CLAMPED PLATE-STYLE RECUPERATOR WITH HIGH TEMPERATURE SEALANT; MODELLING, DESIGN AND EXPERIMENTAL TESTING.

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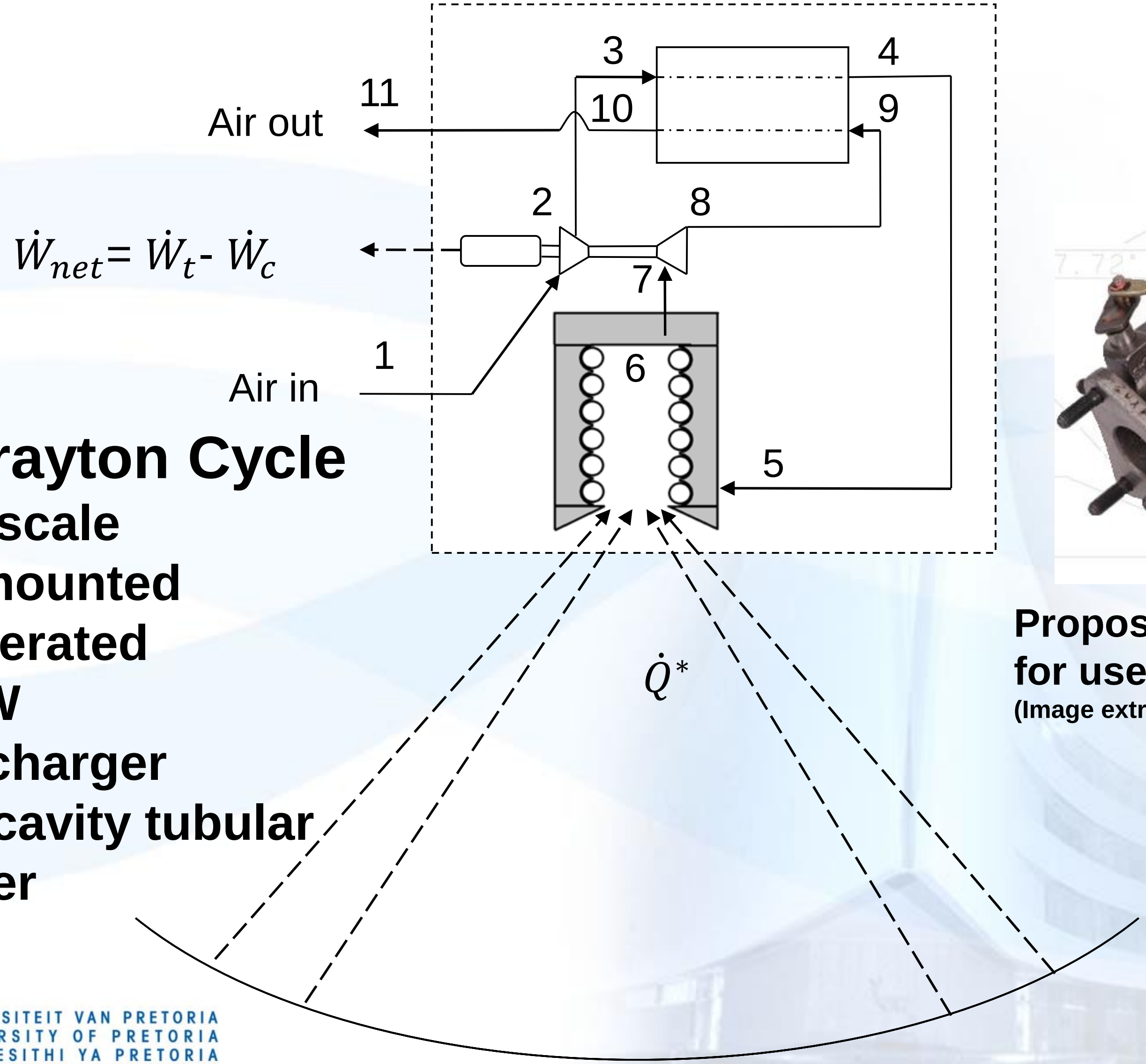
1. Background
Solar thermal Brayton cycle



Solar Brayton Cycle

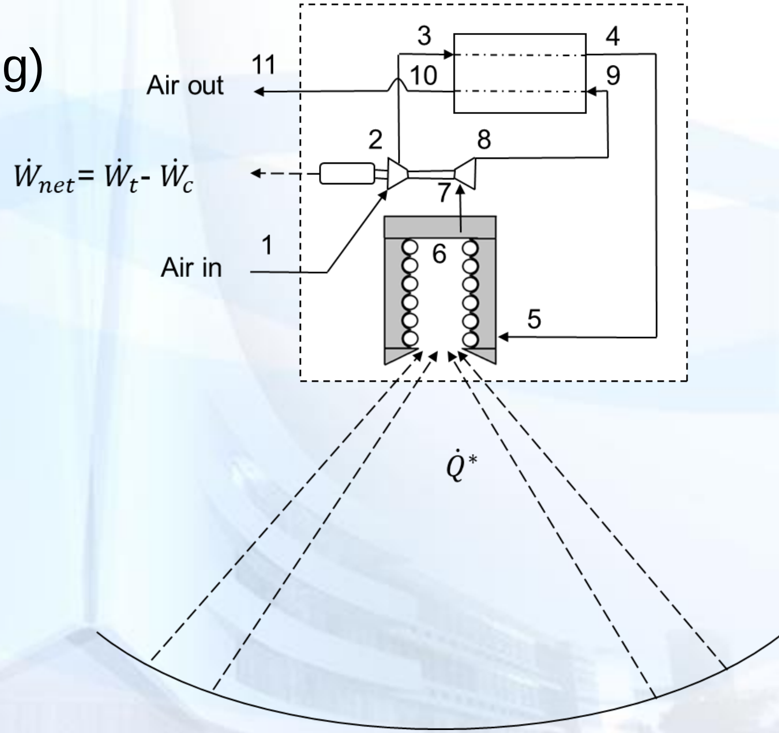
- Small-scale
- Dish-mounted
- Recuperated
- 1-20kW
- Turbocharger
- Open-cavity tubular receiver

Proposed turbocharger; for use as a micro-turbine
(Image extracted from Garrett, 2014)

1. Solar thermal Brayton cycle

Solar thermal Brayton cycle advantages

- Air is the working fluid (simple, free, environmentally friendly)
- Turbocharger as micro-turbine (available, affordable)
- Can also be powered with gas (hybrid system)
- Water heating (cogeneration)
- Absorption refrigeration
- High efficiency potential (reheat and intercooling)
- Small-scale (mobility)
- Cost benefits (bulk manufacturing)
- Storage such as rock bed and lithium fluoride



Expected power load of 1.027 kW and water heating load of 3.45 kW for 4.8m diameter solar dish

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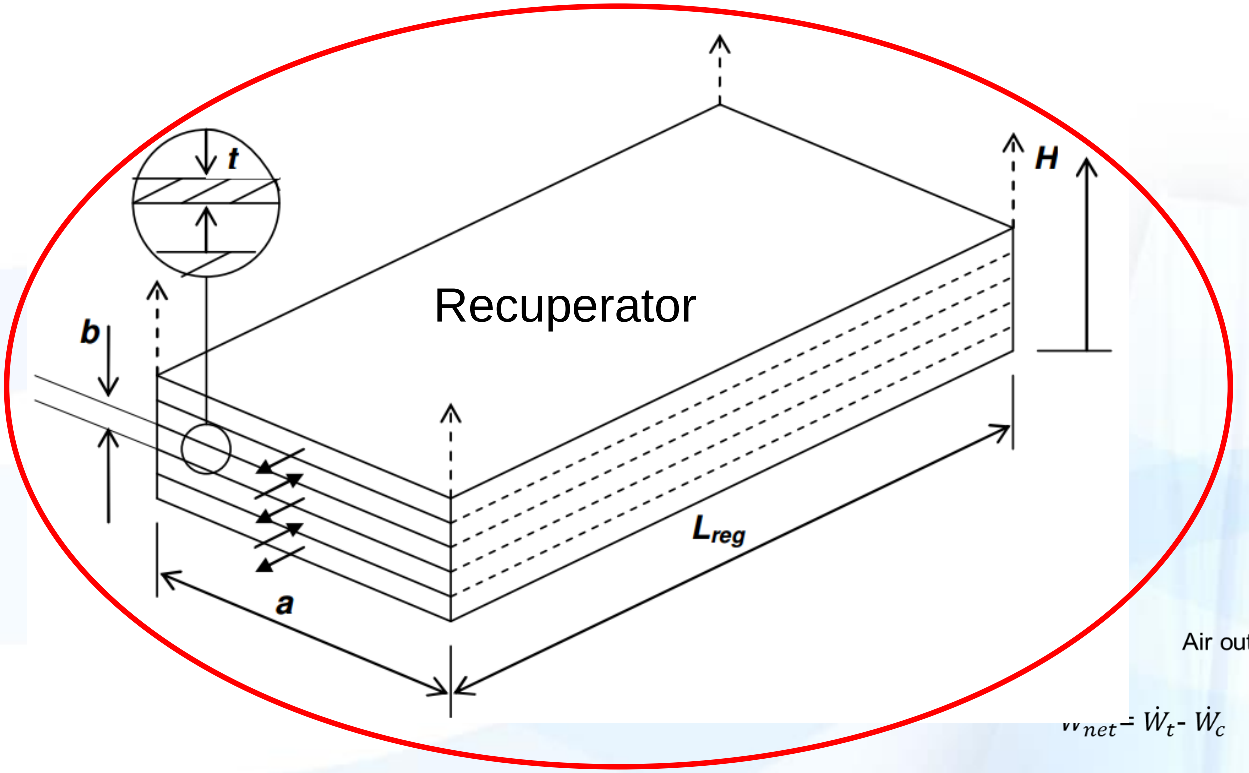
Solar thermal Brayton cycle

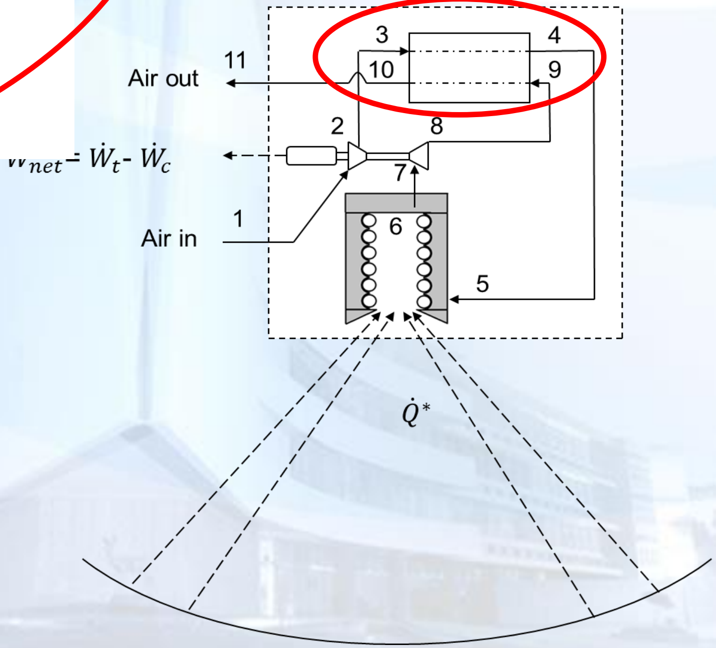
Prototype under construction

- TIA Funding
- RDP Funding
- NRF (IPRR)

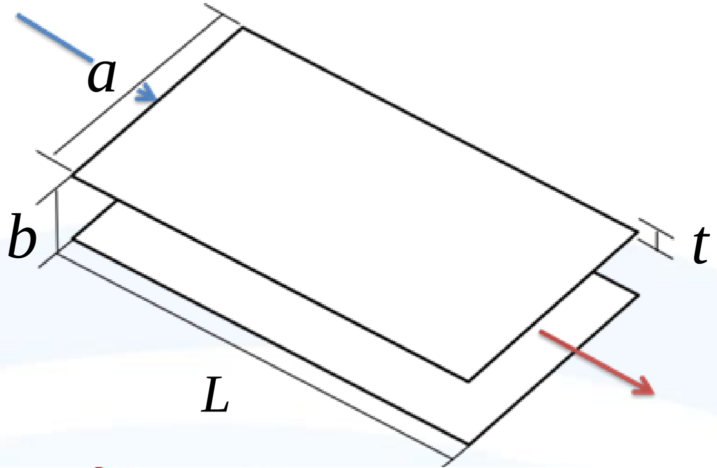
2018 version

Solar thermal Brayton cycle

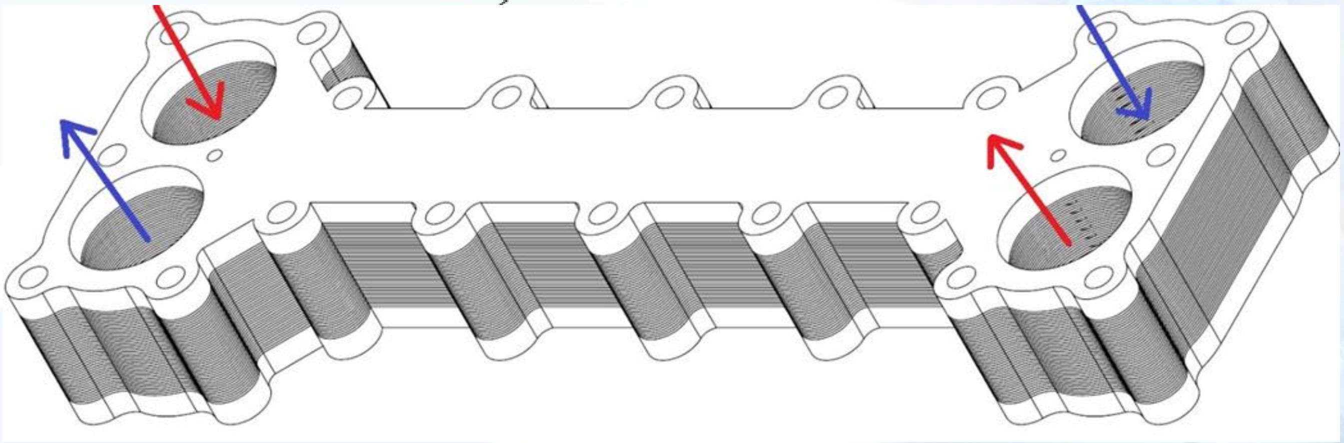




Theoretical model



- Simplified counter-flow arrangement



- Effectiveness-NTU method with heat loss analysis.

Heat loss model

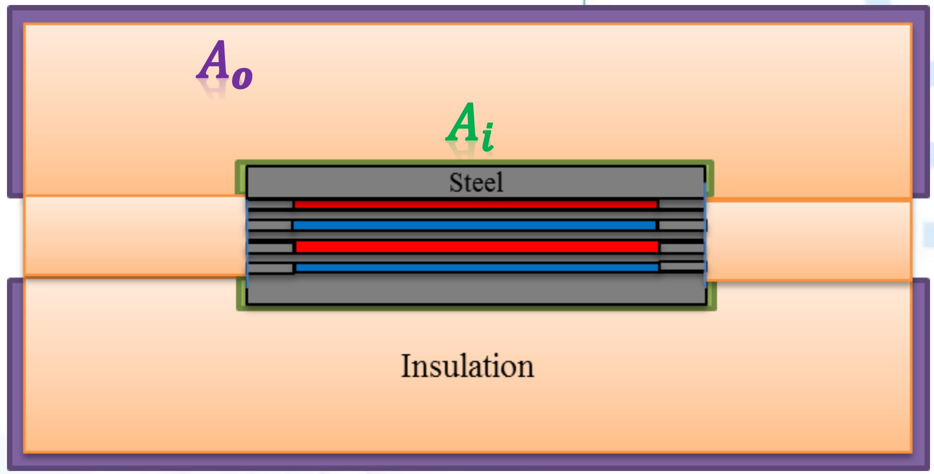
- $\varepsilon_h = \begin{cases} 1-\theta_{X=1}, & C_{rh} < 1 \\ C_{rh}(1-\theta_{X=1}), & C_{rh} > 1 \end{cases}$

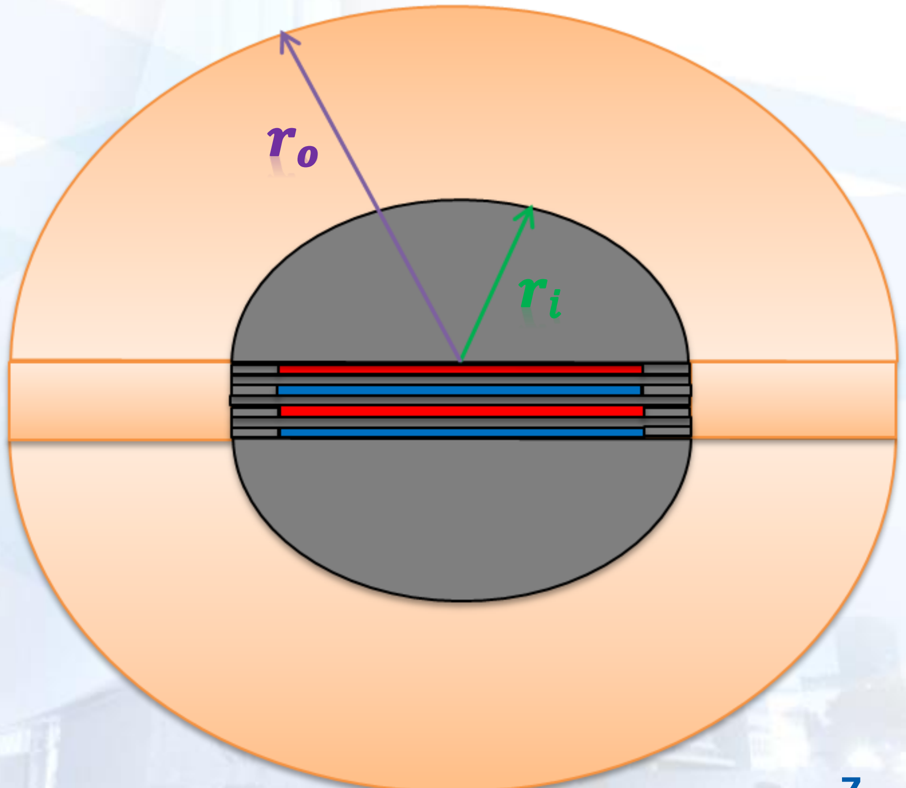
- $\varepsilon_c = \begin{cases} (1-\theta_{X=0})/C_{rh}, & C_{rh} < 1 \\ 1-\theta_{X=0}, & C_{rh} > 1 \end{cases}$

- $\theta_{X=0} = \frac{B+(\chi_h+C_{rh}\cdot\chi_c)[]}{(C_{rh}-1)[e^{NTU_h(C_{rh}-1)}-1/C_{rh}]}$

- $\theta_{X=1} = NTU_h(\chi_c+\chi_h) + \frac{(\theta_{X=0}-1)}{C_{rh}} + 1$

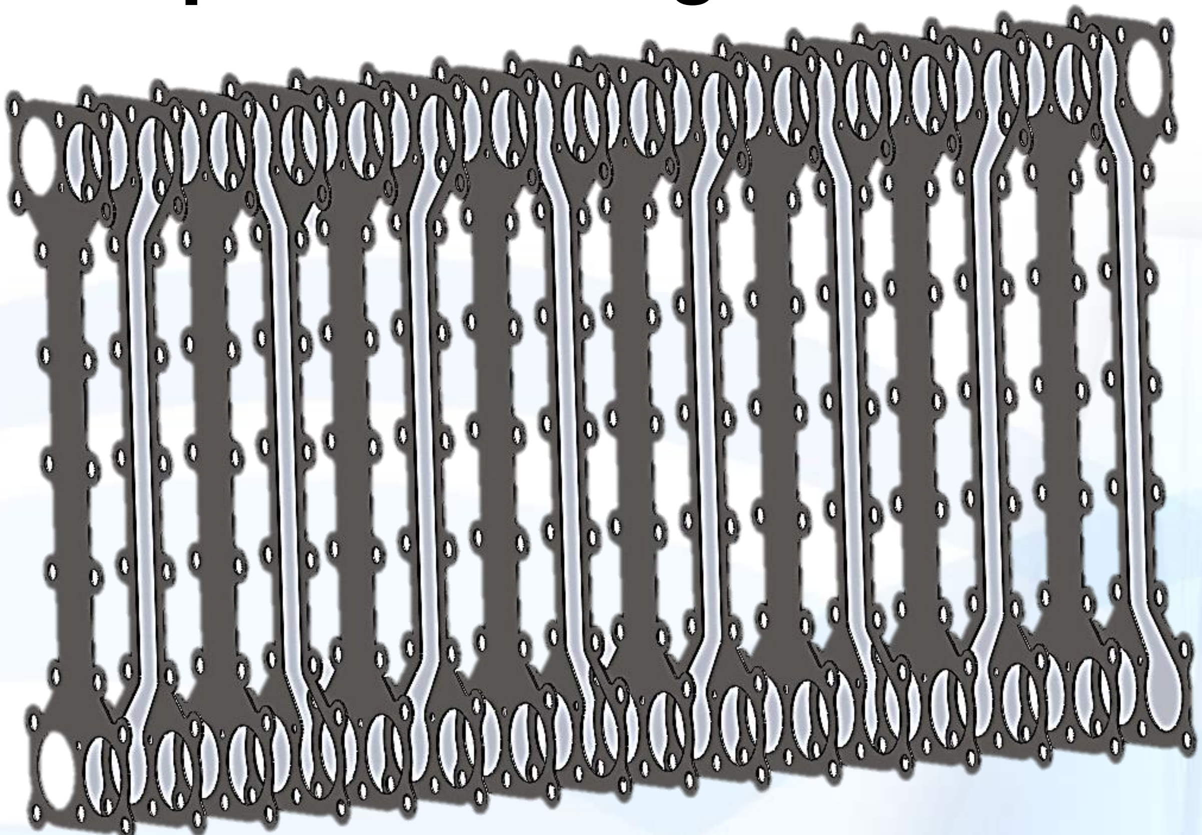
- $\chi_{[h|c]} = -\frac{\dot{Q}_{loss,[h|c]}}{UA(T_{h,i}-T_{c,i})}$

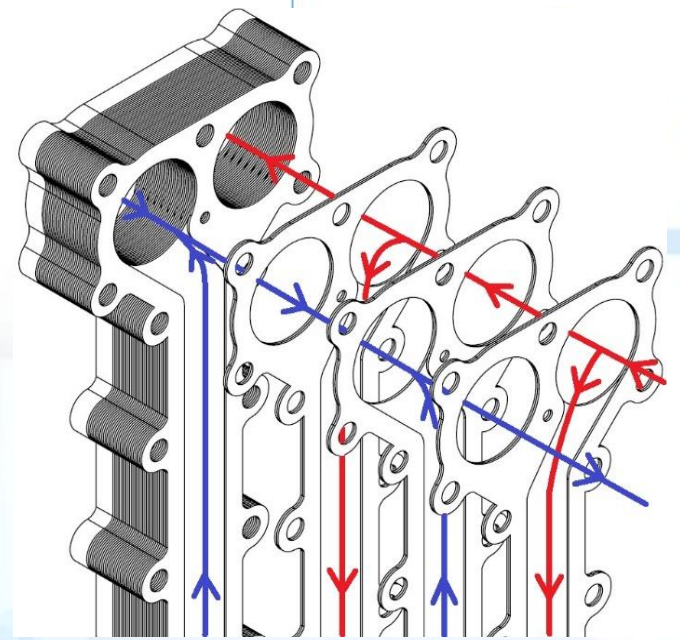




Nellis, G.F. and Pfotenhauer, J.M., 2005, Effectiveness-NTU relationship for a counterflow heat exchanger subjected to an external heat transfer, Journal of Heat Transfer 127, pp. 1071 – 1073.

Recuperator design





Stacked plate design

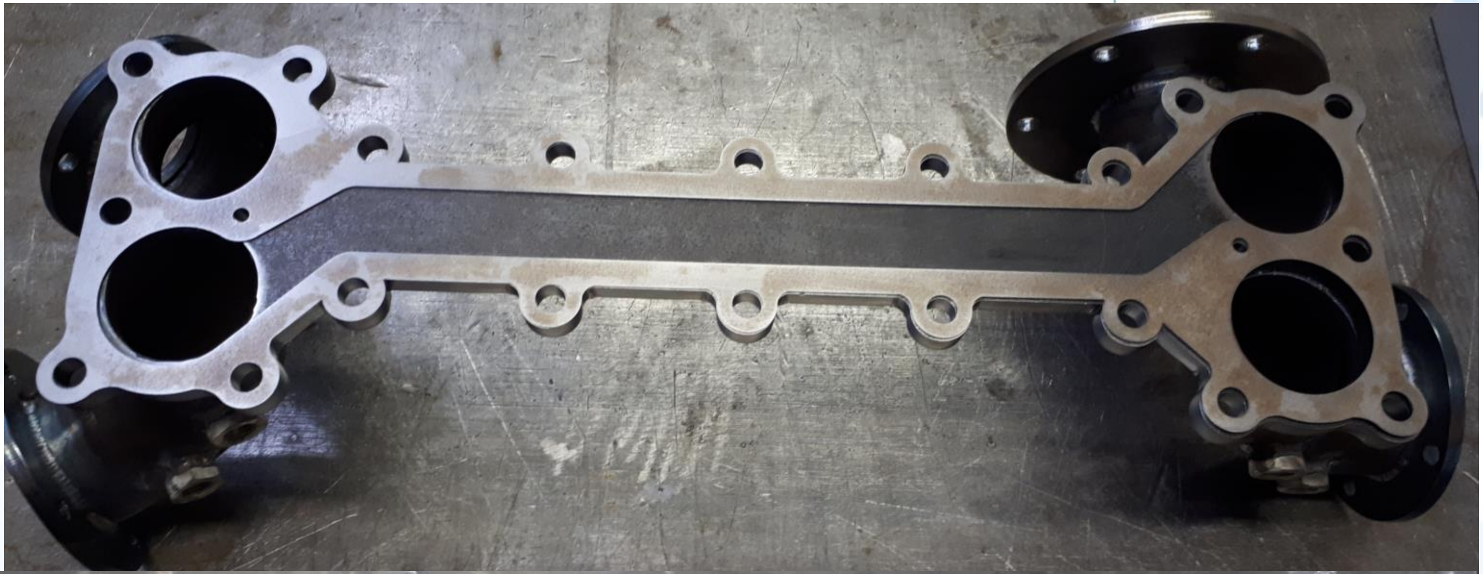
Gaskets

Plates

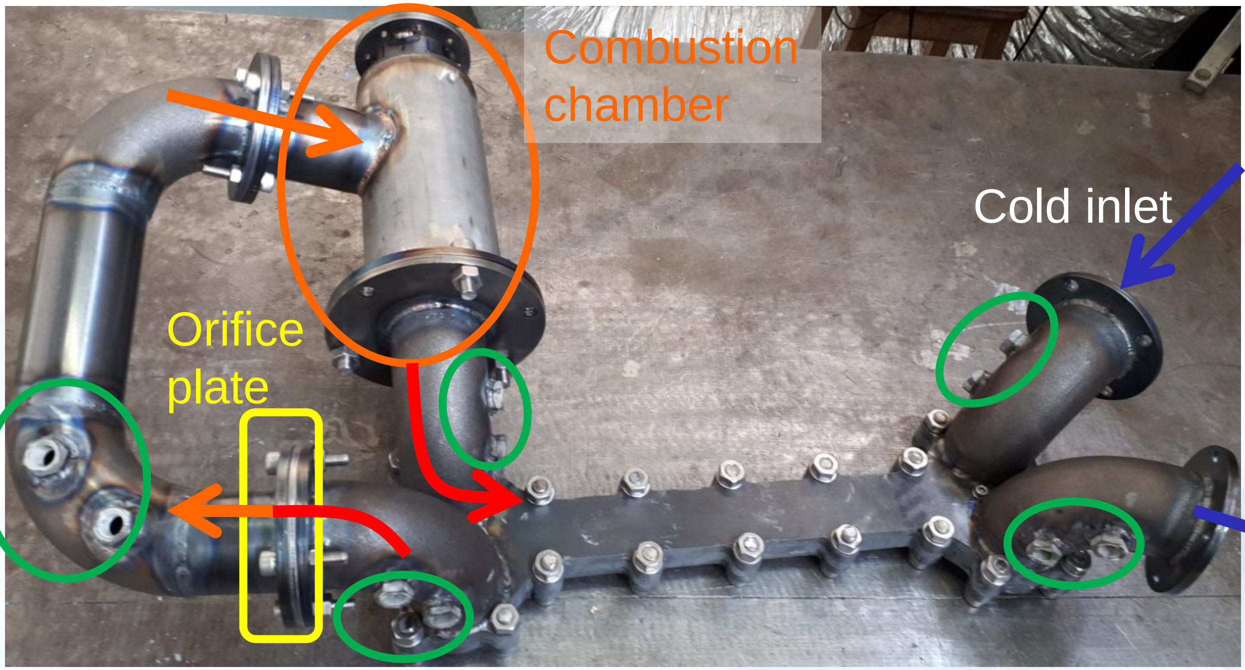
- Variable geometries and configurations.

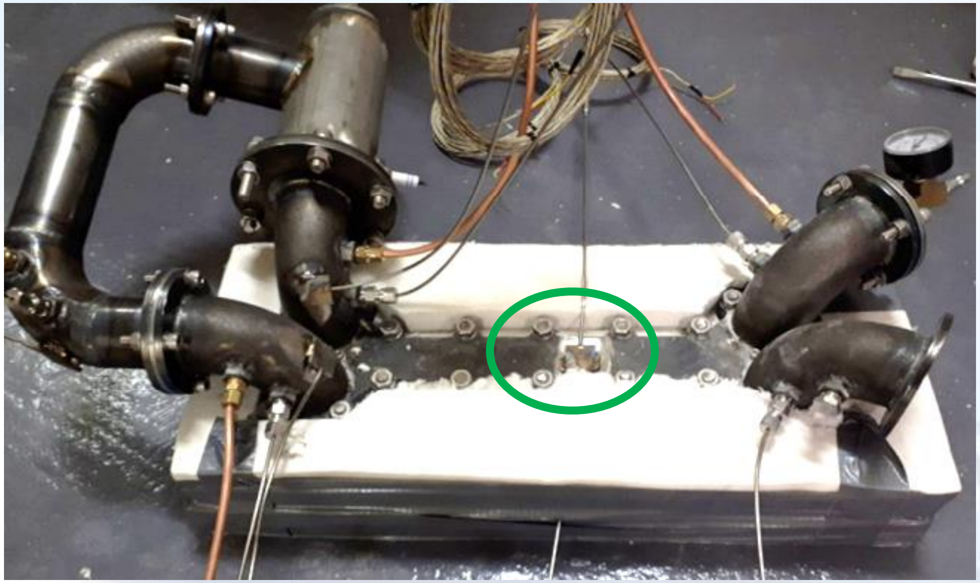
Experimental Setup

Recuperator assembly with sealant.



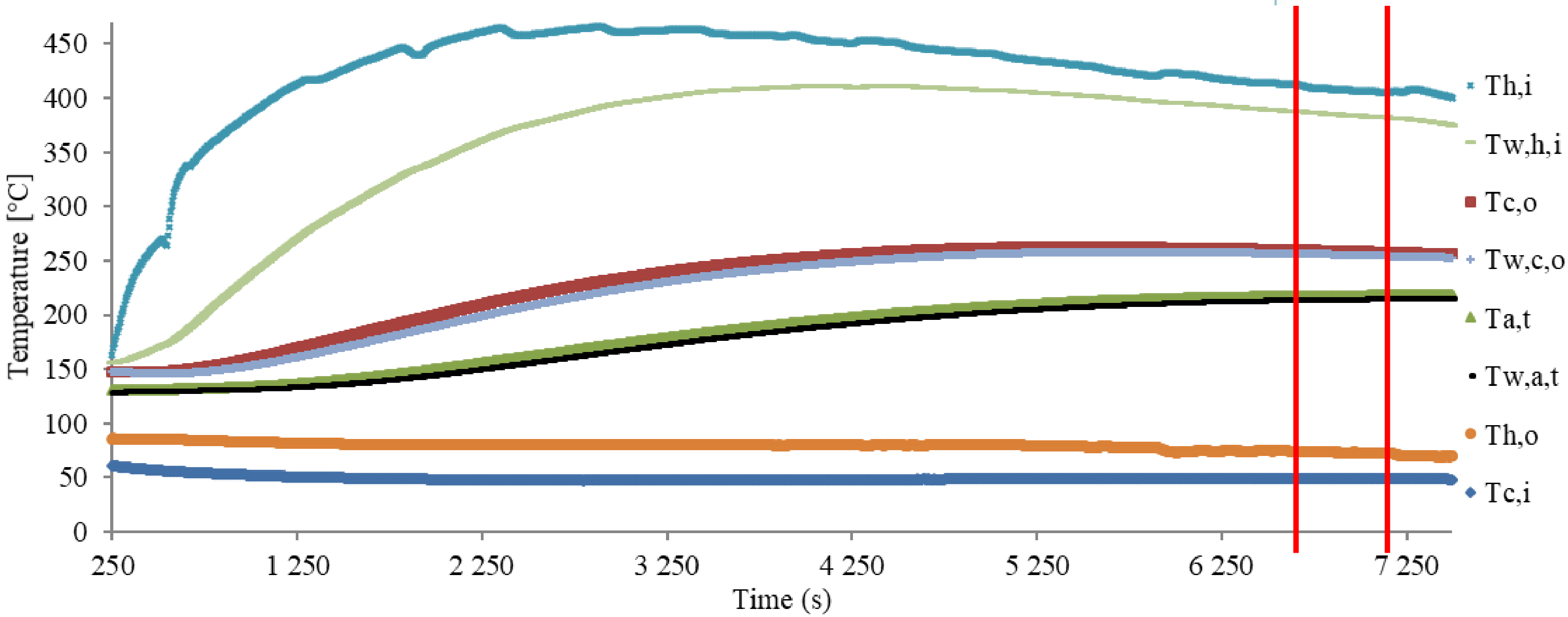
Experimental Setup





Preliminary experimental testing: Research lab prototype.

Results

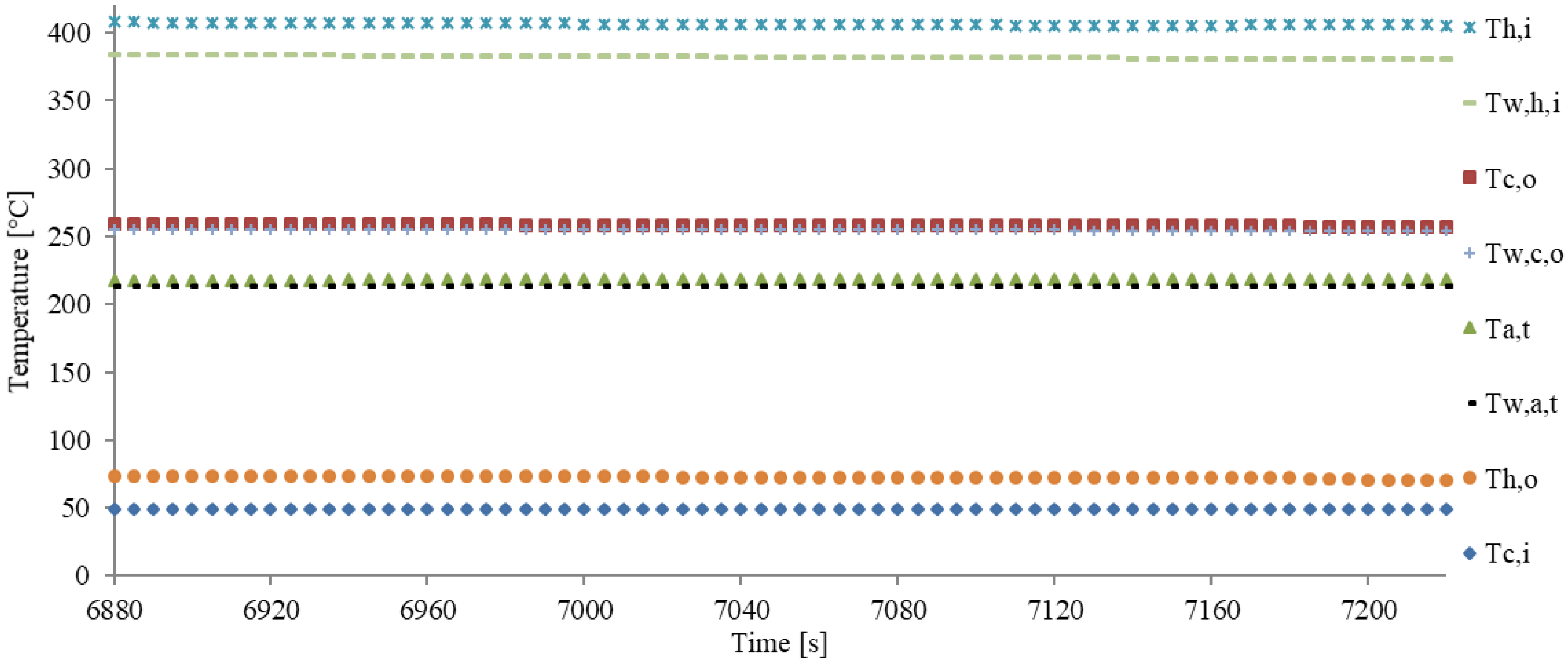


Measured thermocouple temperatures vs. time (Dellar et al., 2018).

- Steady state occurs from 6 880 to 7 220 seconds.

Dellar, K.E., Le Roux, W.G., Meyer, J.P., “Experimental testing of a small-scale solar thermal Brayton cycle recuperator”, IHTC16-23587, International Heat Transfer Conference Proceedings (IHTC, Beijing, China, 2018).

Results



- $T_{h,i}$ = 406 ˚C
- Effectiveness = 59 %
- Total heat loss = 68 W (0,03% error)
- Total pressure loss = 46 kPa (0,02% error)

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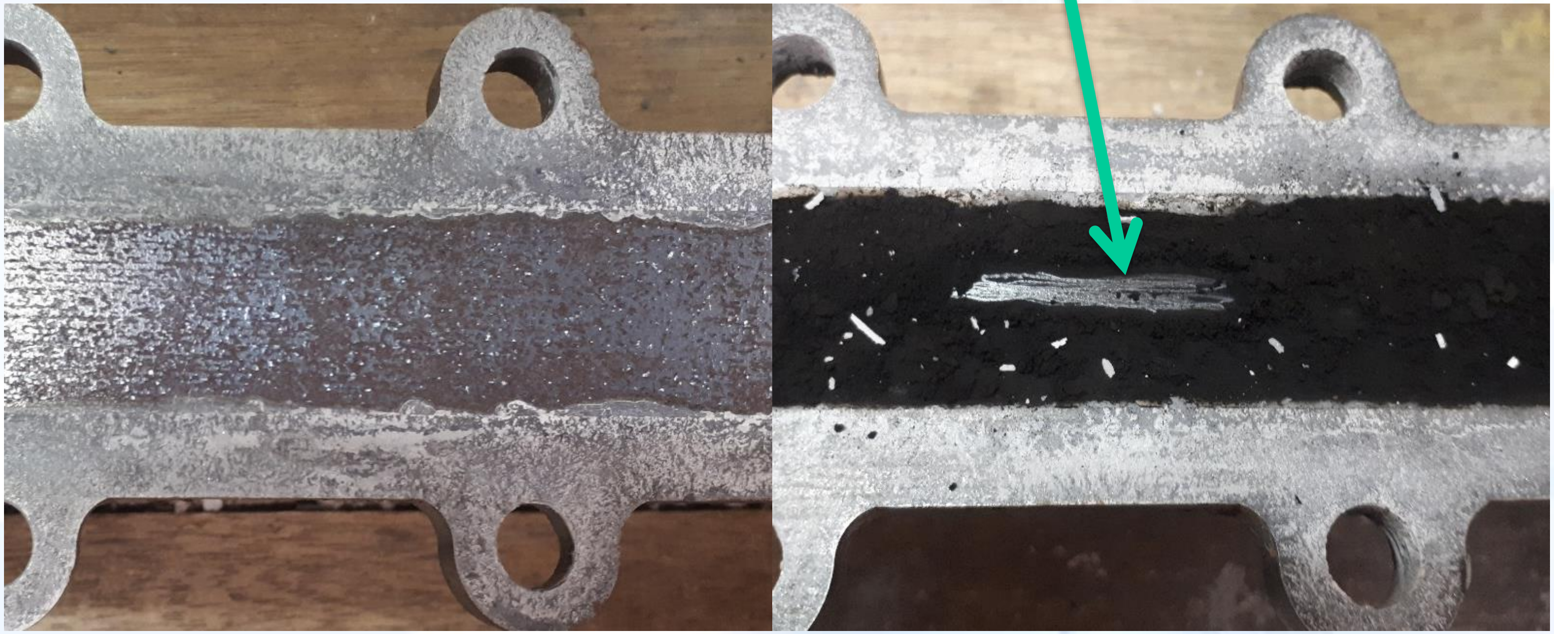
Results

"Clean" channel after use.

Fouling layer due to soot build up.



- Thickness varies between 0,2 mm and 0,4 mm.

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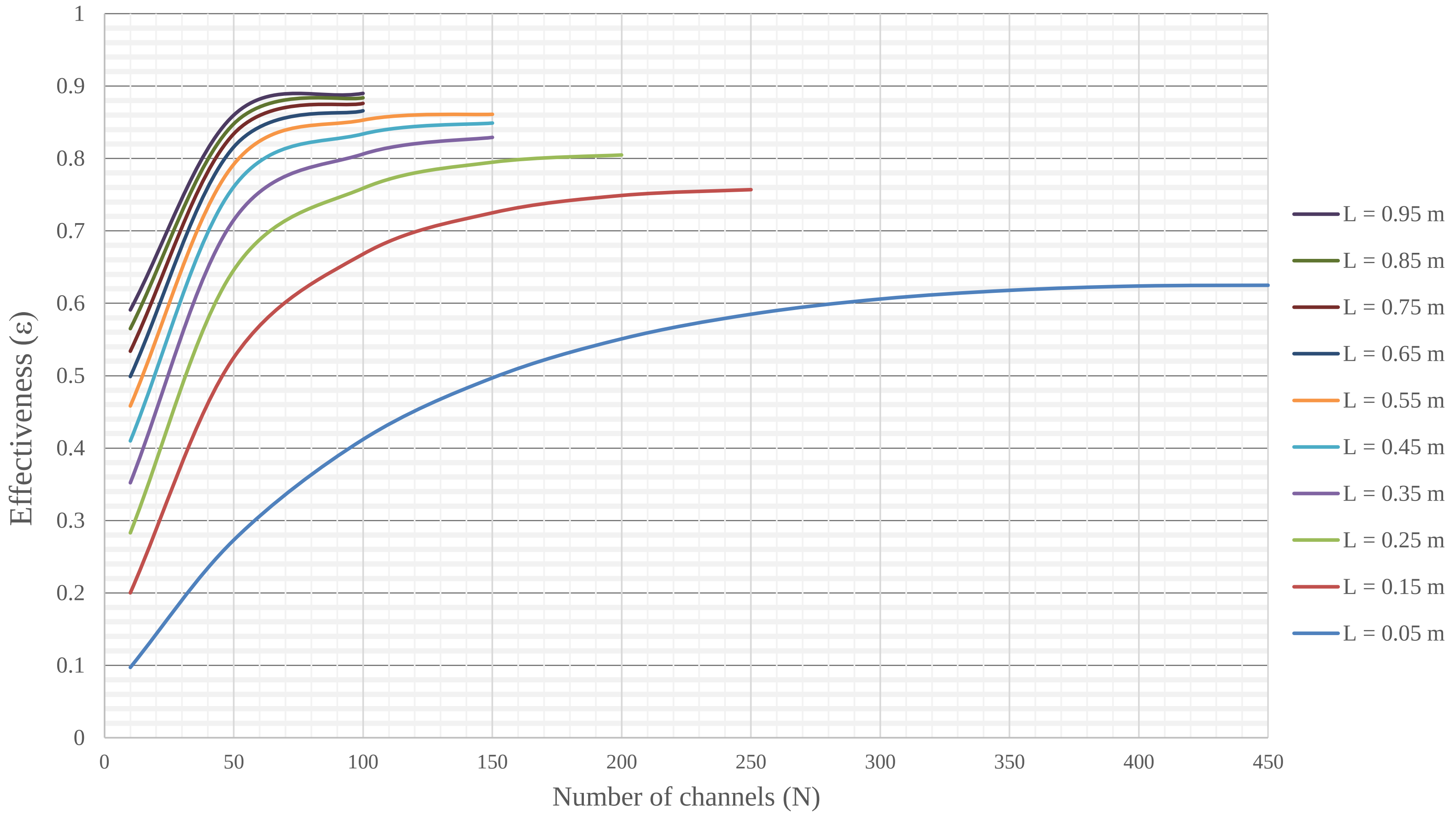
Results



- Effectiveness vs. number of channels at various channel lengths

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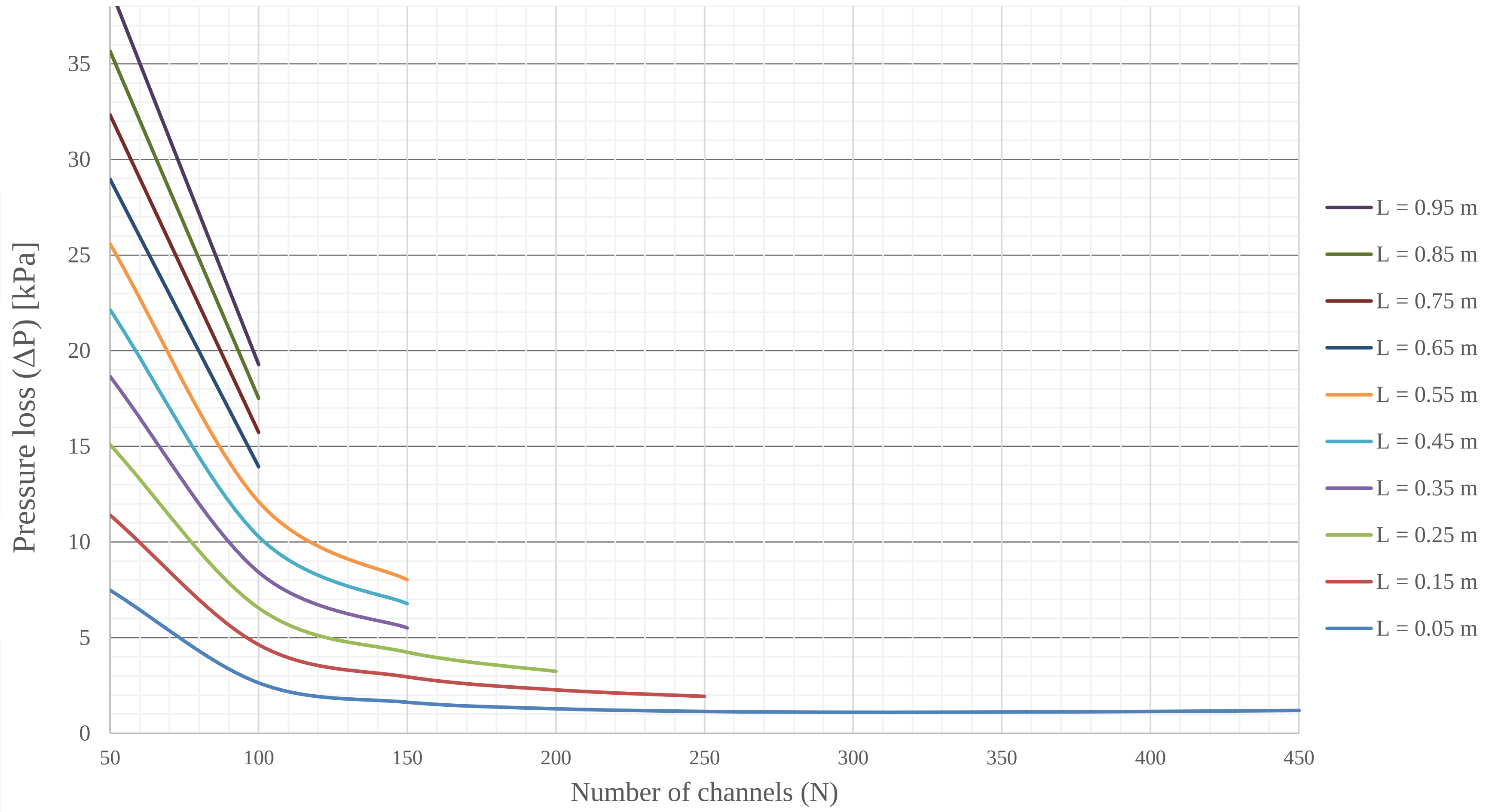
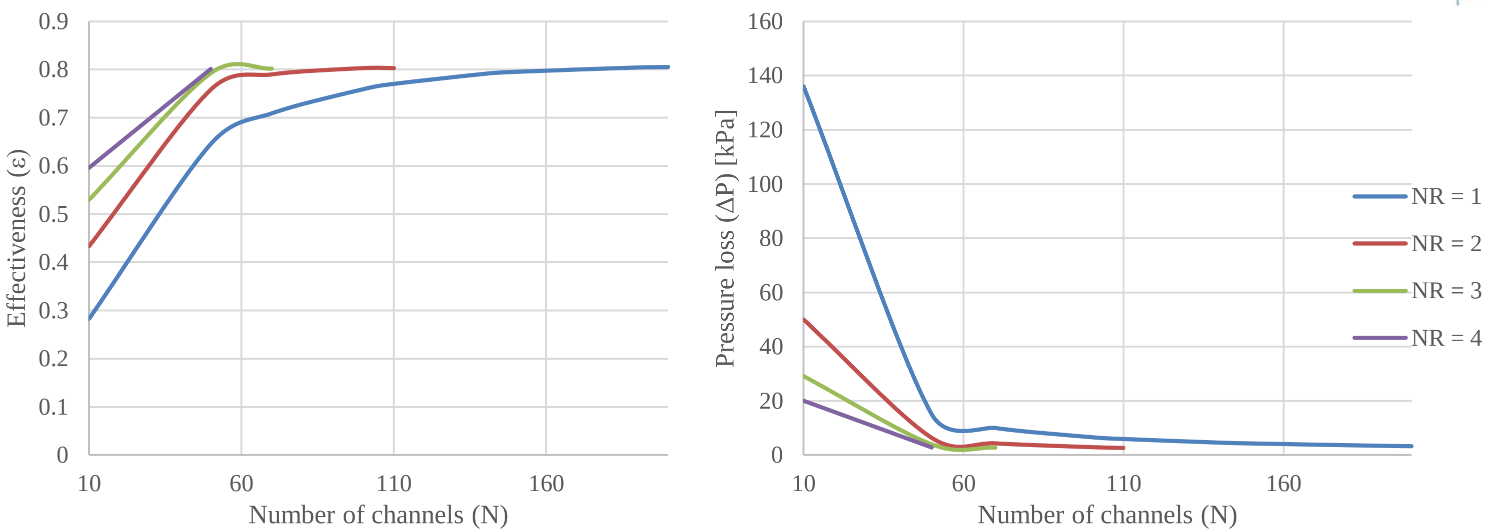
Results

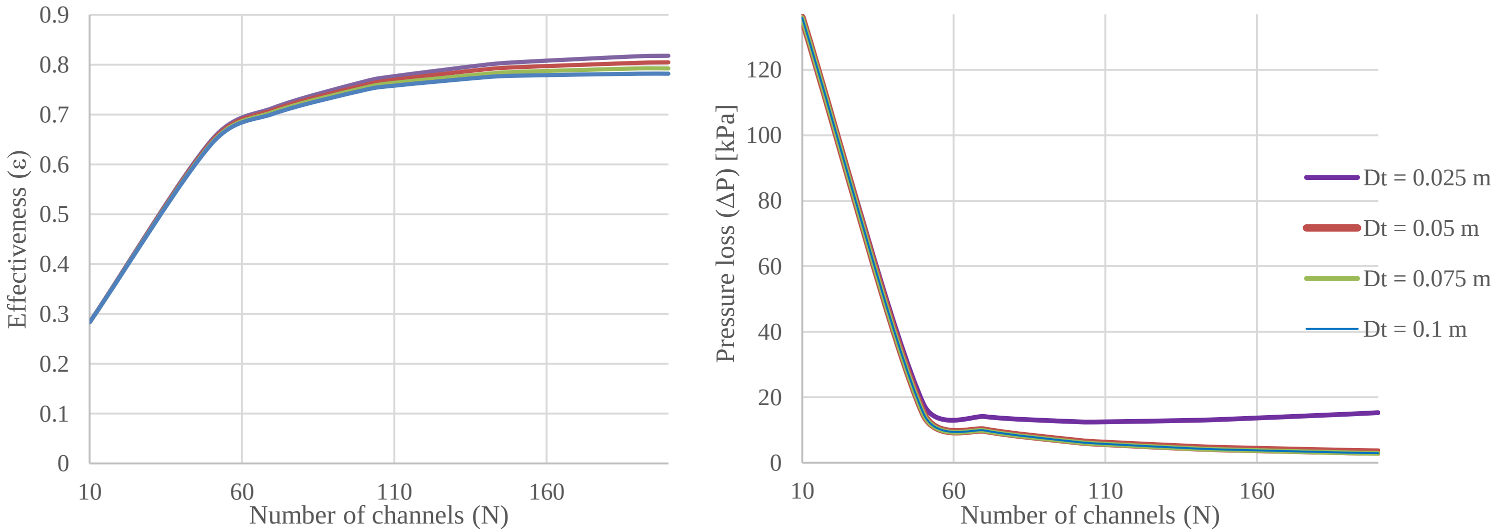


- Pressure loss vs. number of channels at various channel lengths.

Results



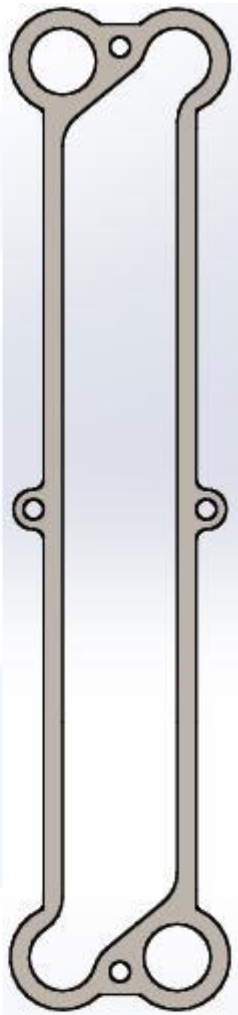
Varying number of recuperators.



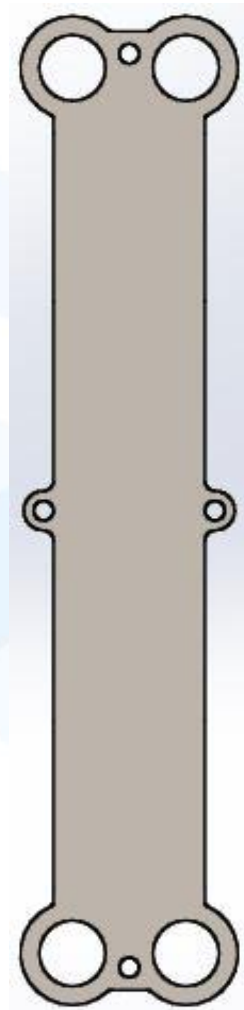
Varying manifold tube diameter.

Future work

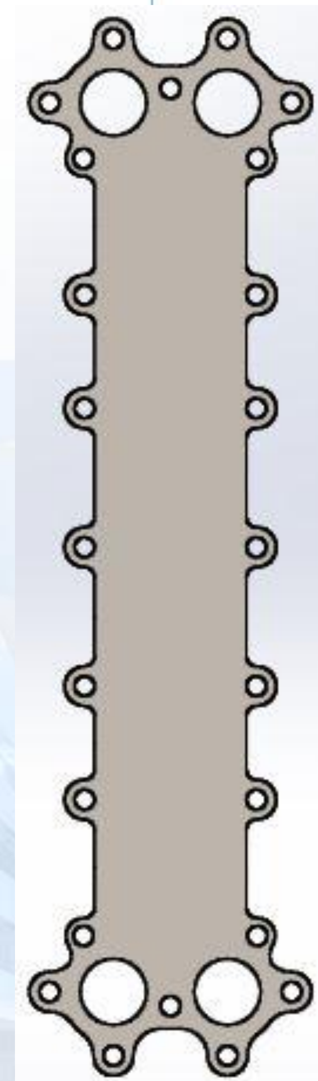
Gasket



Plate



End-plate



Conclusion

- The physical construction was simple, cost effective and the clamped plate, high temperature sealant combination worked very well together.
- The theoretical model accurately predicts the performance of proposed designs.
- The effectiveness values attained are not ideal for the STBC according to the initial cycle analysis (Entropy generation and minimisation).
- Has many potential waste heat extraction uses, where an economical solution is required.

Recommendations

- More data should be acquired with the test rig and it should have the following modifications performed:
  - Re-designed combustion chamber to better combust the LPG, increasing the temperatures and preventing excess fouling from soot.
  - More weld-pad thermocouples should be added to measure the surface of the recuperator to get a better representation of the temperature gradients, and the same must be done on the surface of the insulation.
  - The test-rig must be further insulated, to minimise potential heat losses that are un-accounted for in this analysis.
- Larger mass flow rates could be explored.
- Other geometries should be utilised to gather a wider range of data.

Acknowledgments

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Thank you

Any
Questions?

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