ORC 2017
4th International Seminar on Organic Rankine Cycle Power Systems
WELCOME BACK HOME!

Experimental investigation into an ORC-based low-grade energy recovery system equipped with sliding-vane expander using hot oil from an air compressor as thermal source

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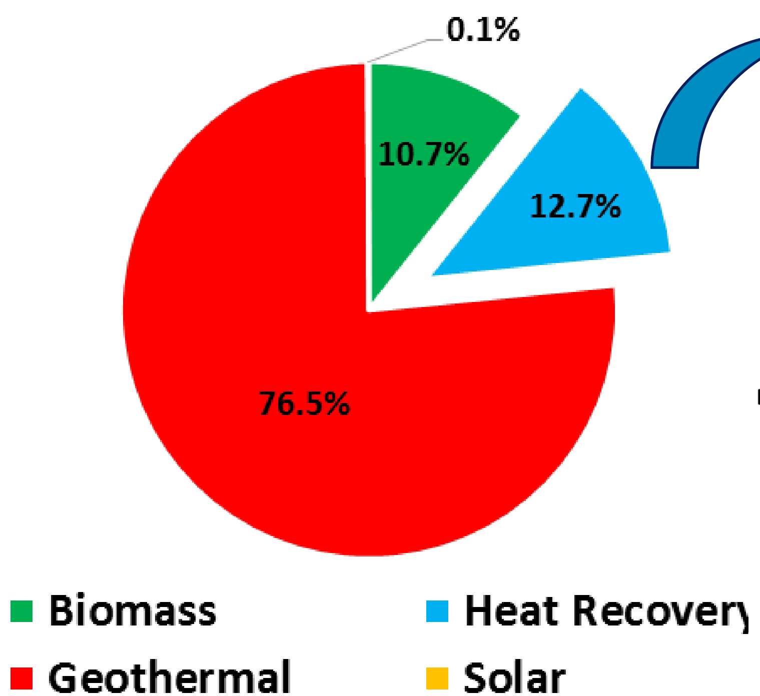
ORGANIC RANKINE CYCLE (ORC)

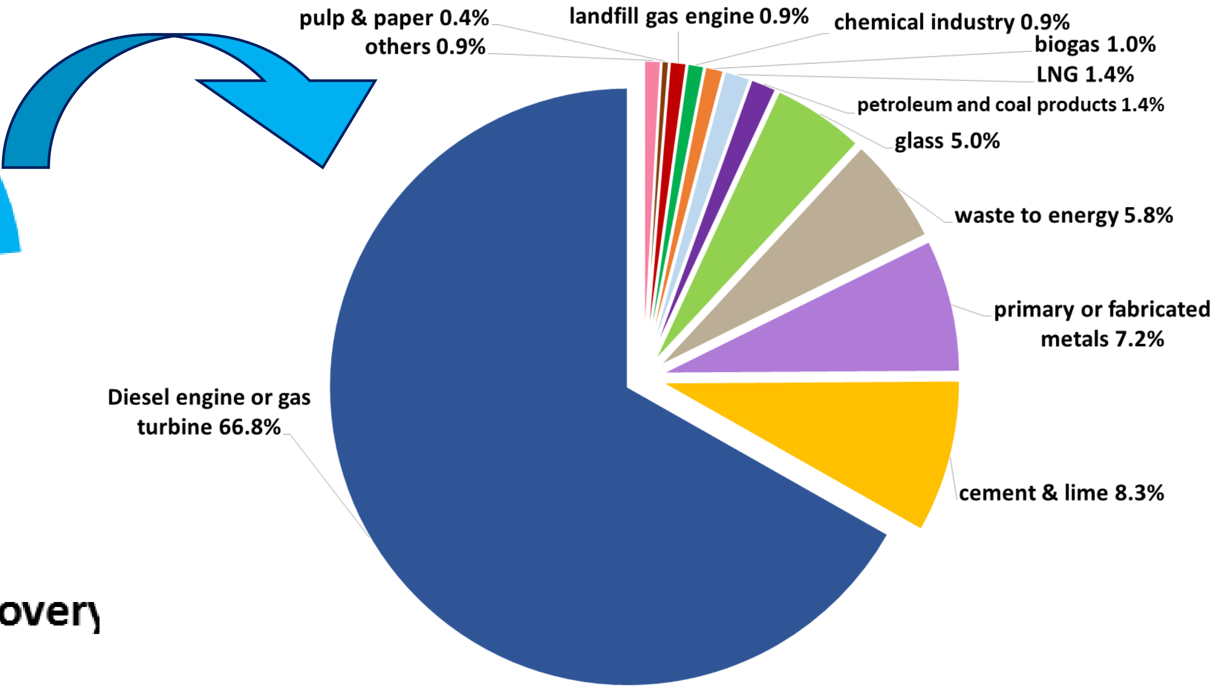
Widespread technology for electric power production using low-grade heat source

Different low-grade energy sources



ORC sources market share (from *orc-world-map.org* 21/01/2016)

Several applications fields for heat recovery



ORC heat recovery share (from *orc-world-map.org* 21/01/2016)

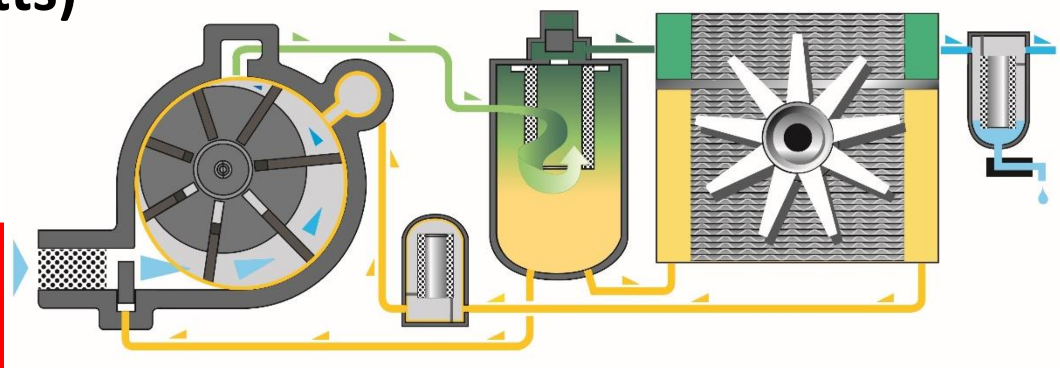
Context

SMALL SCALE ORC (few kilowatts)

Oil-flooded air compressor

Large amount of lubricant that need to be cooled down

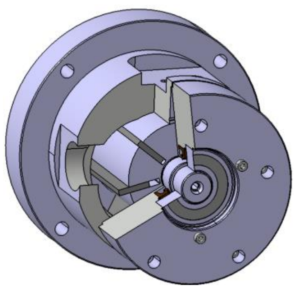
WASTE HEAT SOURCE with temperatures in the range 80-100°C

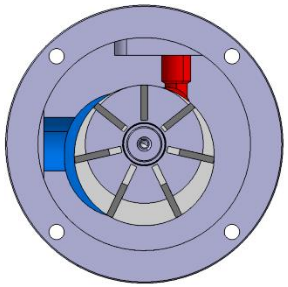


POSITIVE DISPLACEMENT EXPANDERS

Sliding-vane expander features:

- relatively **low rotational speed**
- **high expansion ratio**
- **smooth torque**
- **low noise** and **vibration**
- simple structure and no valves
- need for **lubrication**

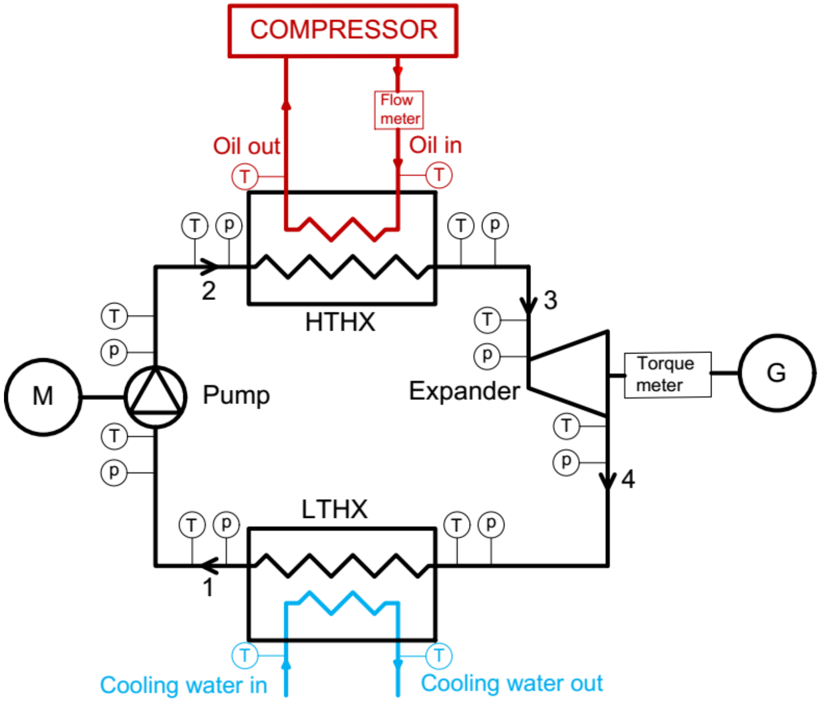




	Displacement	Built-in volume ratio	Rotor length	Rotor diameter
	cm^3	-	*mm*	*mm*
Simple cycle expander	**26.5**	**3.34**	**160**	**80**
Recuperative cycle expander	**19.95**	**2.76**	**90**	**100**

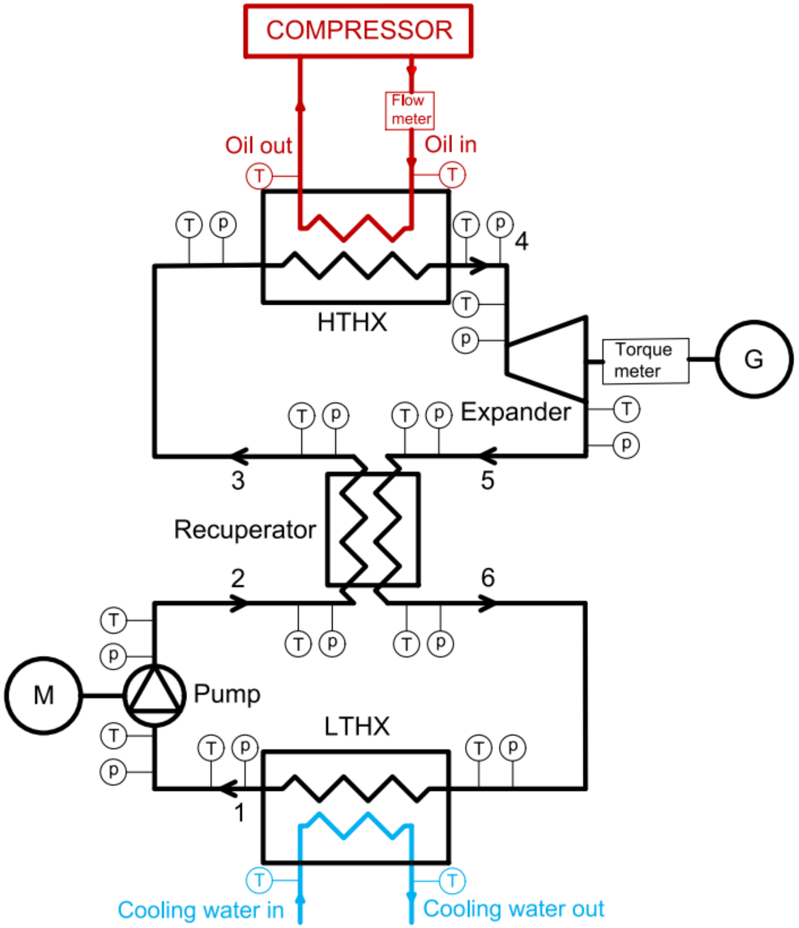
System layouts

Simple cycle



Working fluid	**R236fa**
Hot source	**Air compressor lubricant**
Cold source	**Water**

Recuperative cycle



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COMPRESSED AIR SINCE 1919

Experimental setup

Instrument	Quantity	Uncertainty
Thermocouple	Temperature	0.5°C
Pressure transducer	Pressure	0.08 bar
Piezoelectric pressure transducer	Pressure	0.01 bar
Flow meter	Flow rate	4 l/min
Torque & power meter	Torque	0.1 Nm
	Angular speed	1 rpm

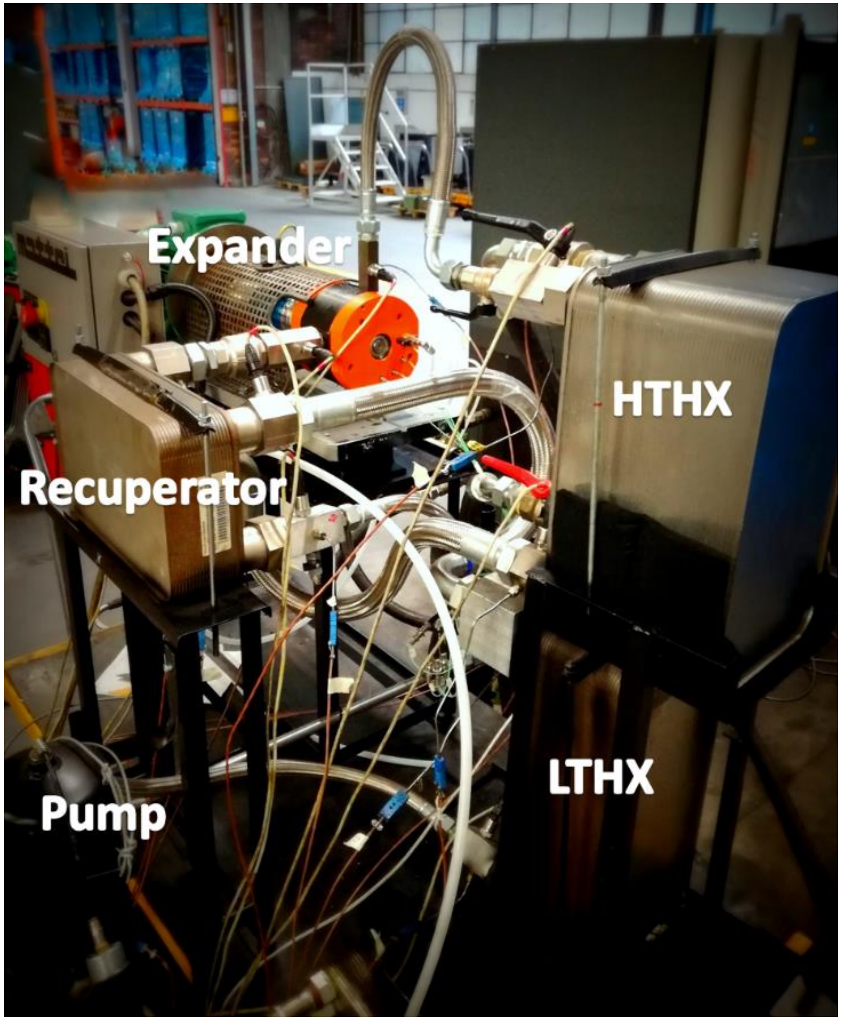
Thermocouple

Pressure transducer ⇨ *Cycle points thermodynamic properties*

Flow meter ⇨ *Compressor oil flow rate*
HTHX rate of heat transfer (indirect)
Working fluid mass flow rate (indirect)

Torque & power meter ⇨ *Expander mechanical power*

Piezoelectric pressure transducer ⇨ *Expander indicated diagram*



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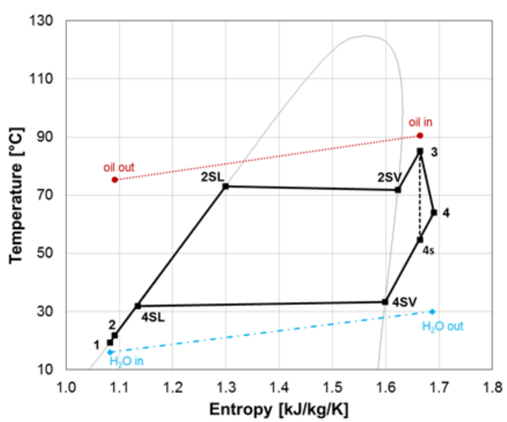
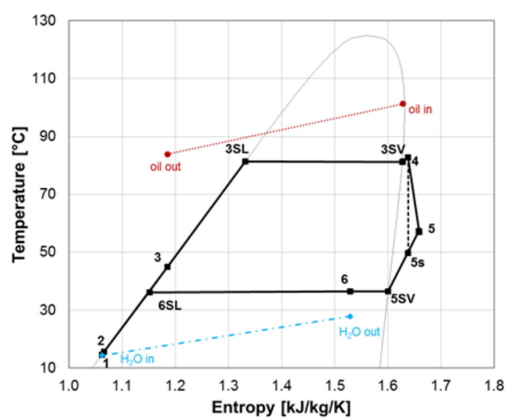
Results and discussion – ORC Performance

Cycle parameters	Simple cycle	Recuperative cycle
Pump in pressure [bar]	3.4	3.76
Pump out pressure [bar]	10.6	13.0
Pump in temperature [°C]	19.3	14.6
HTHX out temperature [°C]	85.2	81.4
Pump mechanical power [kW]	1.10	0.65
Expander mechanical power [kW]	3.23	3.66
Working fluid mass flow rate [kg/s]	0.295	0.394
HTHX heat rate [kW]	57.25	60.78
Net cycle power [kW]	**2.13**	**3.01**
Net cycle efficiency [%]	**3.72**	**4.96**





- The system is controlled through the **pump rotational speed variation** (brushless motor), while the **expander rotational speed** is **constrained by grid frequency**
- **Pressure and temperature levels** are directly related to the heat source (**compressor oil 80-100°C**) and heat sink (**tap water 15-25°C**)
- Both the system operate in similar thermal input condition (alternatively coupled with the same compressor)
- Different mass flow rate (higher pressure in recuperative expander inlet cause a greater WF density)
- **Better performance for the recuperative cycle**, in terms of power production and overall cycle efficiency

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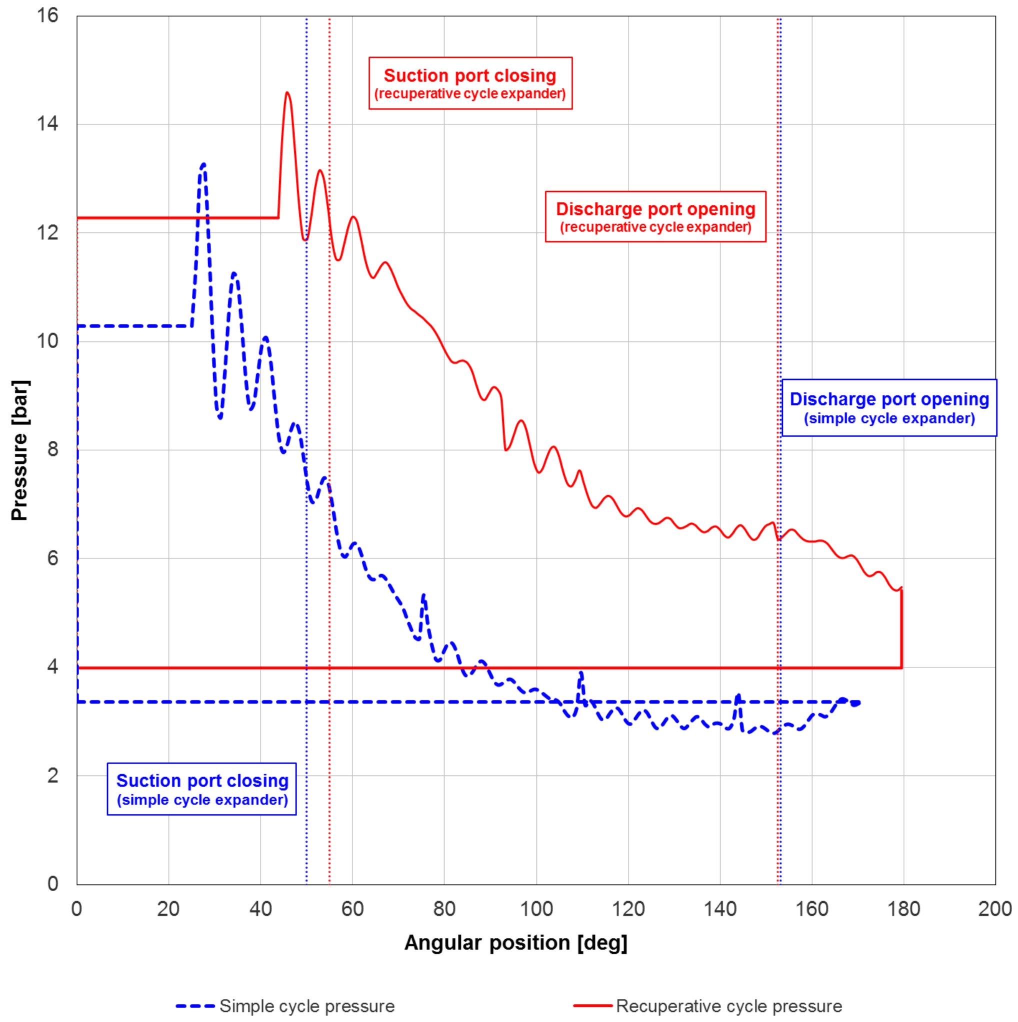
Results and discussion – Indicated diagrams



- The trailing vane is taken as reference for the angular position
- **Expander mechanical efficiency**
  Simple 71.8%
  Recuperative 81.5%
- **Over-expansion** occurs in the **simple cycle expander**, while **under-expansion** occurs in the **recuperative cycle expander**
- Greater mechanical power (enclosed area in P-V diagram) for the recuperative expander

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Results and discussion – Exergy analysis

Exergy analysis

System compared to ideal cycle with finite capacity heat source

IDEAL EFFICIENCY

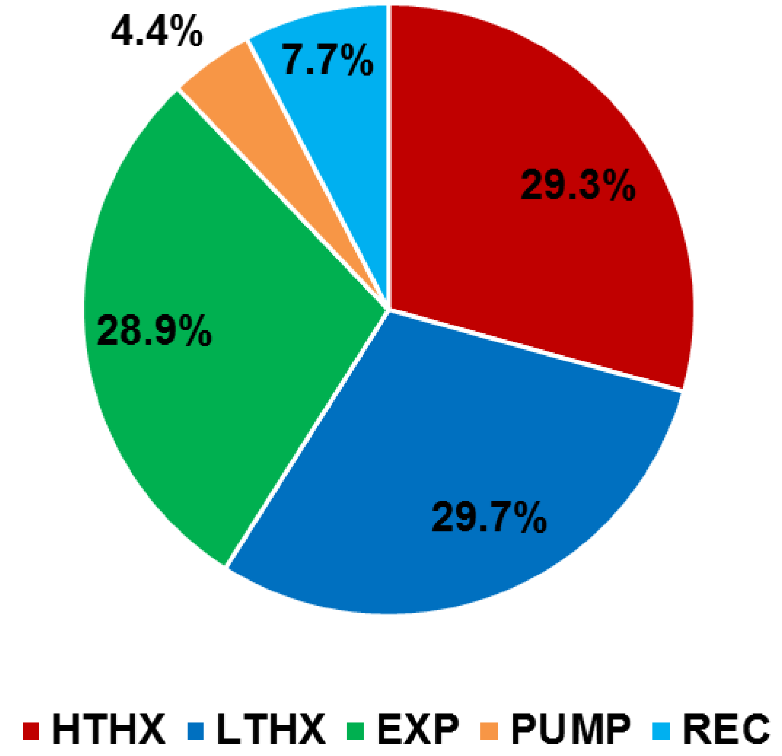
$$\eta_{id} = 1 - \frac{T_0}{LMTD_{heat\ source}}$$

EXERGY EFFICIENCY

$$\eta_{exe} = \frac{\eta}{\eta_{id}}$$

Exergy efficiency	
Simple cycle	19.5%
Recuperative cycle	23.4%

Exergy loss share for recuperative cycle



Main contribution: LTHX, HTHX and expander

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Conclusions

An experimental study is carried out on two **ORC** recovery system equipped with

Sliding-Vane Rotary Expanders

They are respectively in **simple** and **recuperative configurations** and are coupled with the same thermal source: **hot lubricant** from a **mid-size air compressor**

Simple cycle reaches a net power of **2.13 kW** with a cycle efficiency of **3.72%**

Recuperative cycle reaches a net power of **3.01 kW** with a cycle efficiency of **4.96%**

Simple cycle expander has a mechanical efficiency of **71.8%**

Recuperative cycle expander has a mechanical efficiency of **81.5%**

Exergy analysis on the **Recuperative cycle** highlights

the major **exergy loss contribution**: **LTHX, HTHX, expander**

Future works will focus on **system optimization** and **working fluid replacement**

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THANKS FOR YOUR ATTENTION

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