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Thermodynamic optimisation of an open-air solar thermal Brayton cycle with fixed temperature constraints

by

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Process followed

1. Introduction
2. Literature review
3. Problem definition
4. Numerical model
5. Results
6. Conclusions

Introduction

- Currently, the majority of the world's energy supply is generated from fossil fuels. Unfortunately fossil fuel supply is decreasing, while demand increases daily.
- Renewable energy systems are viable solutions when considering future electricity generation.
- Of these systems, solar systems are well worth investigating as solar radiation is readily available on a frequent basis, all across the globe.

Literature review

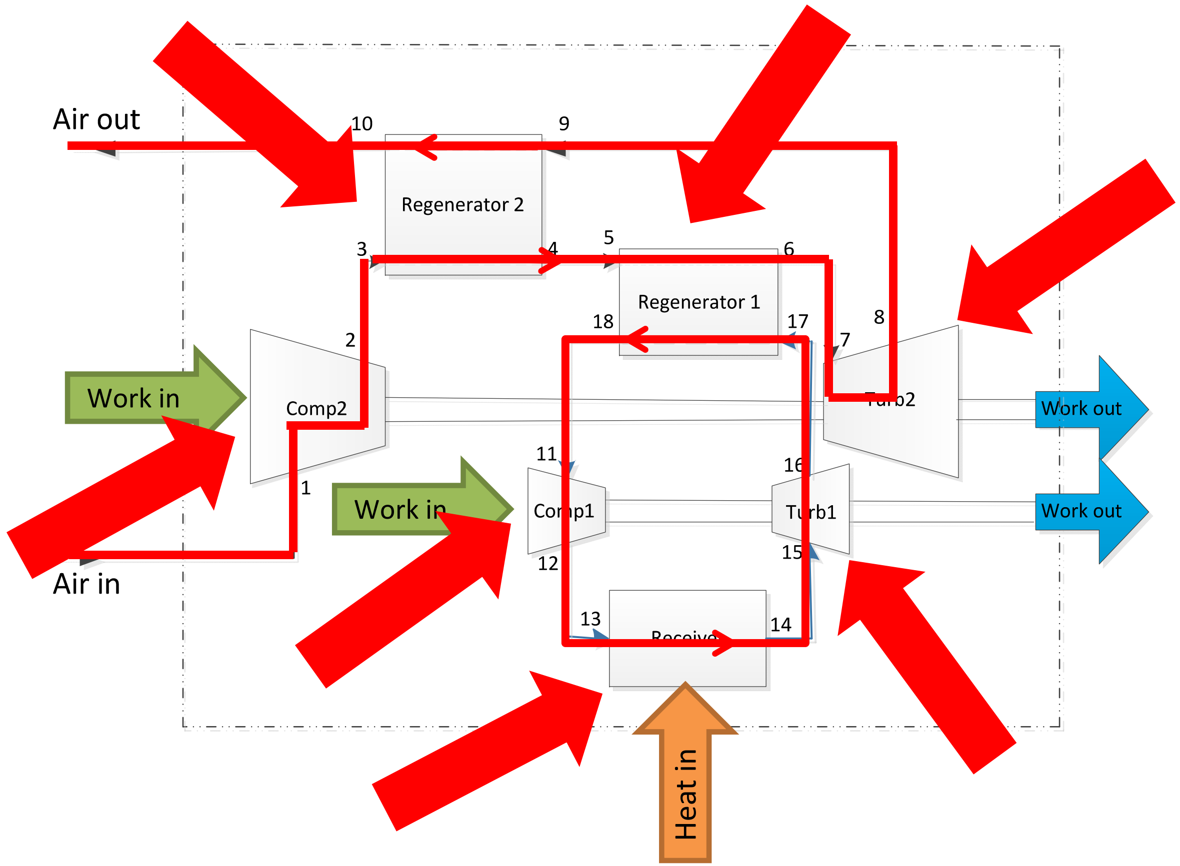
1. Thermal power cycles
   - Brayton cycle with regeneration
2. Types of solar collectors
   - Parabolic dish collector with modified cavity receiver at focal point

Literature review

3. Thermodynamics
   - Second law of thermodynamics
   - Entropy and entropy generation minimisation
   - Exergy and exergy destruction
4. Irreversibilities and Losses
   - Impossible for a system to go back to its original form.

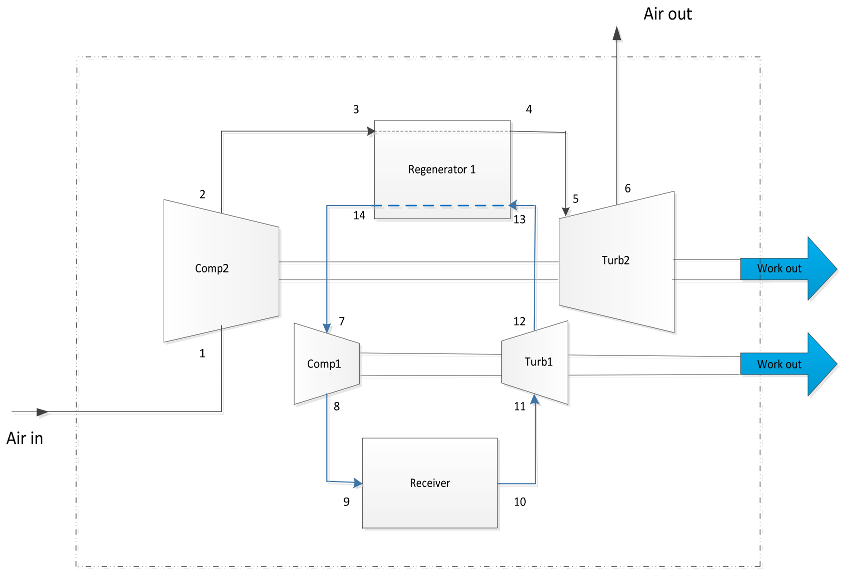
Problem definition: Physical model

- The double open-air solar thermal Brayton cycle

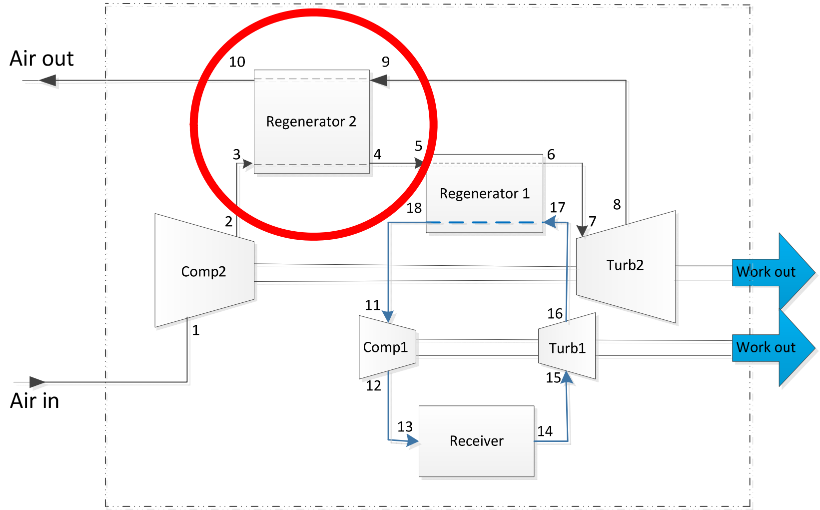


Comparison of cycles

- The single vs. the double open-air solar thermal Brayton cycle



Single



Double

Problem definition

- The objective function

Gouy-Stodola theorem: The entropy generation in a system will be proportional to the lost available work for that same system. For this reason, the sum of all the generated entropy rates in the system can be used to illustrate the maximum net power output.

Exergy destruction

Transfer by heat

Transfer by shaft and boundary work

$$\dot{W}_{net} = -T_0\dot{S}_{gen} + \left(1 - \frac{T_0}{T^*}\right)\dot{Q}^* + \dot{m}C_{p0}(T_{in} - T_{out}) - \dot{m}C_{p0}T_0 \ln\left(\frac{T_{in}}{T_{out}}\right)$$

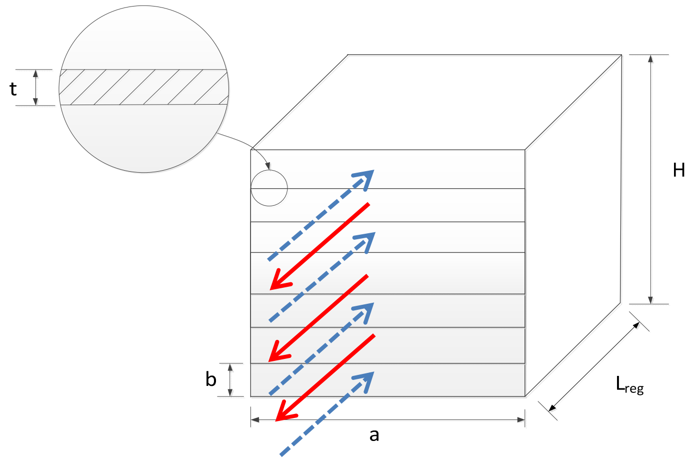
where

$$\dot{S}_{gen} = \dot{S}_{gen,comp} + \dot{S}_{gen,reg} + \dot{S}_{gen,turb} + \dot{S}_{gen,rec} + \dot{S}_{gen,ducts}$$

Problem definition

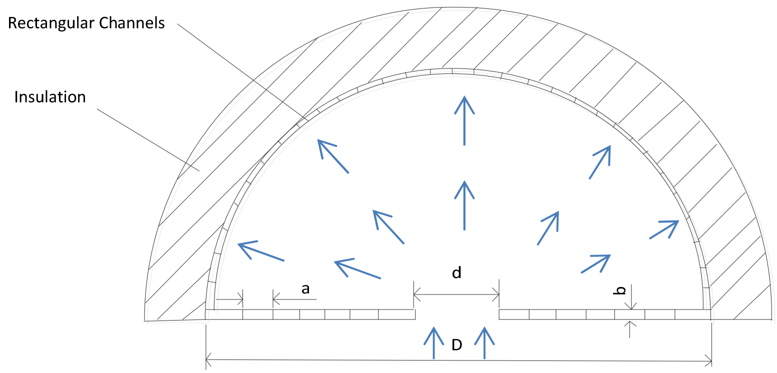
Component parameters:

The regenerators



$(a/b)_{reg}$ D_{hreg} L_{reg}

The receiver



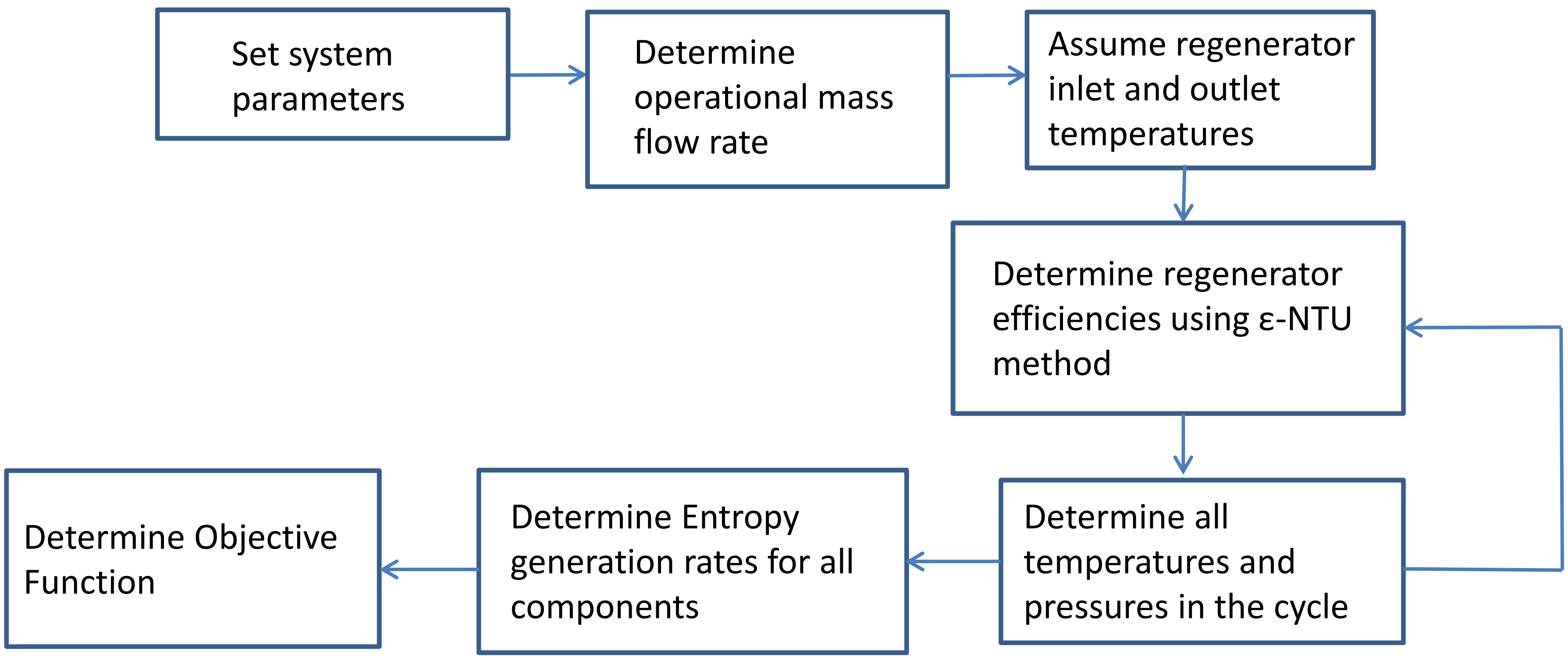
$(a/b)_{rec}$ D_{hrec} L_{rec}

Numerical model

1. Parameters influencing procedure
   - Regenerator and receiver dimensions
   - Choice of temperature for compressor inlet and receiver outlet in primary cycle
   - Turbine choice

Numerical model

2. Program structure

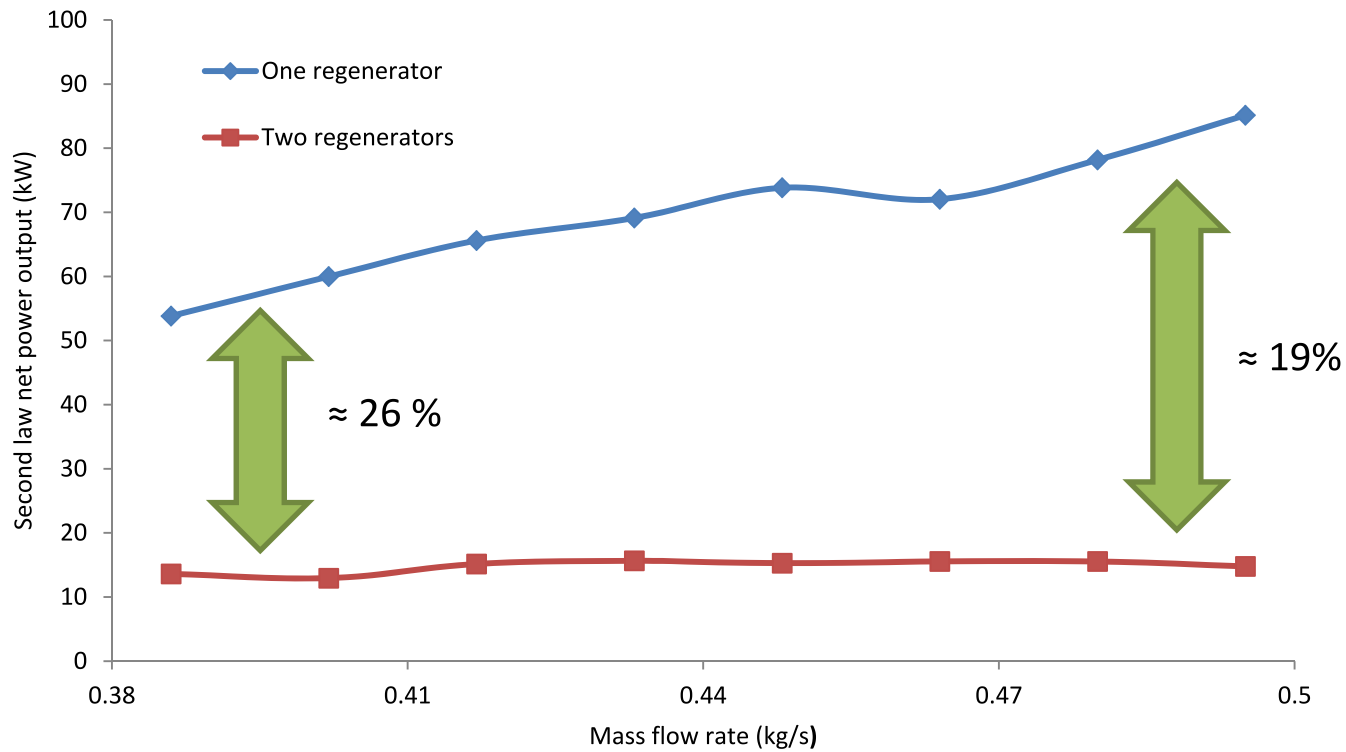


Results

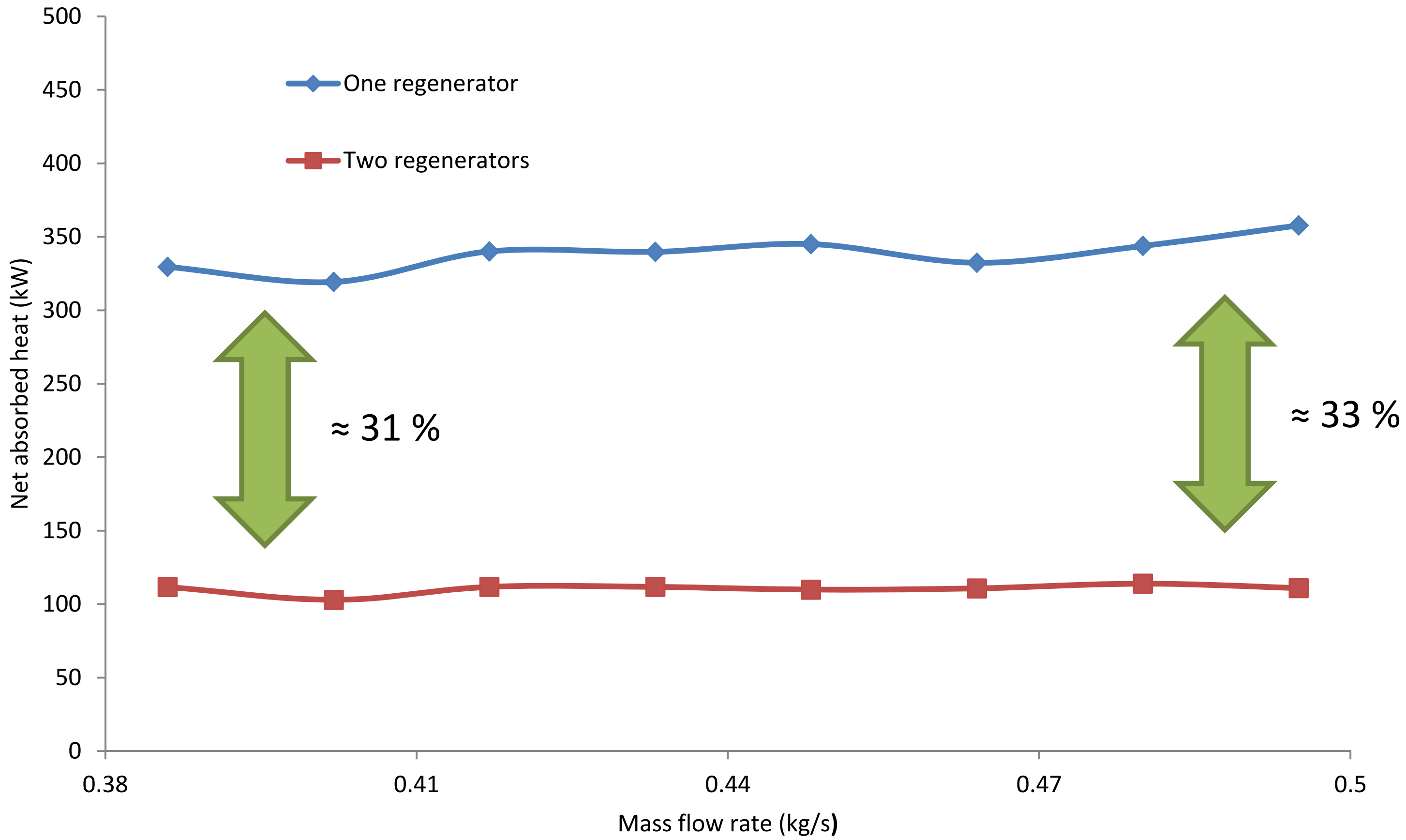
1. Objective function (a.k.a. second law net power output)
2. Net absorbed heat
3. Efficiency
4. Irreversibilities

Results: Objective function

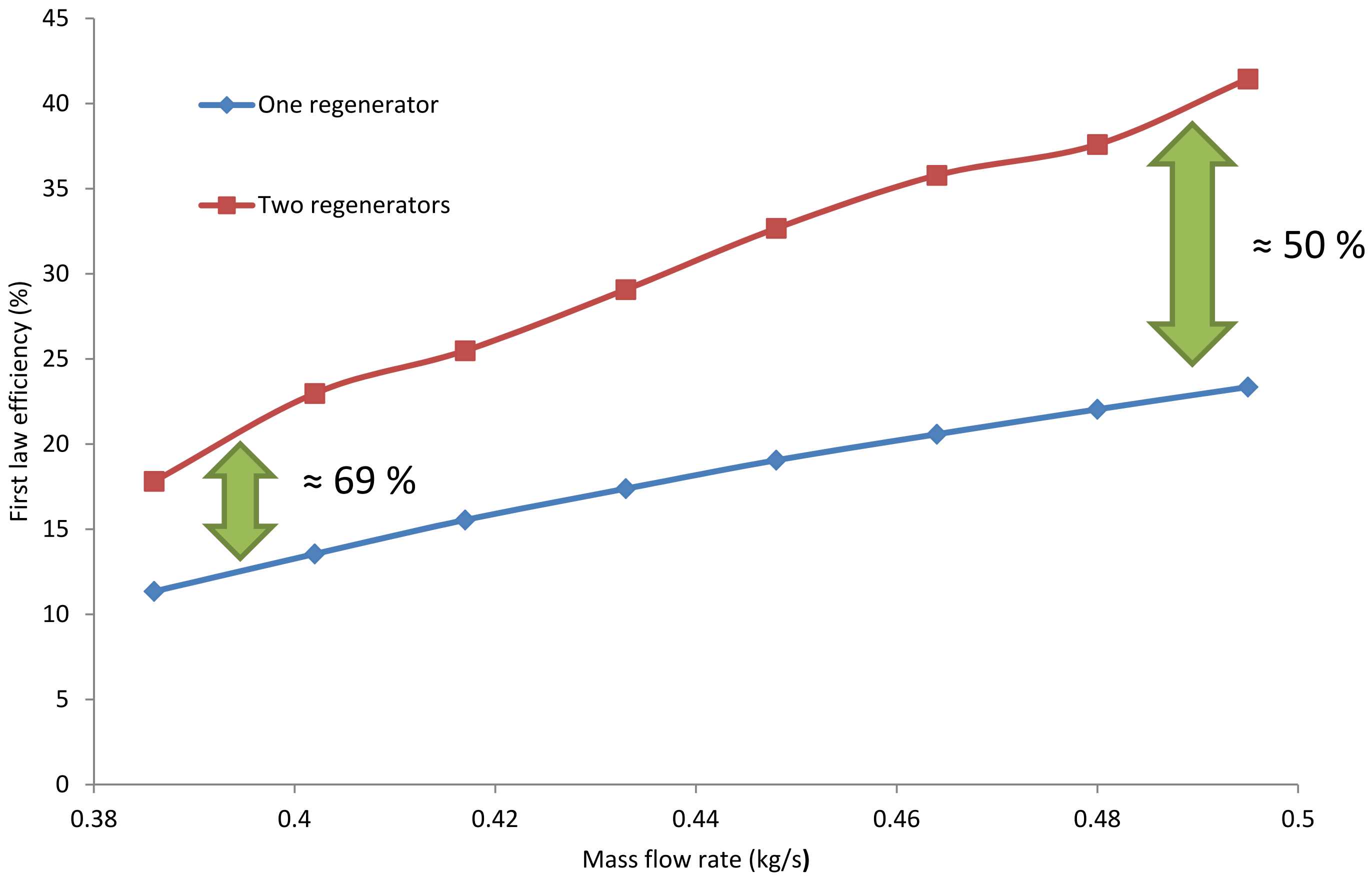
(a.k.a. second law net power output)



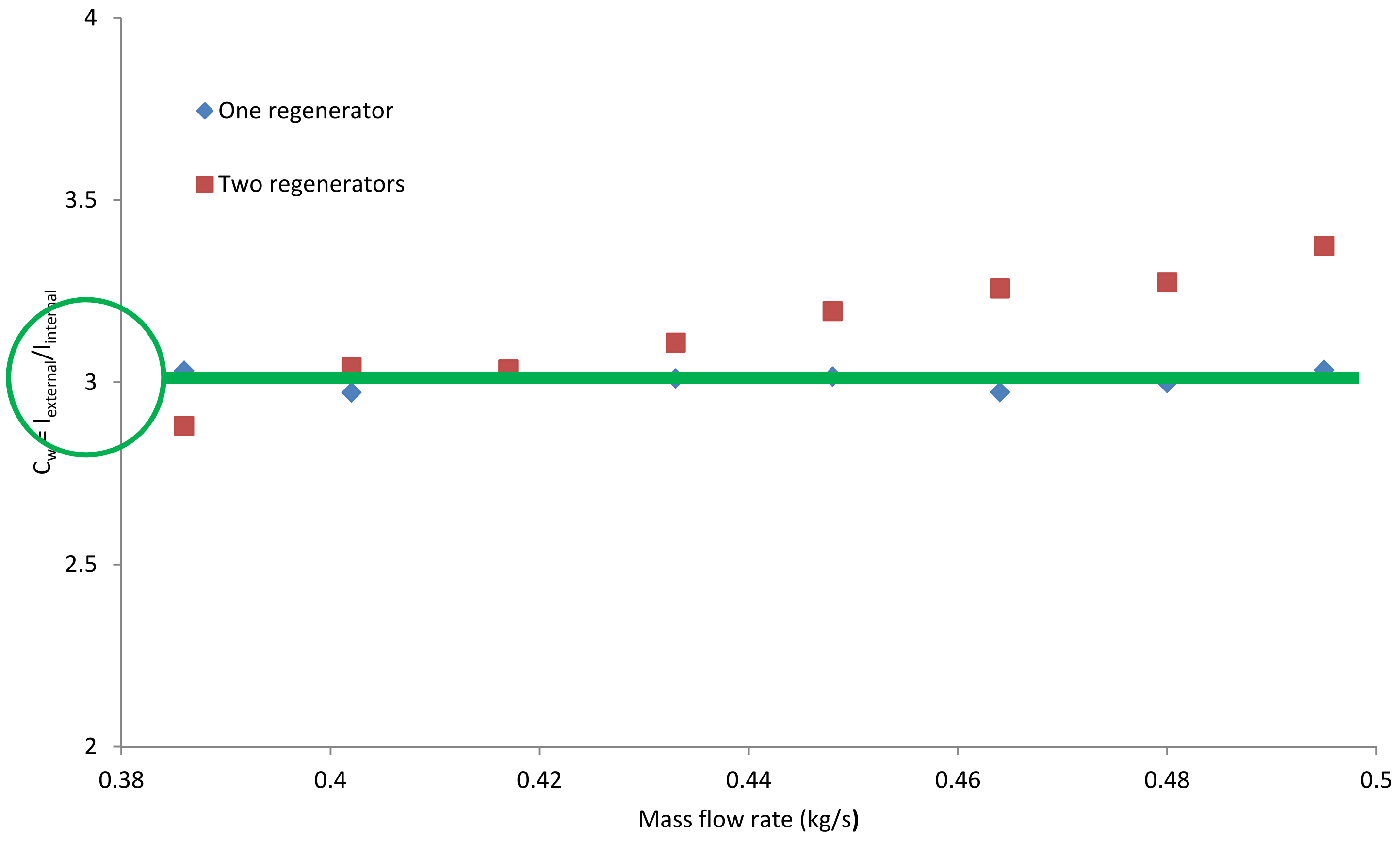
Results: Net absorbed heat



Results: Efficiency



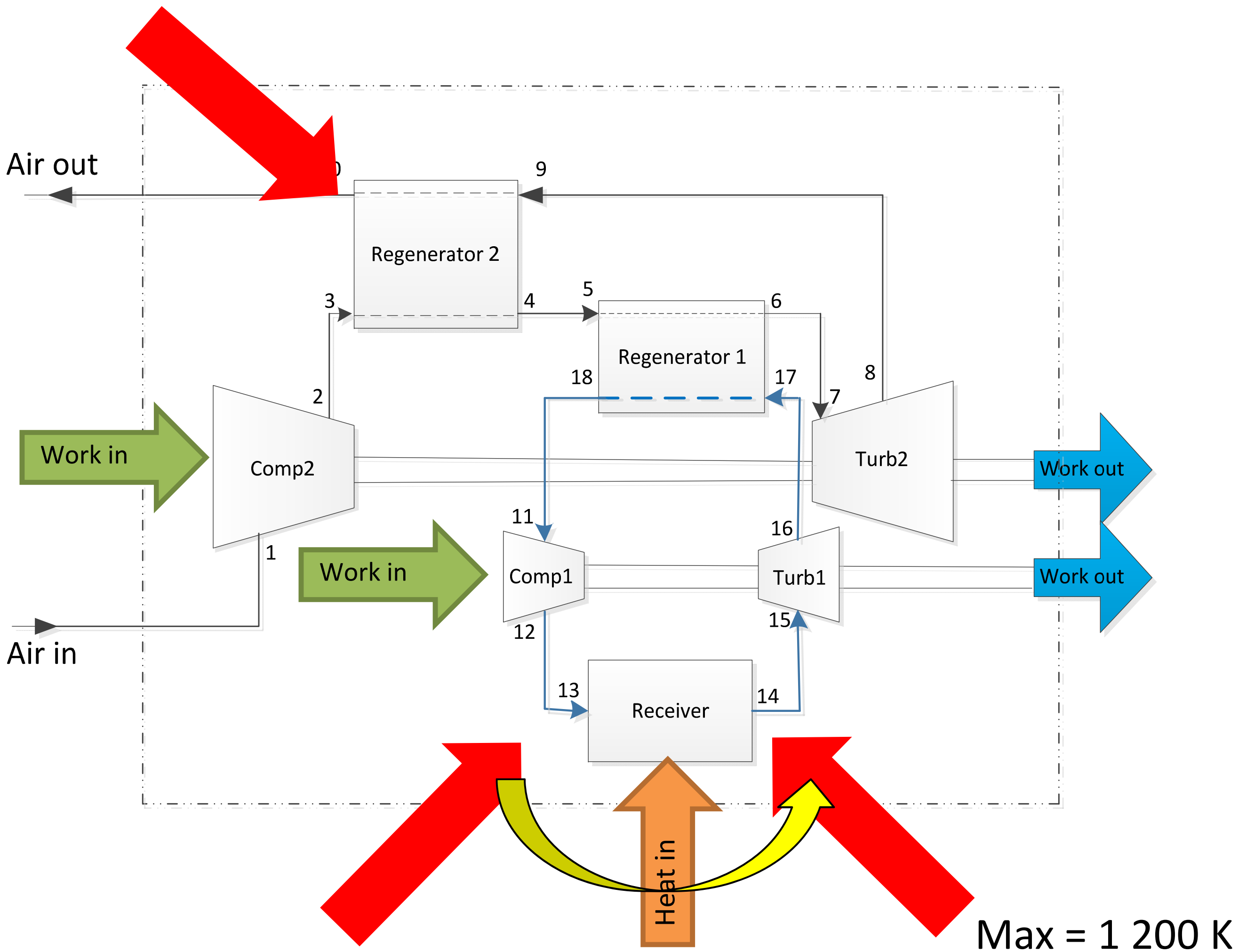
Results: Irreversibilities (comparison)



Conclusions

- Brayton cycle with regeneration deemed best choice for the problem at hand
- Parabolic dish collector with modified cavity receiver suggested for Brayton cycles with regeneration in solar thermal power systems
- For the double cycle, it was found that more than 15kW of power can be generated at an efficiency of 29% when the mass flow rate is around 0.4 kg/s.
- The single cycle produces roughly 68kW at an efficiency of 15% at the same mass flow rate as the double regenerator cycle

Conclusions



Conclusions

- Regenerator 2 increases efficiency in double cycle by decreasing the net absorbed heat needed for power generation.
- Single cycle has higher net absorbed heat, thus higher second law power output, thus higher generation of entropy and more irreversibilities. This leads to a less efficient cycle.
- The component parameters are also larger in the single cycle than in the double cycle.
- Due to the scalable nature of the open-air solar thermal Brayton cycle, the double cycle seems the best choice as the cycle can be scaled up to generate a similar amount of power as the single cycle already generates, however it will do so at a higher efficiency than the single cycle.

Thank you

Any questions?

Possible questions

1. What is the relation between convection, conduction and radiation heat loss in the modified cavity receiver.
2. What is the influence of wind on the amount of heat that can be generated by such a cycle?
3. What other ways are there to improve absorption of the receiver?
4. How will energy supply be enforced in overcast and bad weather days?