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

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2019/07/11

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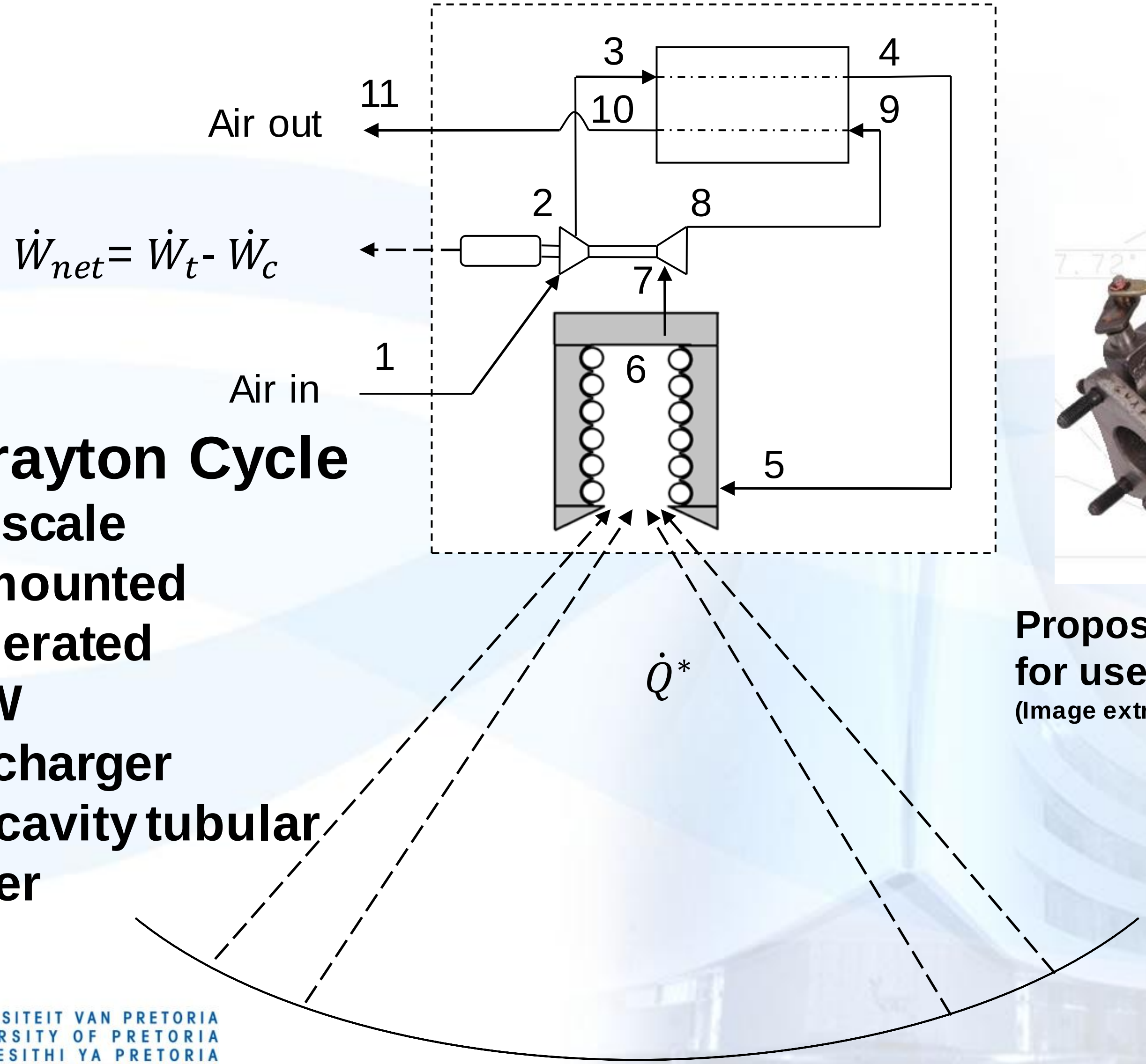
STERG
SOLAR THERMAL ENERGY RESEARCH GROUP

1. Background
Solar thermal Brayton cycle



Solar Brayton Cycle

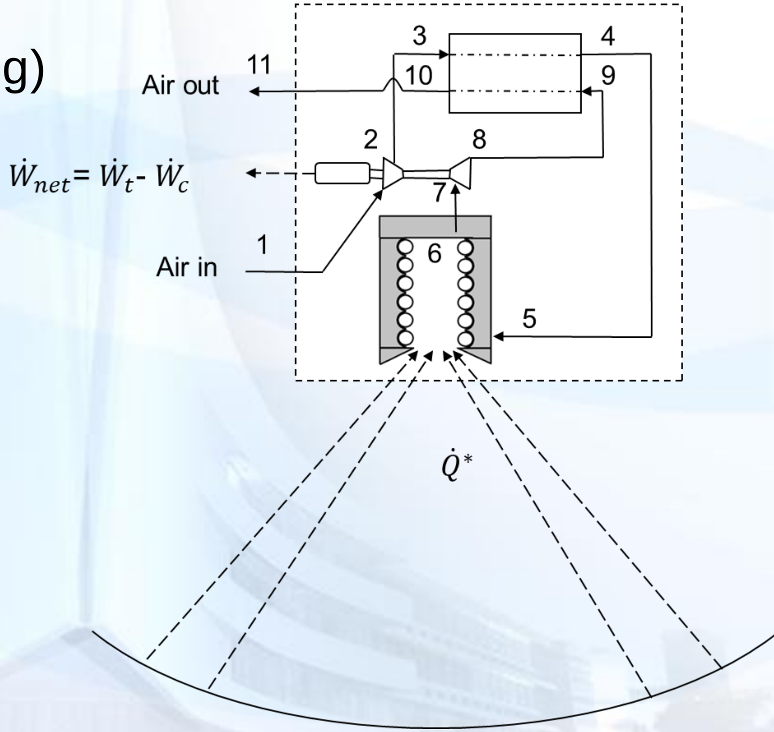
- Small-scale
- Dish-mounted
- Recuperated
- 1-20kW
- Turbocharger
- Open-cavity tubular receiver

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

Solar thermal Brayton cycle

Prototype under construction

- TIA Funding
- RDP Funding
- NRF (IPRR)

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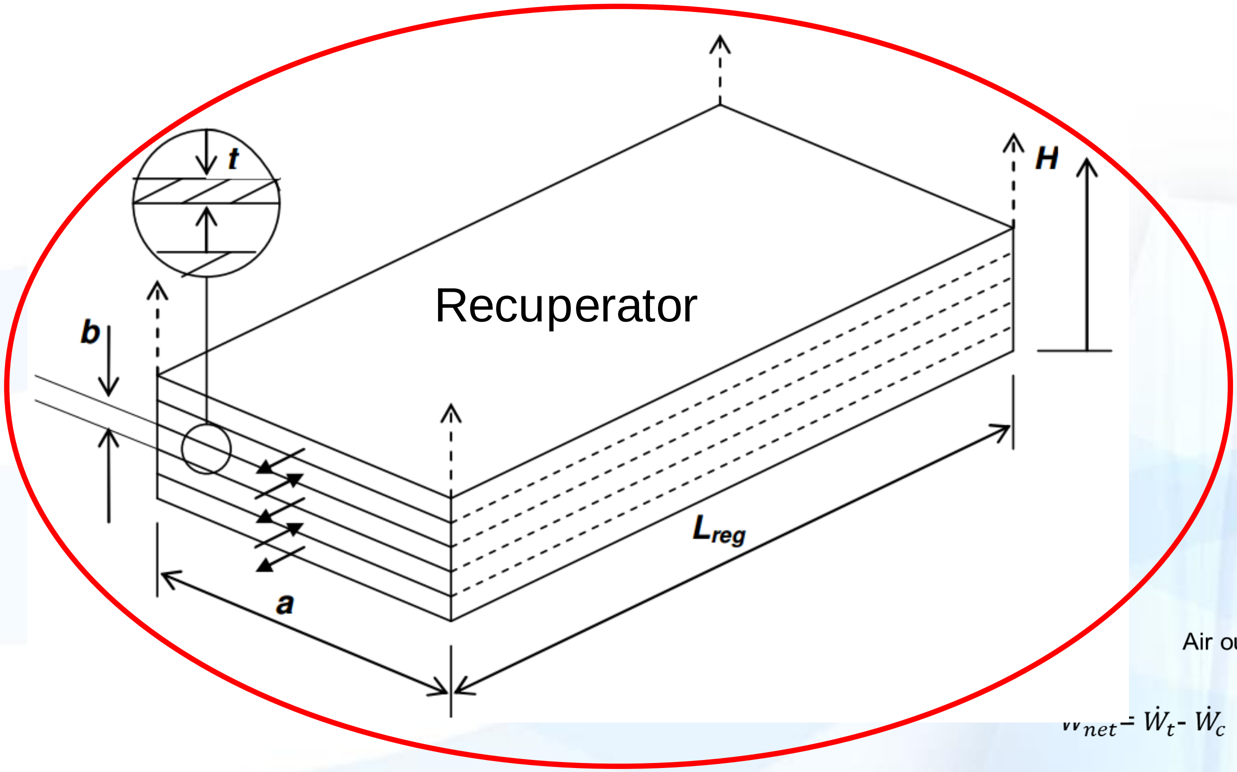
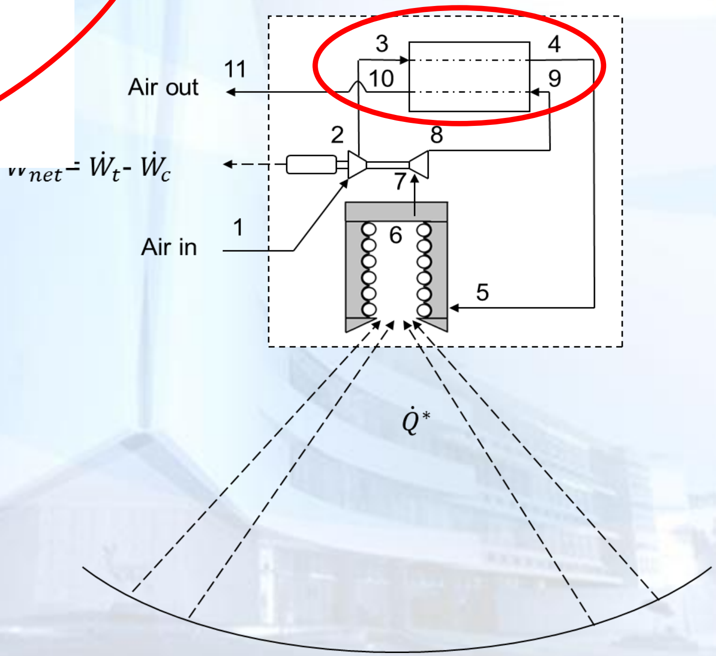
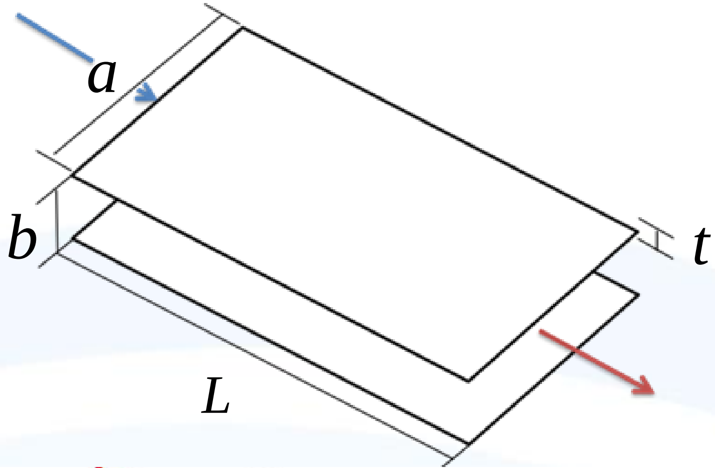
2018 version

Solar thermal Brayton cycle

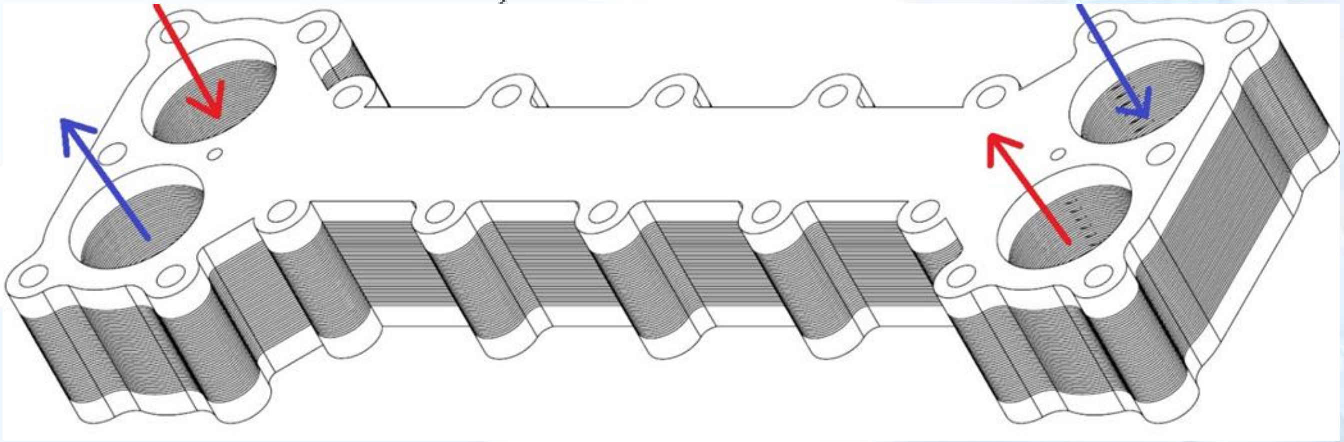




Theoretical model



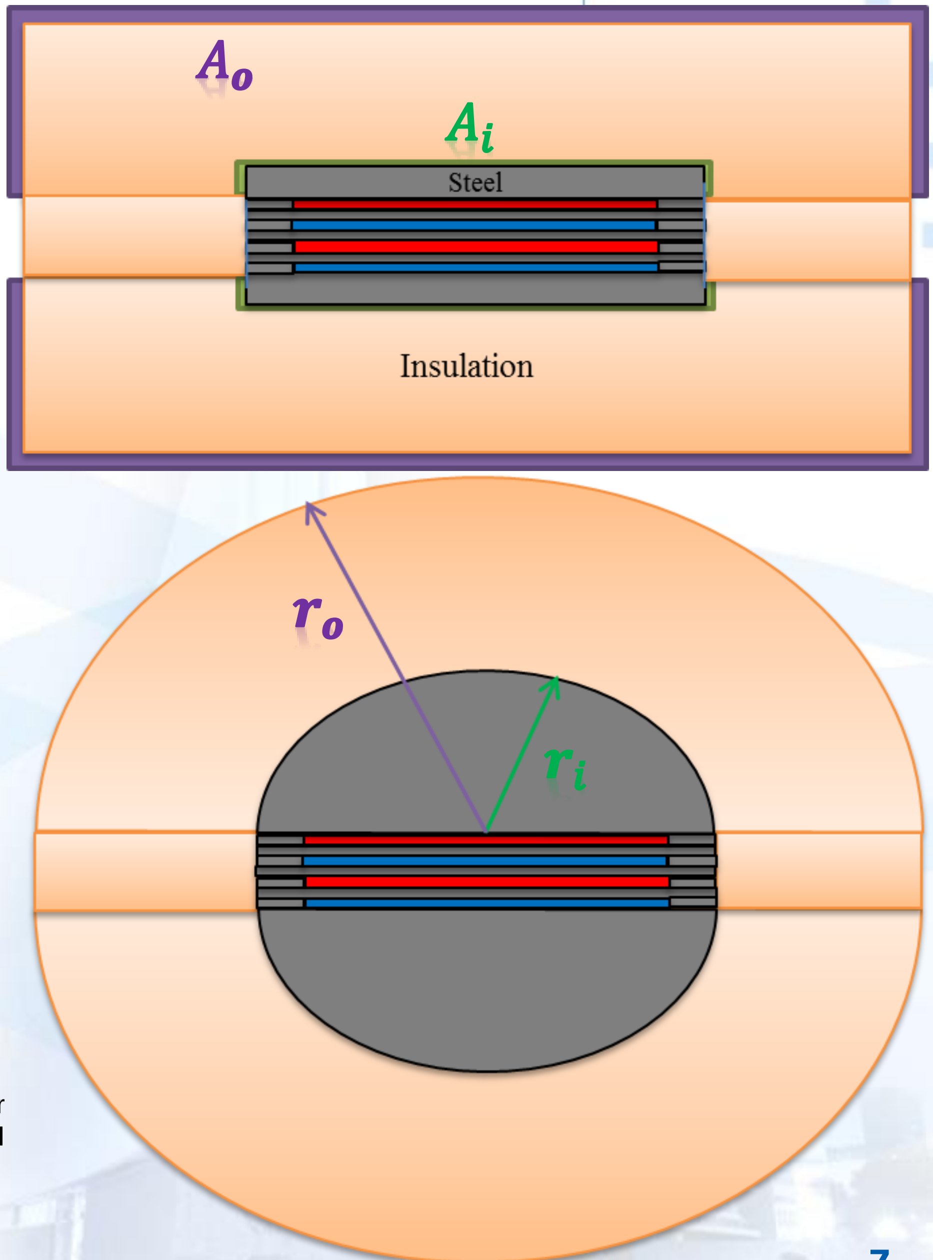
- Simplified counter-flow arrangement



- Effectiveness-NTU method with heat loss analysis.

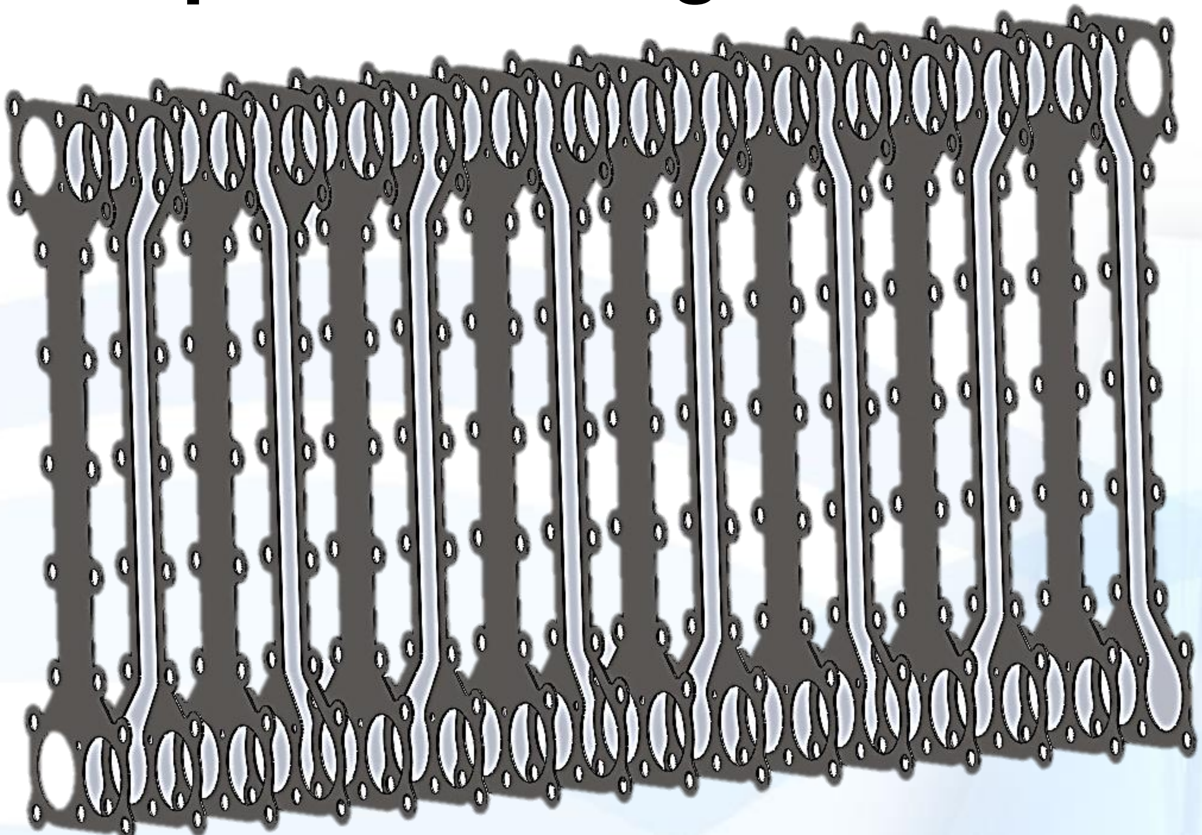
Heat loss model

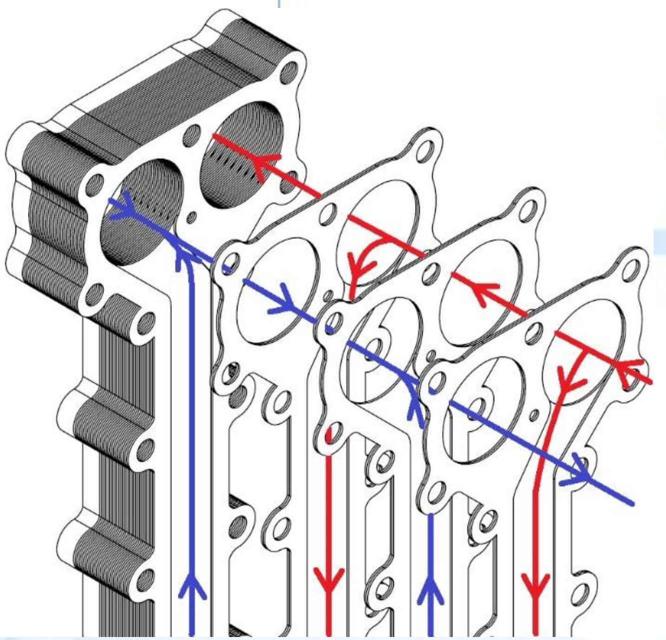
- $$\varepsilon_h = \begin{cases} 1-\theta_{X=1}, & C_{rh} < 1 \\ C_{rh}(1-\theta_{X=1}), & C_{rh} > 1 \end{cases}$$
- $$\varepsilon_c = \begin{cases} (1-\theta_{X=0})/C_{rh}, & C_{rh} < 1 \\ 1-\theta_{X=0}, & C_{rh} > 1 \end{cases}$$
- $$\theta_{X=0} = \frac{B+(\chi_h+C_{rh}\cdot\chi_c)[]}{(C_{rh}-1)[e^{NTU_h(C_{rh}-1)}-1/C_{rh}]}$$
- $$\theta_{X=1} = NTU_h(\chi_c+\chi_h) + \frac{(\theta_{X=0}-1)}{C_{rh}} + 1$$
- $$\chi_{[h|c]} = -\frac{\dot{Q}_{loss,[h|c]}}{UA(T_{h,i}-T_{c,i})}$$



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



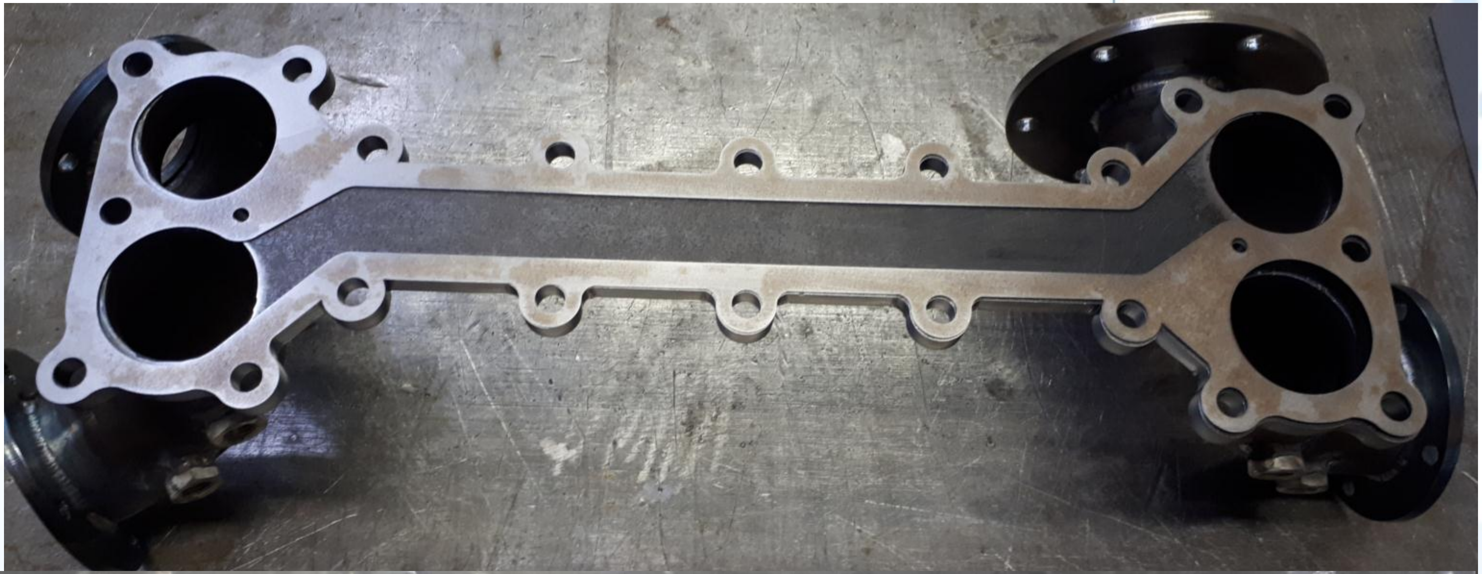


Stacked plate design

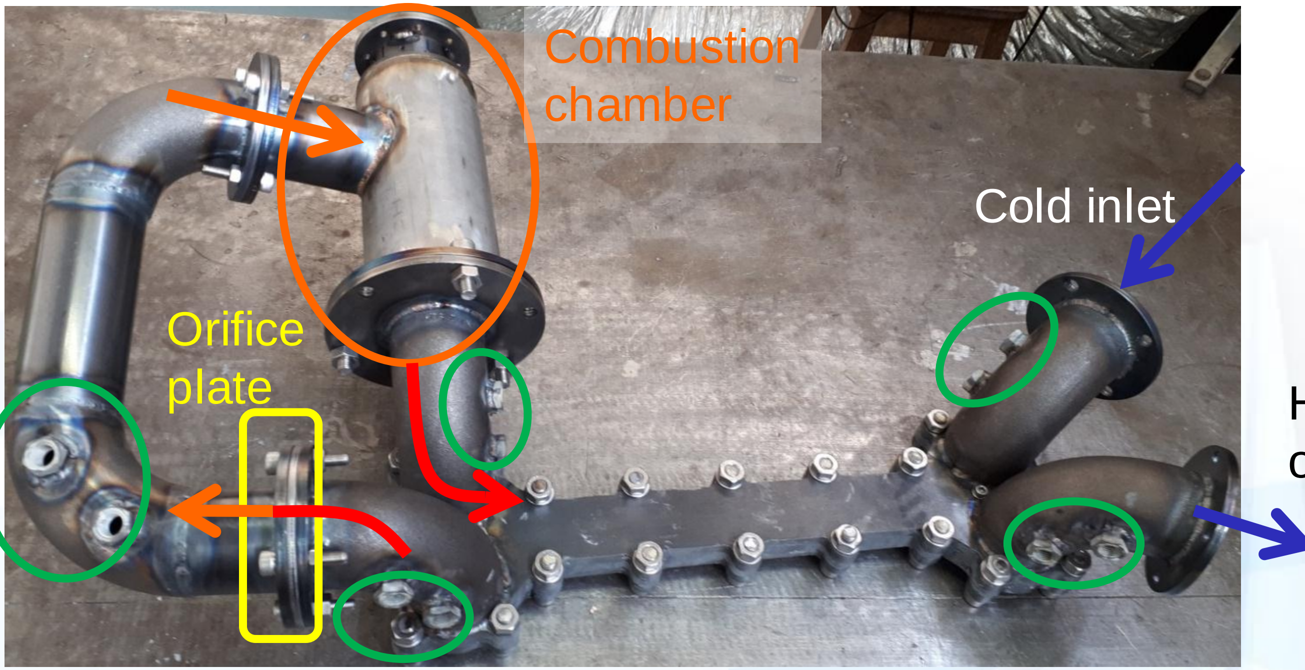
- Variable geometries and configurations.

Experimental Setup

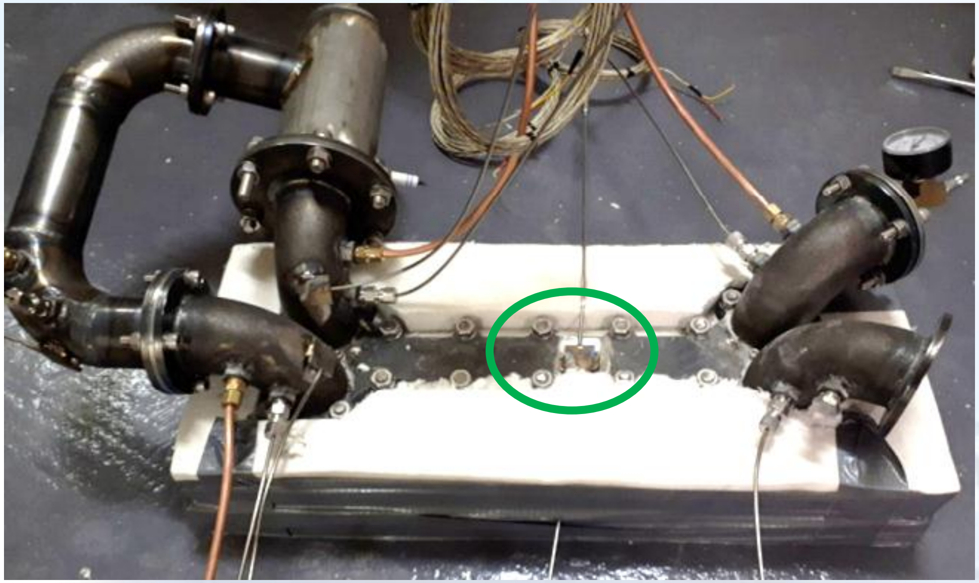
Recuperator assembly with sealant.



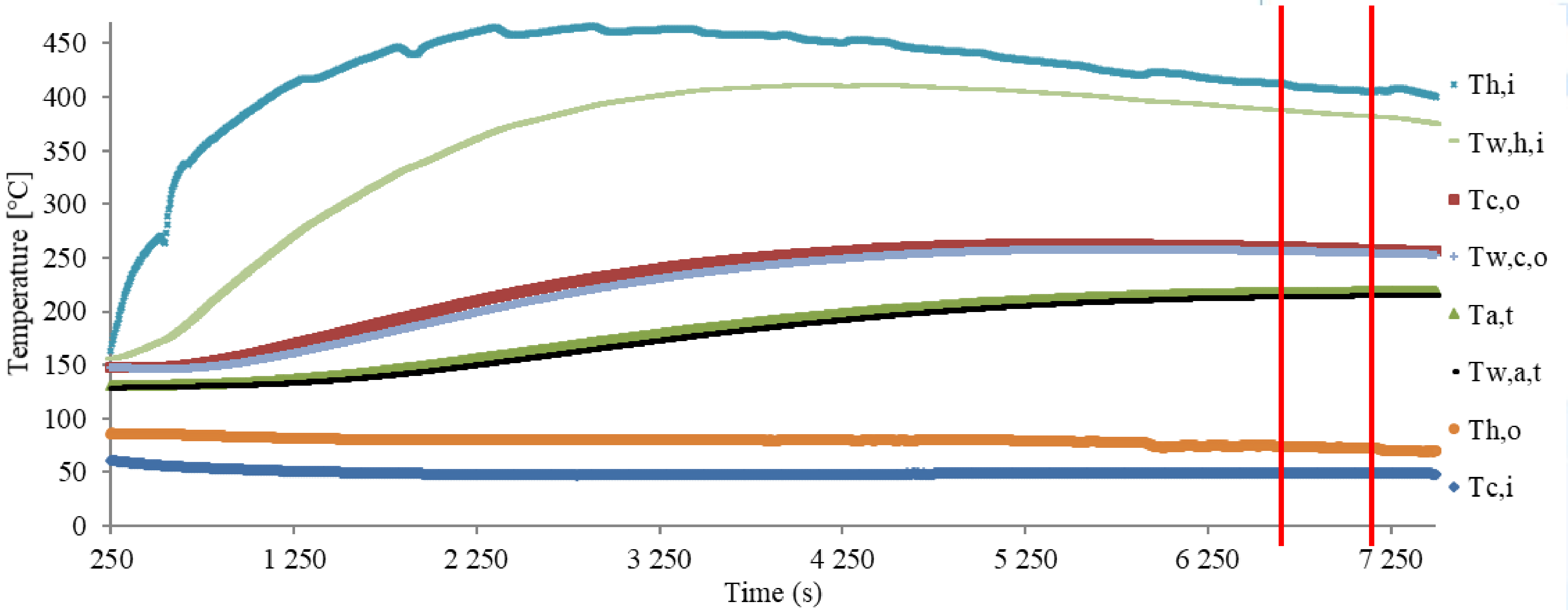
Experimental Setup



Preliminary experimental testing: Research lab prototype.



Results

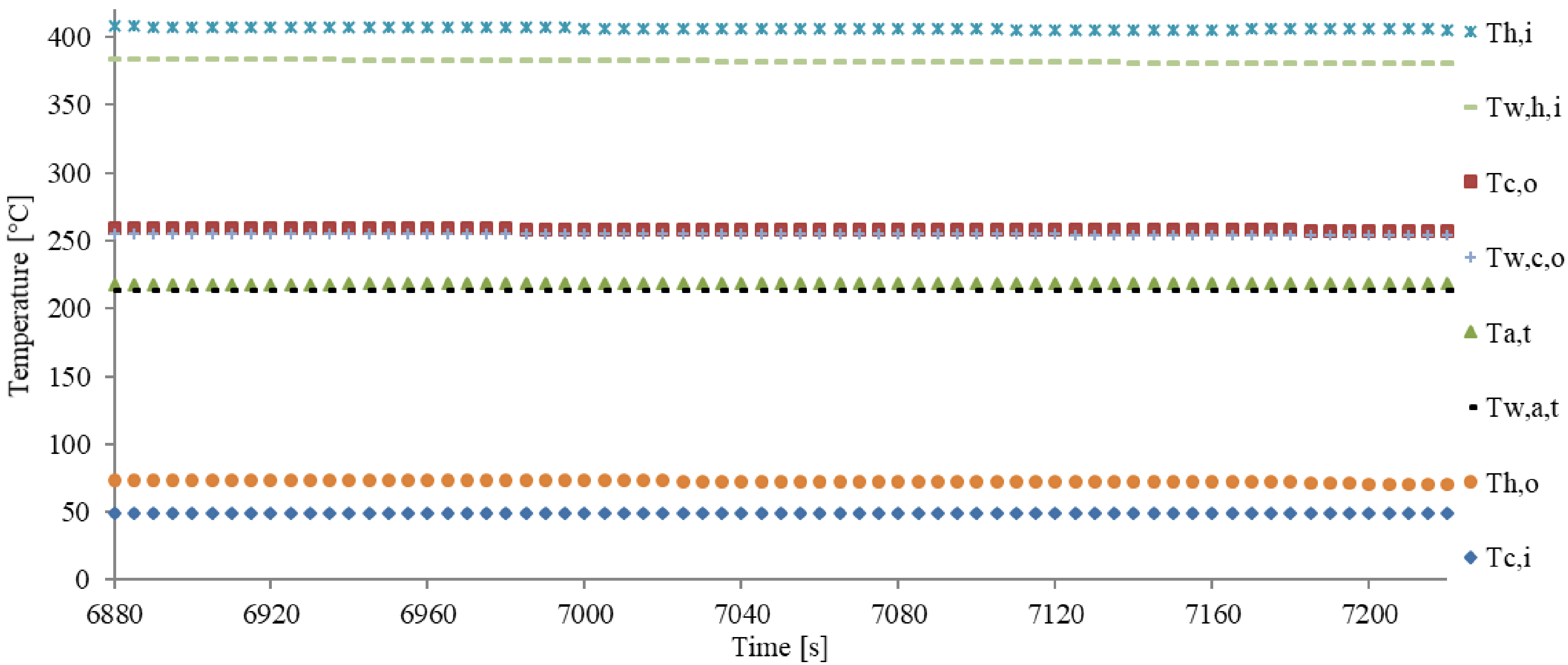


Measured thermocouple temperatures vs. time (Dellar et al., 2018).

- 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

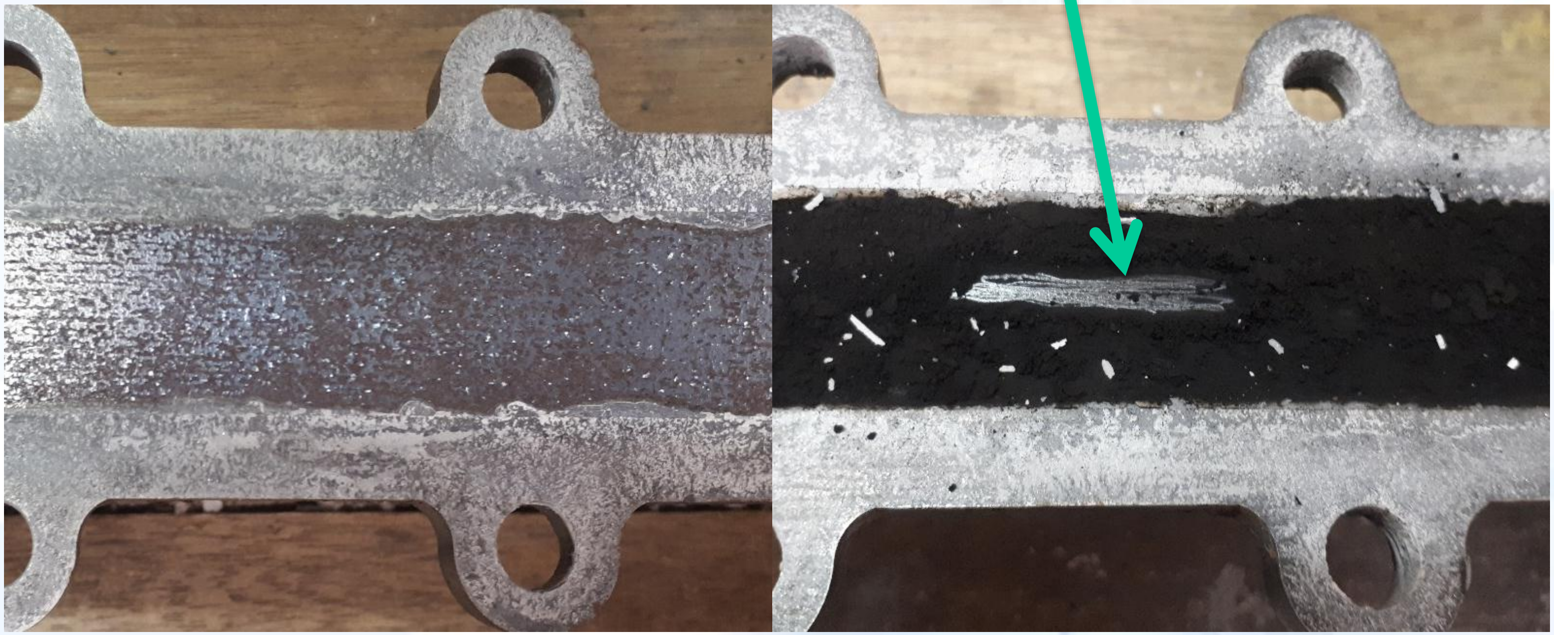


- $T_{h,i}$ = 406 ˚C
- Effectiveness = 59 %
- Total heat loss = 68 W (0,03% error)
- Total pressure loss = 46 kPa (0,02% error)

Results

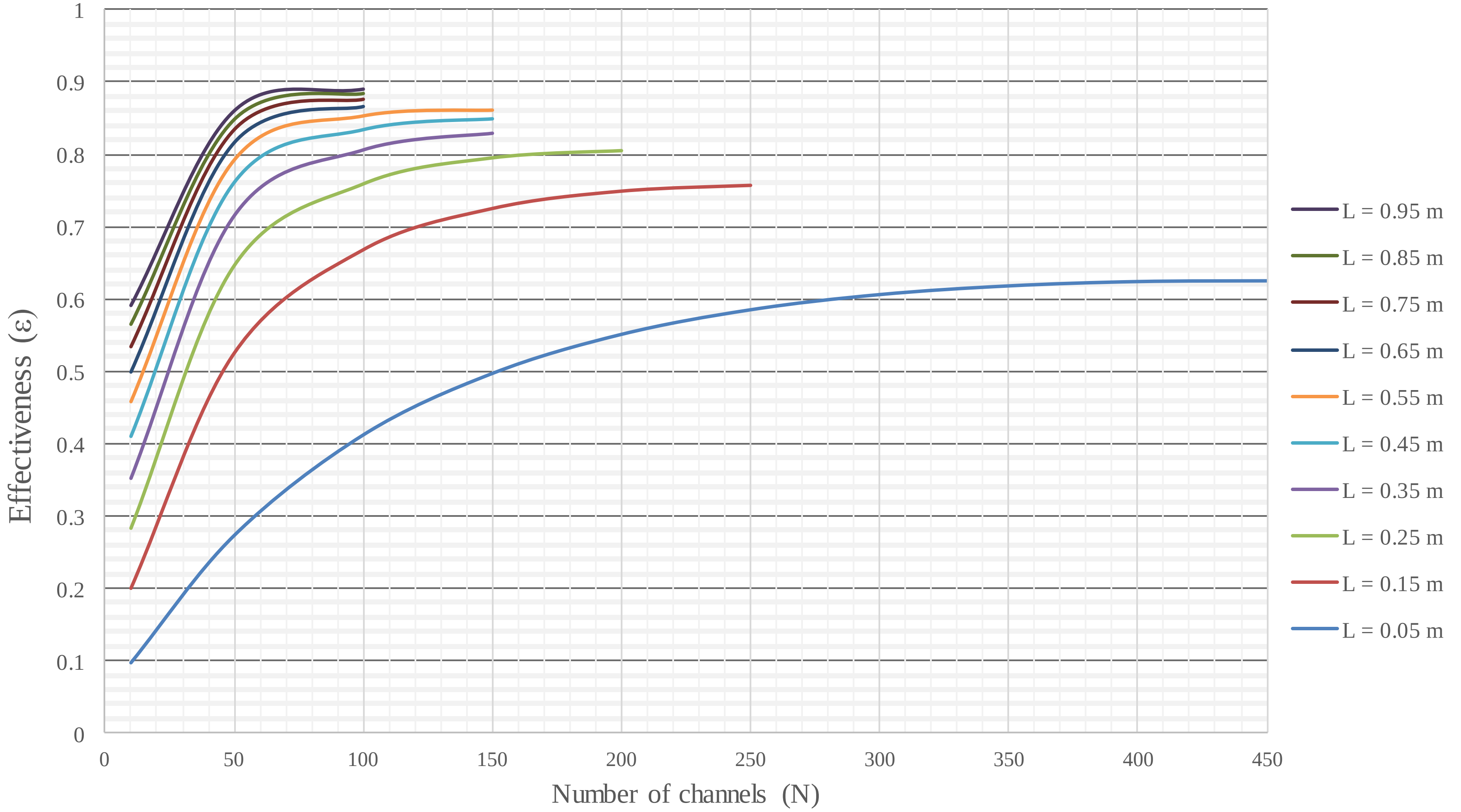
"Clean" channel after use.

Fouling layer due to soot build up.



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

Results



- Effectiveness vs. number of channels at various channel lengths

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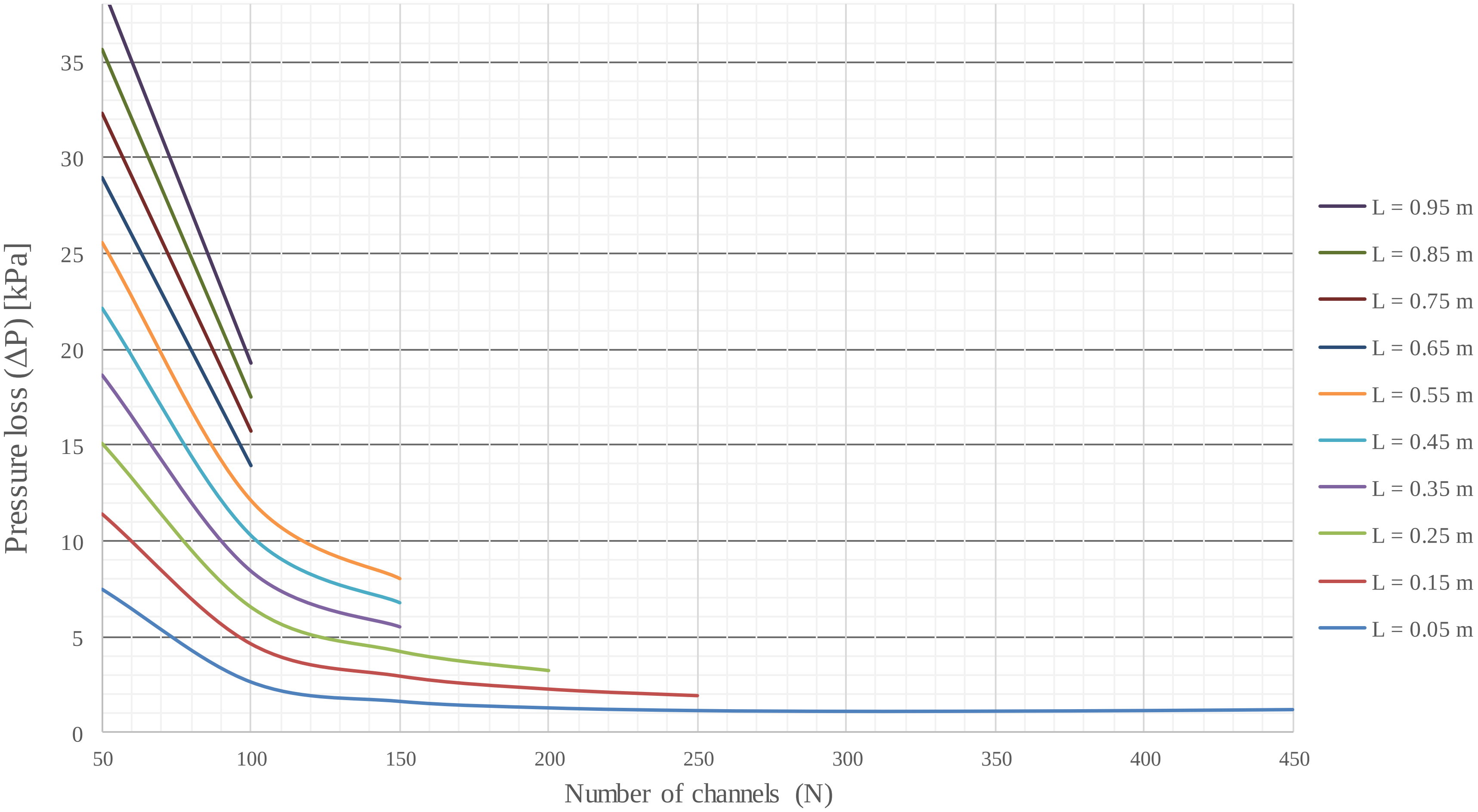
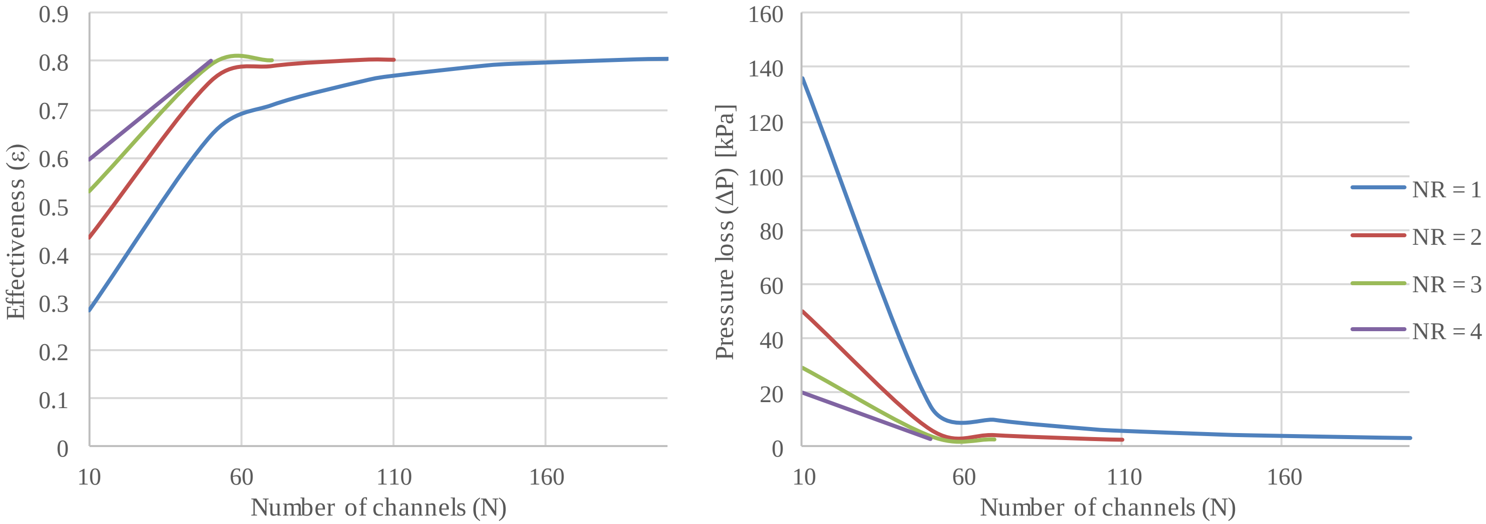
Results

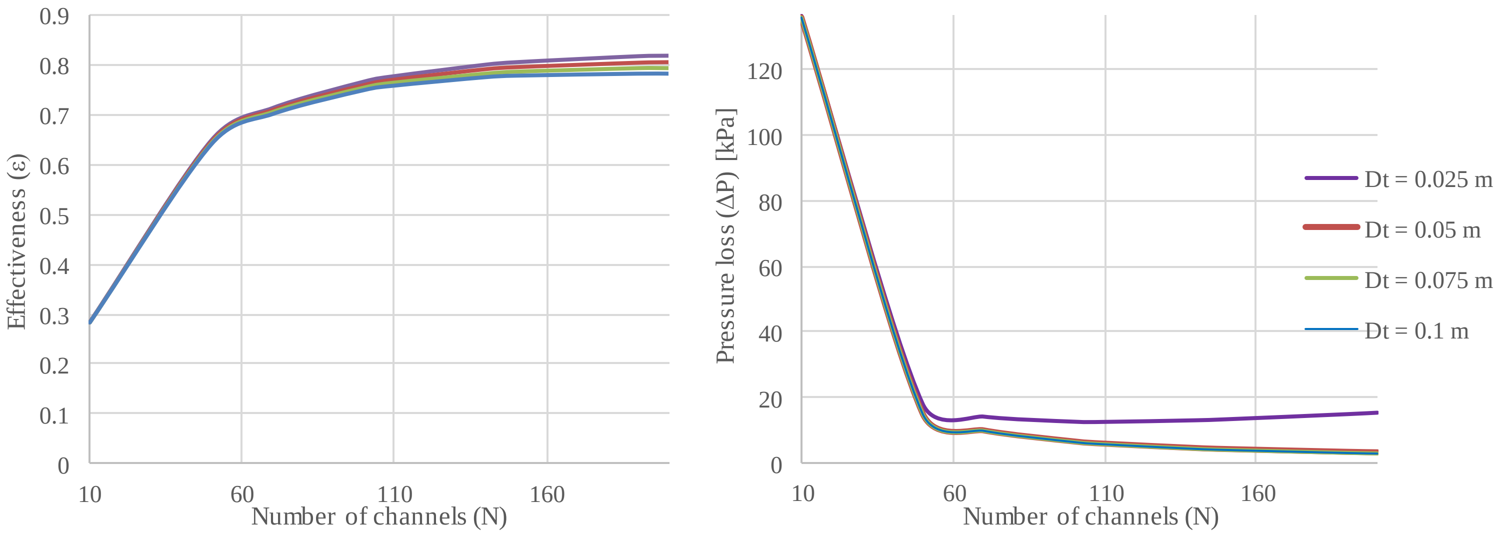


- Pressure loss vs. number of channels at various channel lengths.

Results



Varying number of recuperators.



Varying manifold tube diameter.

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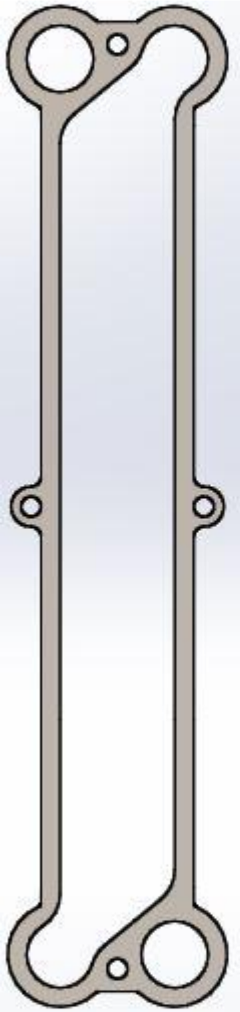
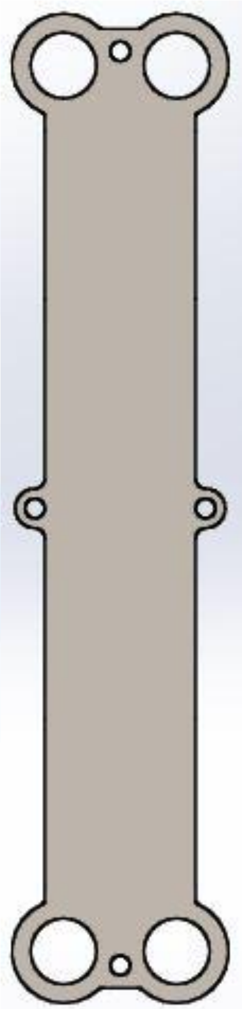
Future work

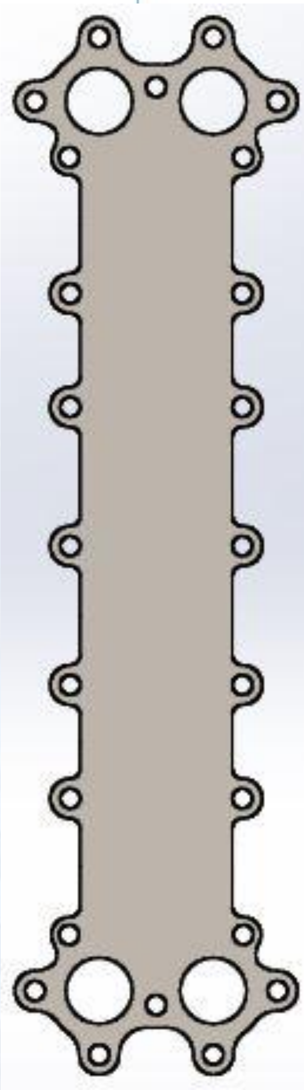
Gasket



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

- This work is based on the research supported by the Technology and Innovation Agency (**TIA**), the National Research Foundation (**NRF**) and the University of Pretoria's Research and Development Plan (**RDP**).

- The author would like to thank Dr Willem le Roux for being a great supervisor and mentor and Prof J.P. Meyer for being co-supervisor.

Thank you

Any
Questions?

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