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Integration of a power cycle with the SOCRATCES scheme

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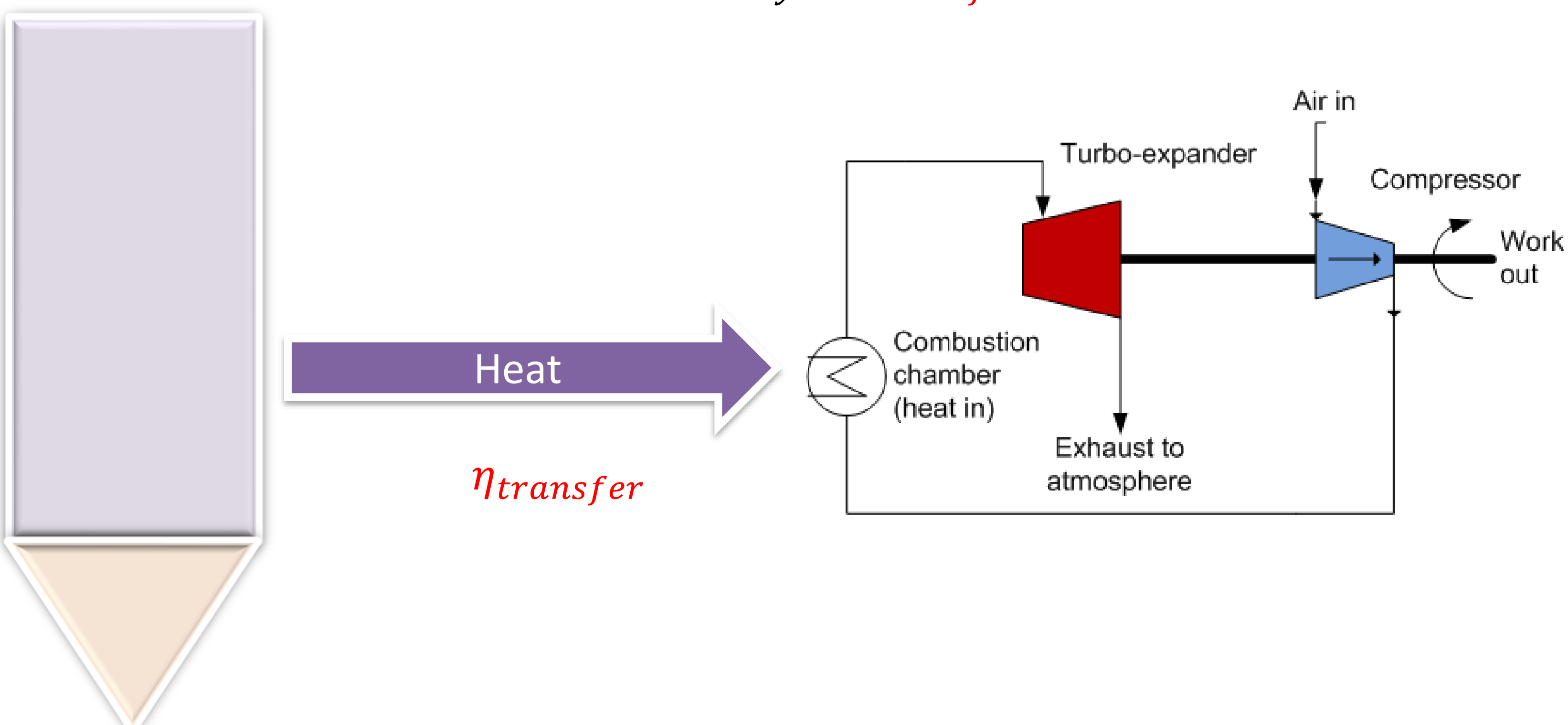
SOLAR CALCIUM-LOOPING INTEGRATION FOR THERMO-CHEMICAL ENERGY STORAGE

The power block within SOCRATCES

Hooking up conventional thermal-electrical conversion technologies to the SOCRATCES scheme

$$\eta_{overall} = \eta_{cycle}\,\eta_{transfer}$$



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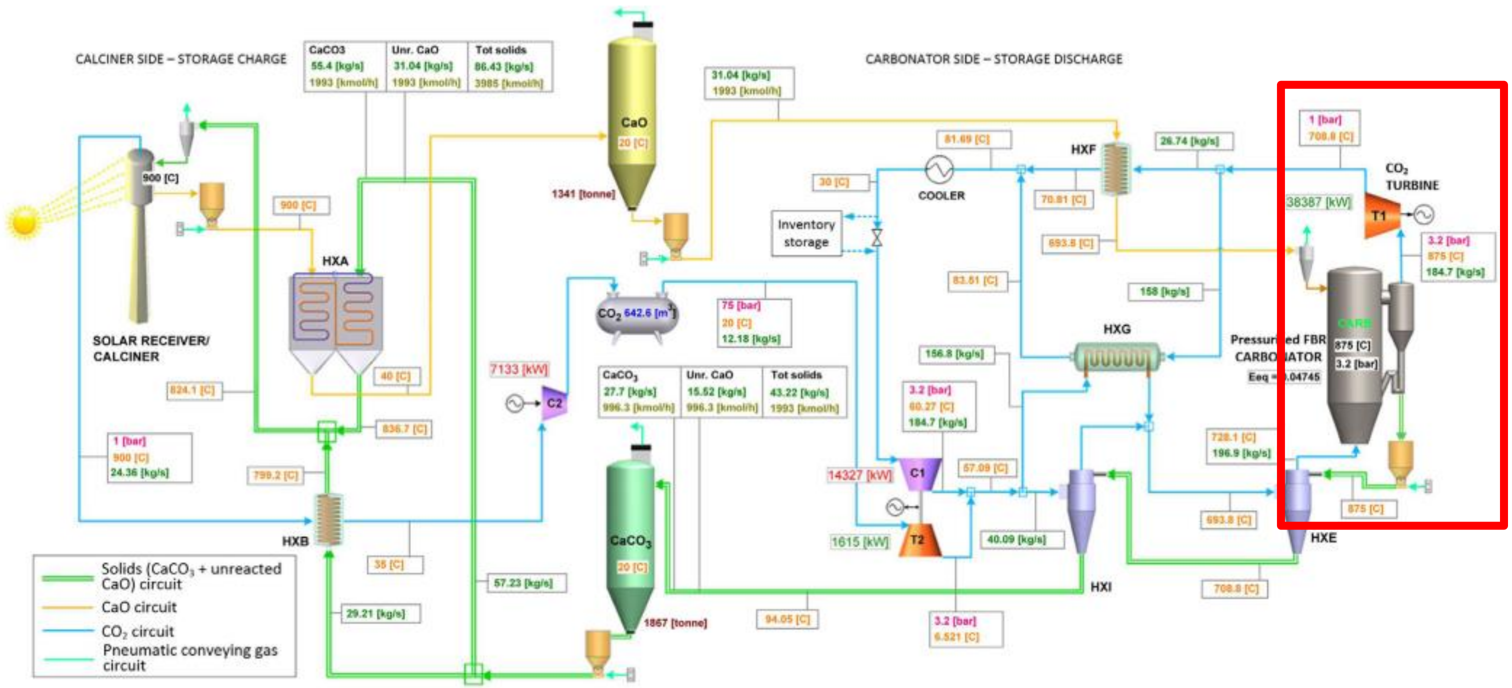
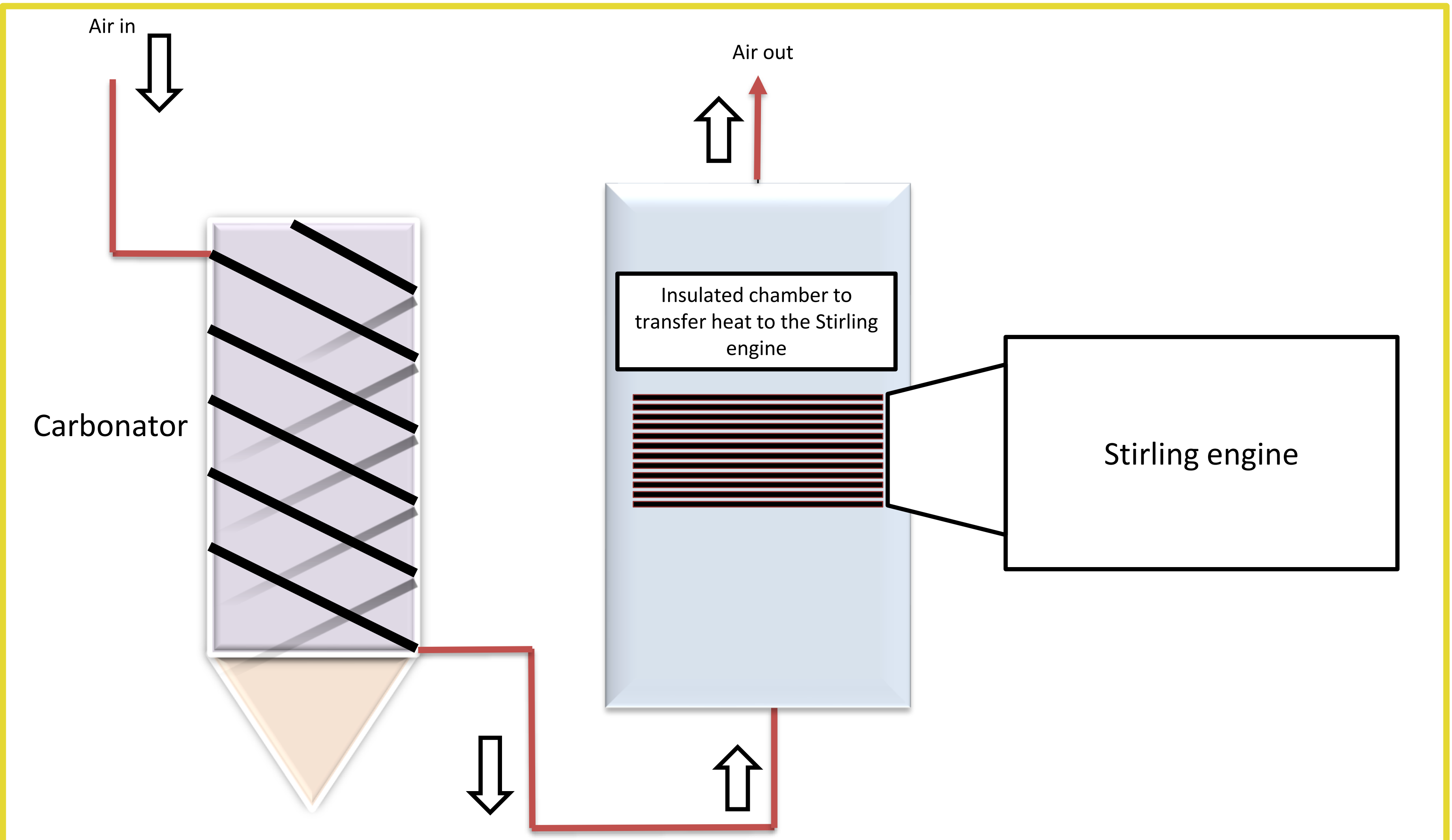
Direct integration

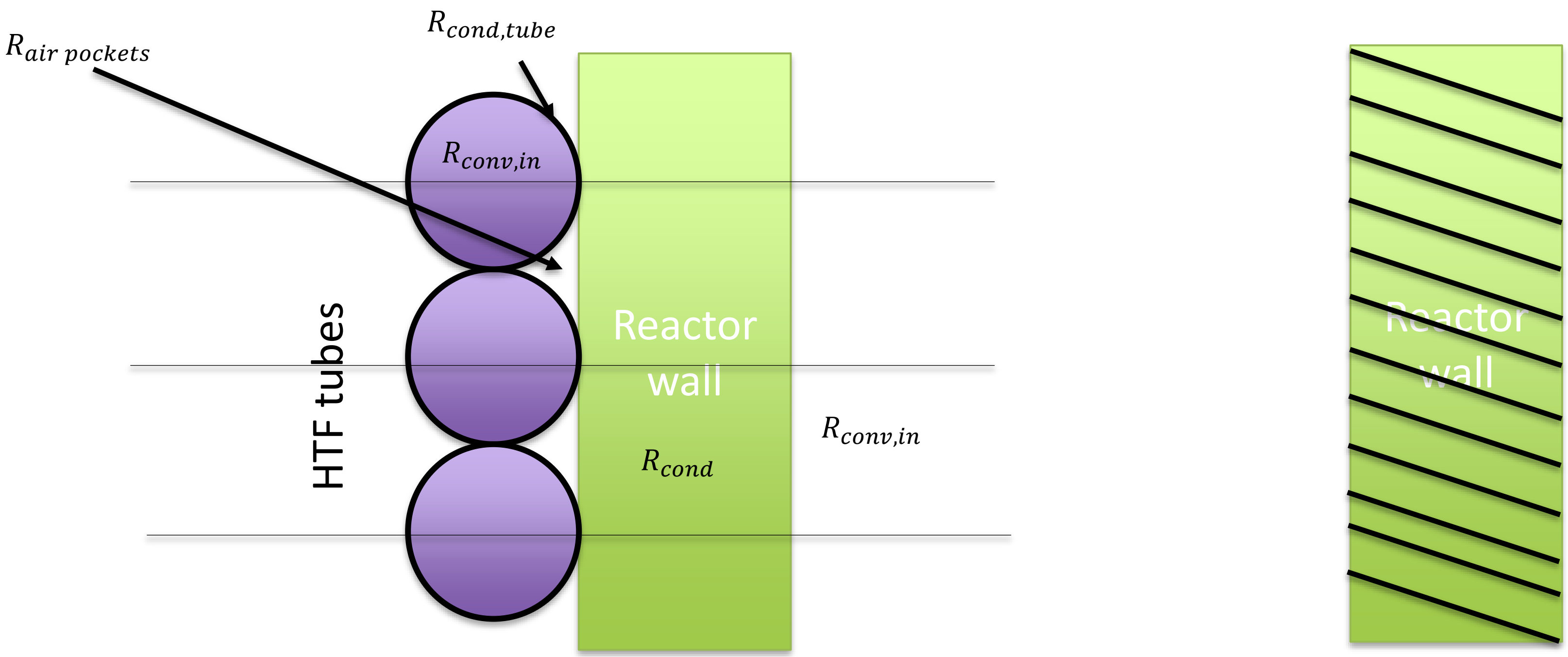
Ortiz et al. (2019)



Pilot scale integration for the prototype in Spain

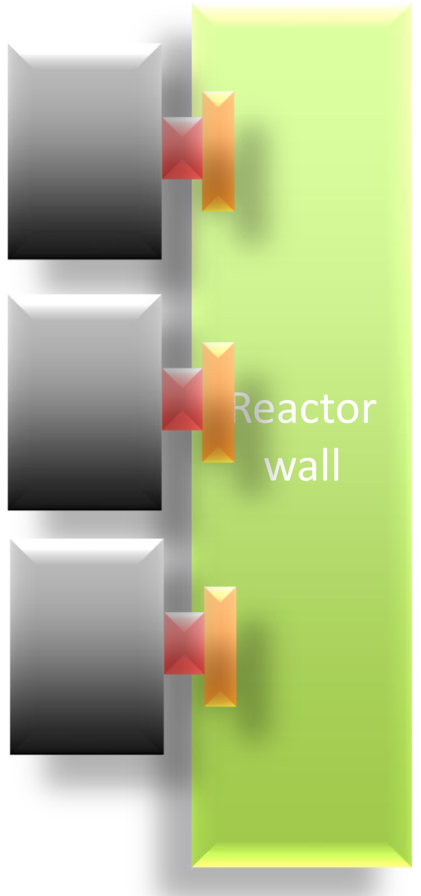


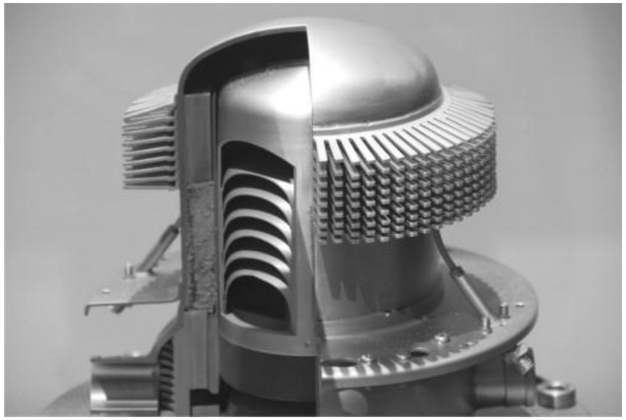
Stirling engine integration optimization with the carbonator



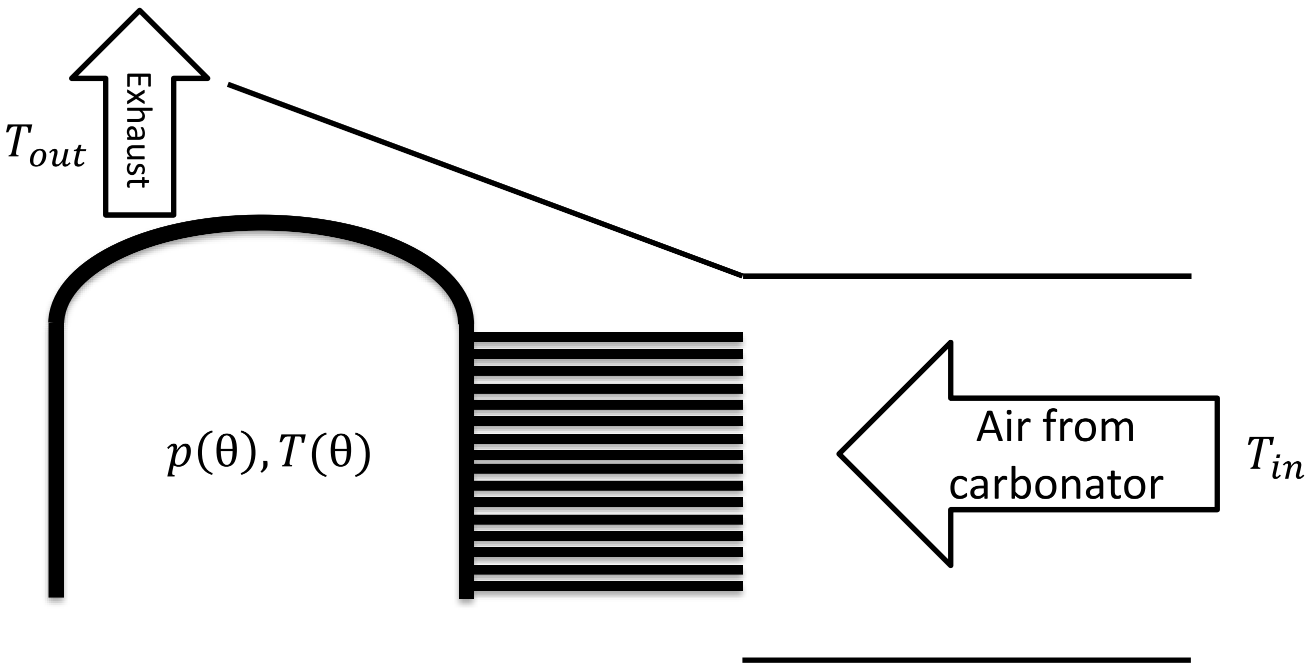
- Pressure issues
- Contact issues at high temperatures
- Avoidable thermal resistances are there
- Very little contact area, making heat transfer slower

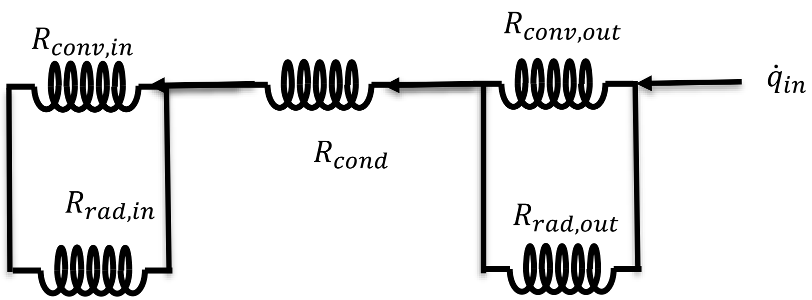
Stirling engine integration optimization with the carbonator

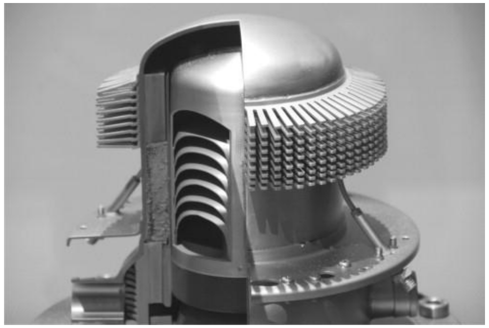




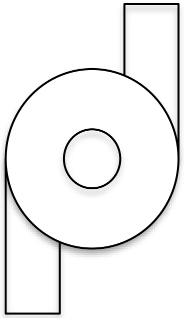
Stirling engine integration optimization with the carbonator



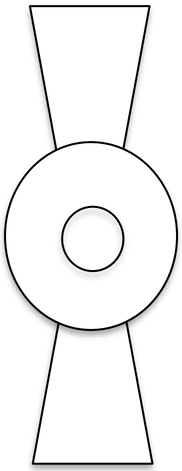




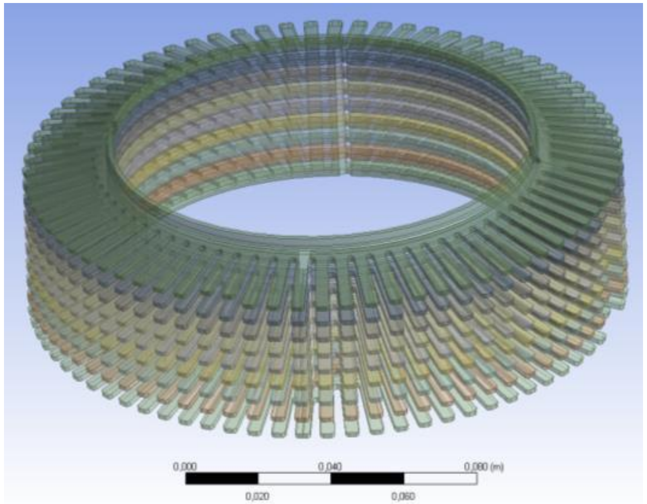
Investigated configurations



Configuration 1:
Opposed tangential inlets with axial exit



Configuration 2:
Opposed radial inlets with axial exit



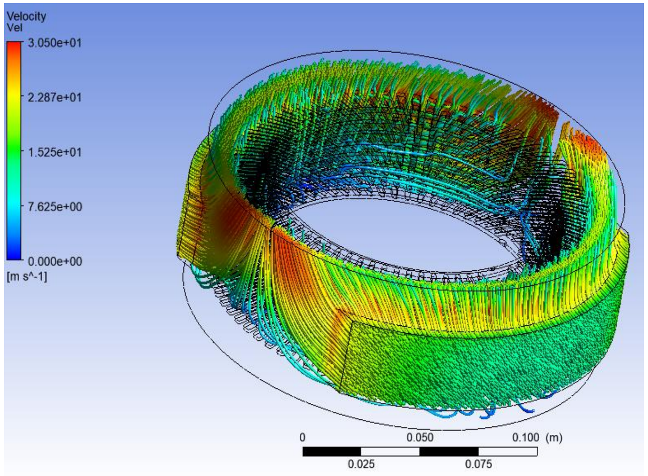
The heat exchanger (hot side) of the Microgen 1 kW engine

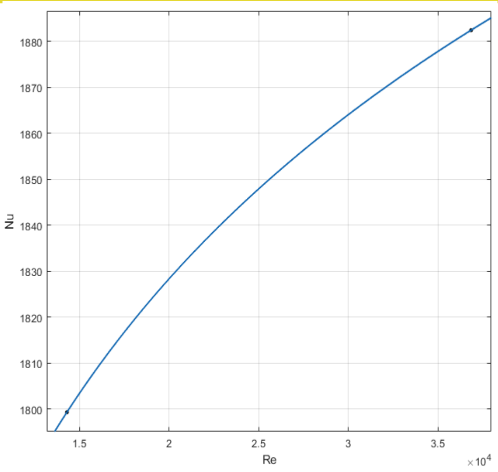
Mathematical model

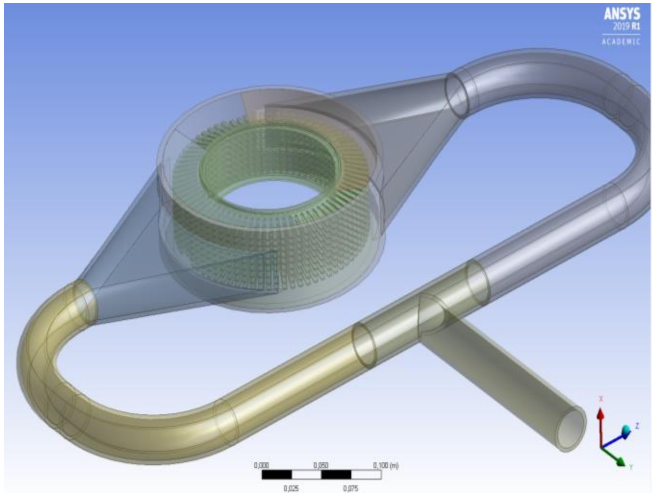
$\frac{dQ_k}{d\theta} = \frac{V_k c_v dp}{R d\theta} - c_p(T_{ck} m_{ck'} - T_k m_{kr'})$ $\frac{dQ_r}{d\theta} = \frac{V_k c_v dp}{R d\theta} - c_p(T_k m_{kr} - T_k m_{krh})$ $\frac{dQ_k}{d\theta} = \frac{V_h c_v dp}{R d\theta} - c_p(T_h m_{rh'} - T_{he} m_{he'})$ $\frac{dW_c}{d\theta} = \frac{p dV_c}{d\theta}$ $\frac{dW_e}{d\theta} = \frac{p dV_e}{d\theta}$ $\frac{dW}{d\theta} = \frac{dW_c}{d\theta} + \frac{dW_e}{d\theta}$	Work and heat content derivatives
$\frac{dT_c}{d\theta} = T_c\left(\frac{dp}{p d\theta} + \frac{dV_c}{V_c d\theta} - \frac{dm_c}{m_c d\theta}\right)$ $\frac{dT_e}{d\theta} = T_e\left(\frac{dp}{p d\theta} + \frac{dV_e}{V_e d\theta} - \frac{dm_e}{m_e d\theta}\right)$	Compression and expansion space derivatives
$m_c = \frac{pV_c}{RT_c}, m_k = \frac{pV_k}{RT_k}, m_r = \frac{pV_r}{RT_r}$ $m_h = \frac{pV_h}{RT_h}, m_e = \frac{pV_e}{RT_e}$	Mass contents of the five different zones at any specific θ

$\frac{dm_c}{d\theta} = \frac{\left(\frac{p dV_c}{d\theta} + \frac{V_c}{\gamma}\frac{dp}{d\theta}\right)R}{T_{ck}}$ $\frac{dm_e}{d\theta} = \frac{\left(\frac{p dV_e}{d\theta} + \frac{V_e}{\gamma}\frac{dp}{d\theta}\right)R}{T_{he}}$ $\frac{dm_k}{d\theta} = \frac{m_k dp}{p d\theta}$ $\frac{dm_r}{d\theta} = \frac{m_r dp}{p d\theta}$ $\frac{dm_h}{d\theta} = \frac{m_h dp}{p d\theta}$	Mass content derivatives
$T_{ck} = T_c; m_{ck'} > 0$ $T_{ck} = T_k; m_{ck'} \leq 0$ $T_{ck} = T_h; m_{he'} > 0$ $T_{he} = T_e; m_{he'} \leq 0$	Temperature conditions
$q_{out} = (1 - \epsilon_\omega) q_{in,rad} + n^2 \epsilon_\omega \sigma T_w^4$ $q_{in,rad} = \int_{\vec{s}.\vec{n} > 0} I\vec{s}\cdot\vec{n} \, d\Omega'$ $\nabla(I(\vec{r},\vec{s})\vec{s}) + (a + \sigma_s)I(\vec{r},\vec{s}) = an^2\frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi}\int_0^{4\pi} I(\vec{r},\vec{s}\,')\Phi(\vec{s}.\ \vec{s}\,')d\Omega'$	Radiative heat transfer equations

Results and conclusions





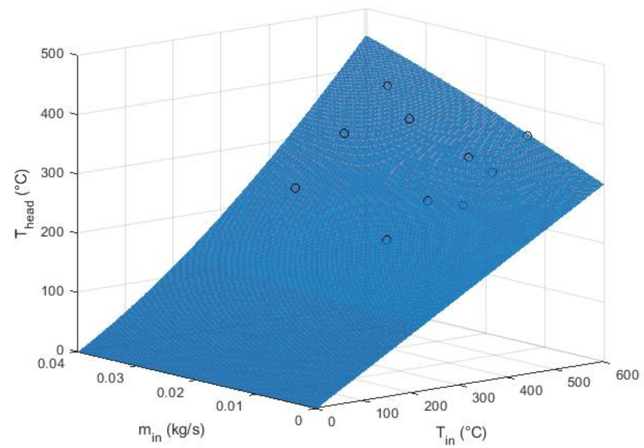


Average radiative heat rate	1.07 kW
Average convective heat rate	4.6 kW
Total heat flow through the heat-exchanger's external wall	5.67 kW
Average convective heat transfer coefficient at the heat-exchanger's external wall	245.65 W/m^2.K
Average velocity	9.08 m/s
Maximum velocity	34 m/s
Minimum velocity	0.0008 m/s
Pressure at inlet (gauge)	120 Pa
Pressure at outlet (gauge)	-0.27 Pa
Pressure difference	120.27 Pa
Film temperature at the heat-exchanger's external wall	799.9 K

Results and conclusions

Type 1 performance

Flow rate (kg/s)	Incoming HTF T (K)	Power (W)	Thermal efficiency (%)
0.046	1083	1102	**18.0**
0.021	818	225	**8.7**

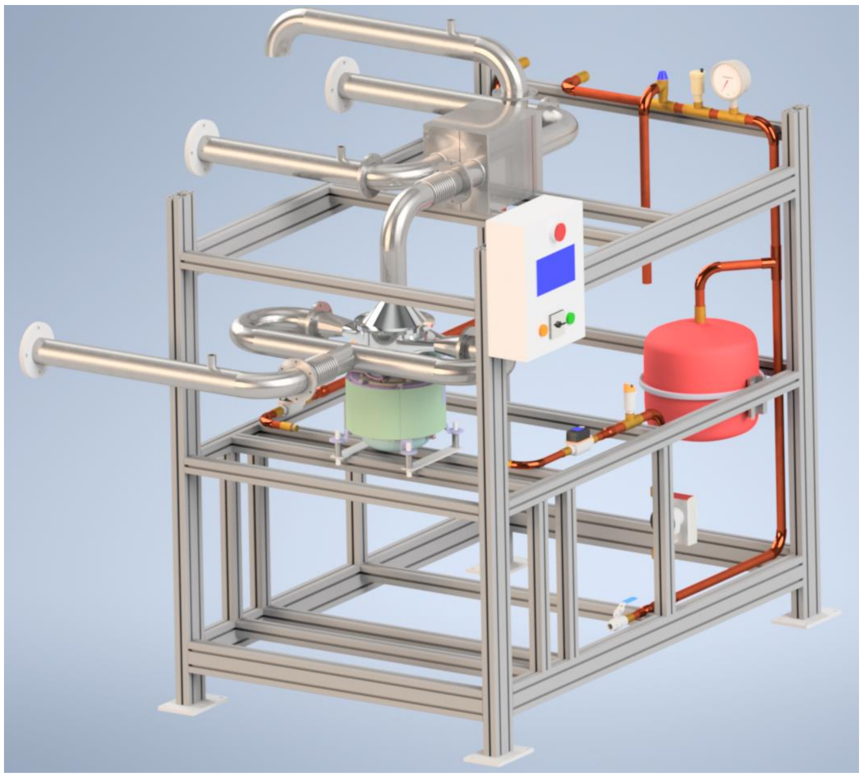


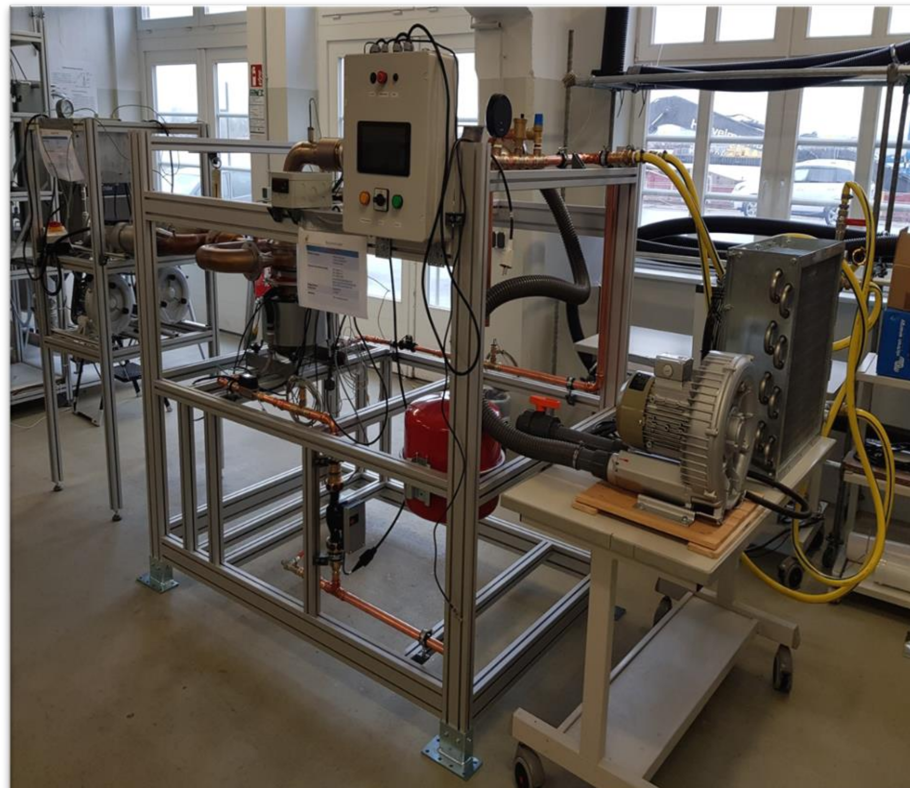
Type 2 performance

Flow rate (kg/s)	Incoming HTF T(K)	Power (W)	Thermal efficiency (%)
0.033	829	636	**24.52**
0.026	792	510	**18.67**

- Considerable improvement in performance achieved with very little change introduced.
- Considerably higher turbulence in type 2 configuration.

The power block





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Thanks for your attention

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