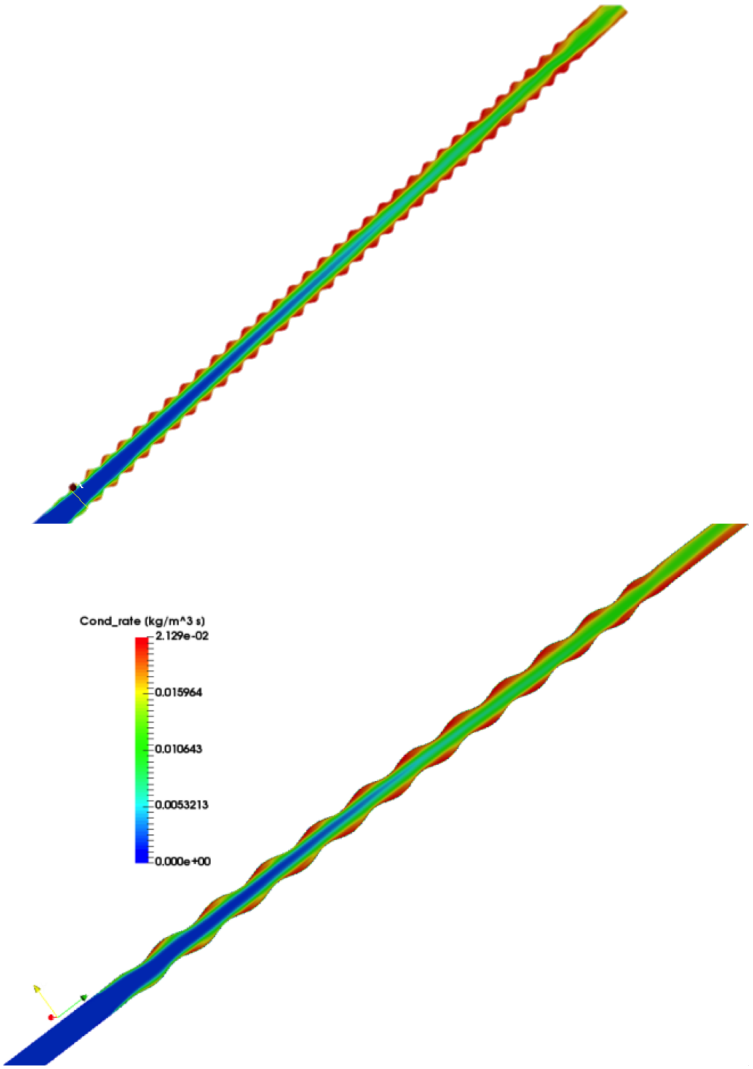
Condensation Rate and Water Volume Fraction





1. As expected the water volume fraction is growing near the wall.
2. Condensation rate is high near the inlet then gradually decreases.
3. New design microchannel gives highest condensation rate

Condensation Rate Profile



1. As expected the water volume fraction is growing near the wall.
2. New designed microchannels are shown in blue deliver the best performance.

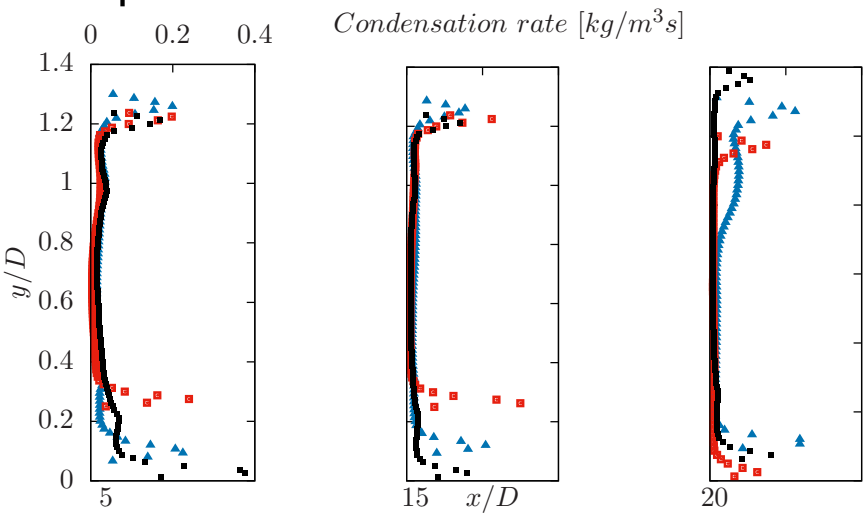
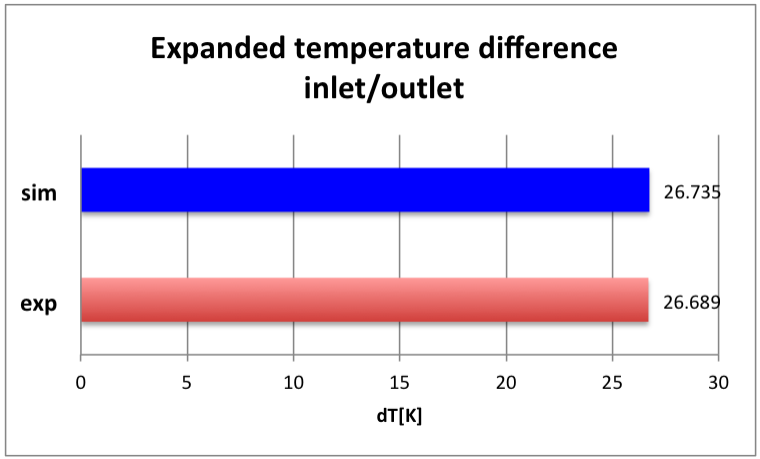
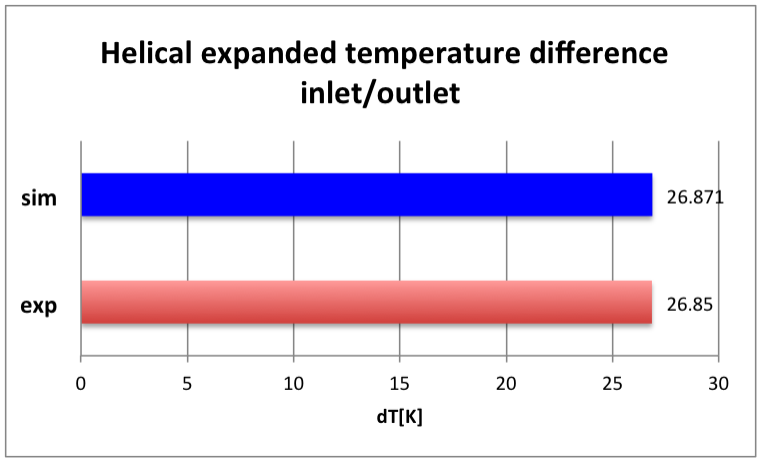


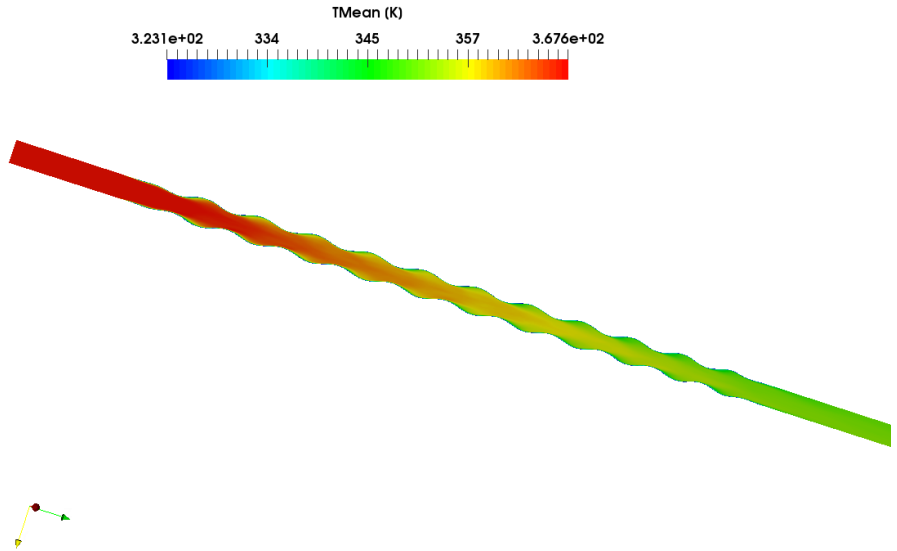
Figure 1: Condensation rates for the different geometries.

Inlet/Outlet Temperature Comparison

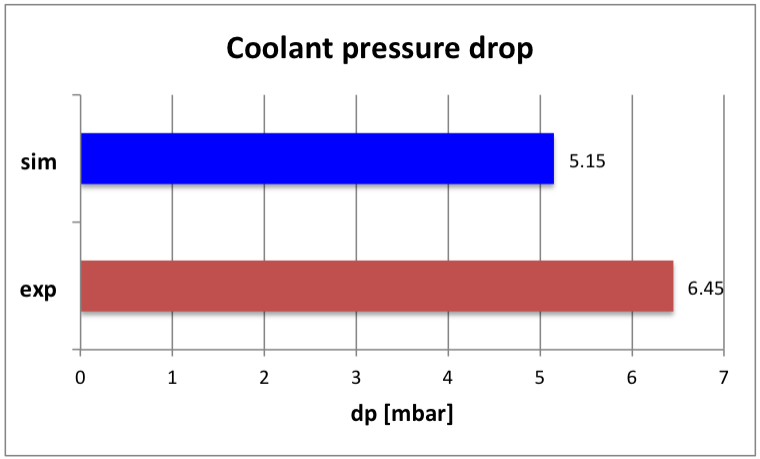




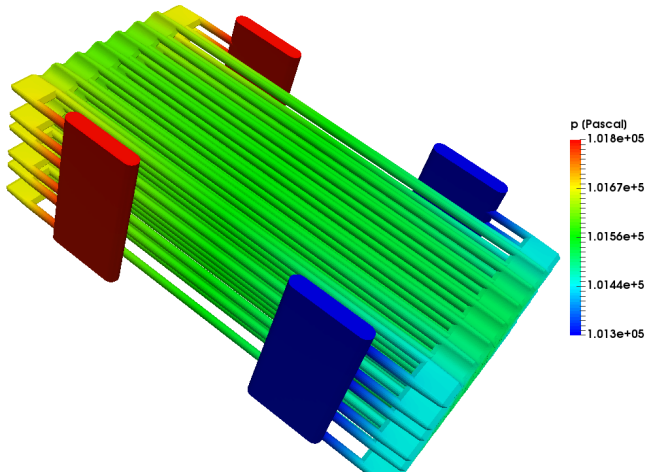
1. Error $5 - 10\%$.
2. Good agreement with experimental results.

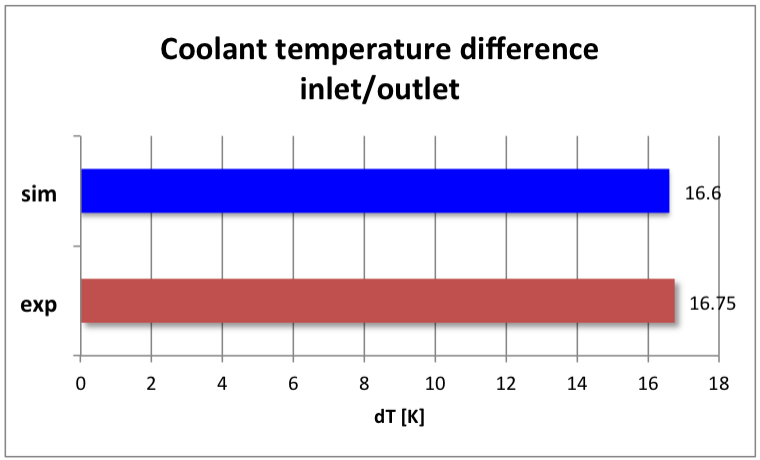


Pressure Drop in Coolant Side



- Difference in pressure drop could be due to higher surface roughness in the experiment.





Conclusion and Future Work

- Simulations are in good agreement with experimental data.
- Condensation takes place mostly near the wall region as expected.
- CHT simulatons are in good agreement with experimental results.
- Possible future work could include coupling condensation with conjugate heat transfer.
- Extending condensation model by adding temperature and pressure dependant material properties (e.g density, specific heat capacity, thermal conductivity).

Thank you!

Innovate UK
Technology Strategy Board