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Experimental Investigations on CO_2-Based Transcritical Rankine Cycle (CTRC) for Waste Heat Recovery of Diesel Engine

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Outline

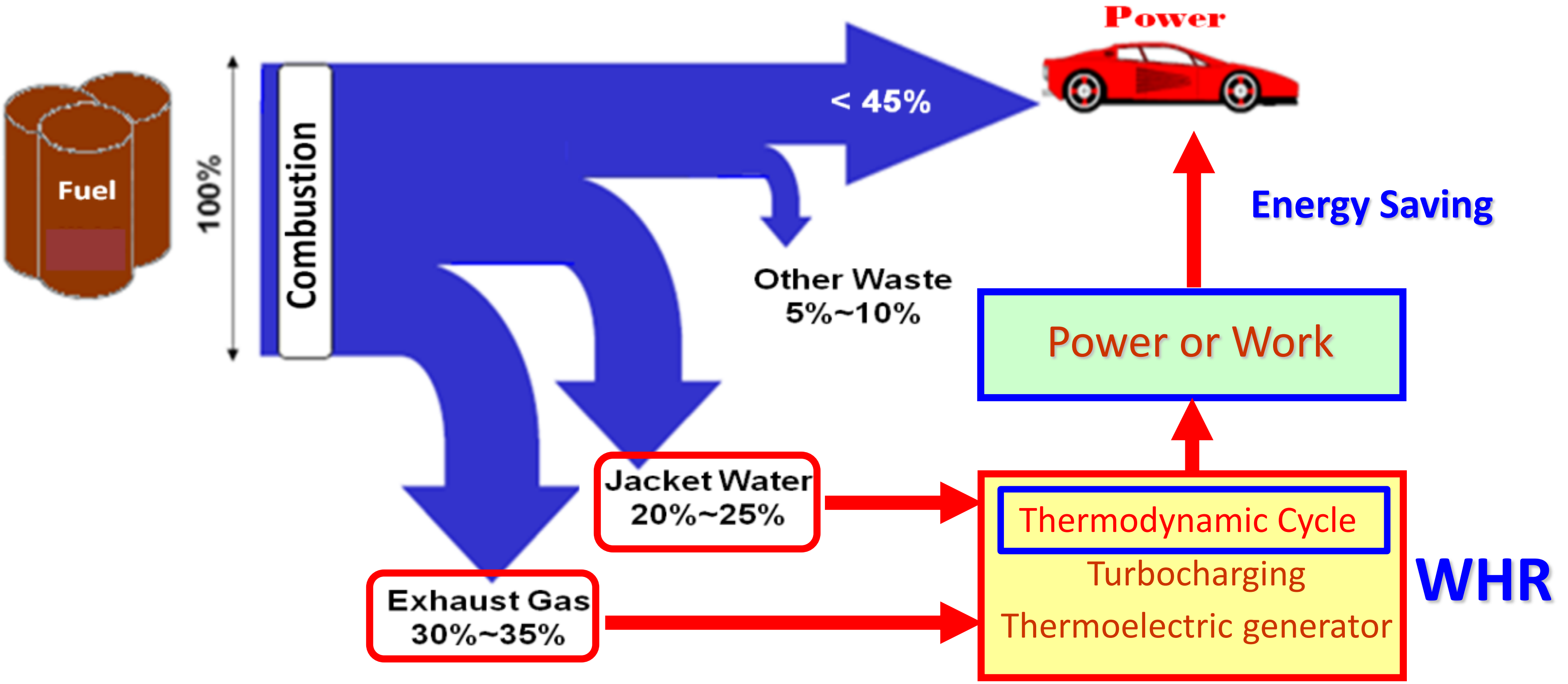
1. Background

2. System and Method

3. Results

4. Summary

Background-Why Engine WHR?



Thermodynamic Cycle: High efficiency

Well thermal match

Good feasibility

Backgroud-Why CTRC?

CO_2 is a natural working fluid

Safe: non-toxic, non-corrosive, inflammable, non-explosive

Environmentally friendly: ODP=0, GWP=1

High thermal stability: direct contact with HT exhaust gas

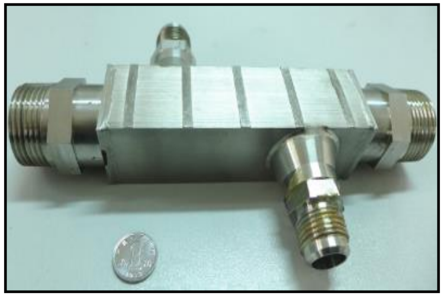
Supercritical CO_2 has unique thermophysical properties

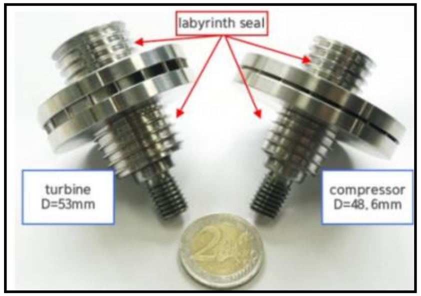
Tcrit=31.1 °C; Pcrit=7.38 MPa

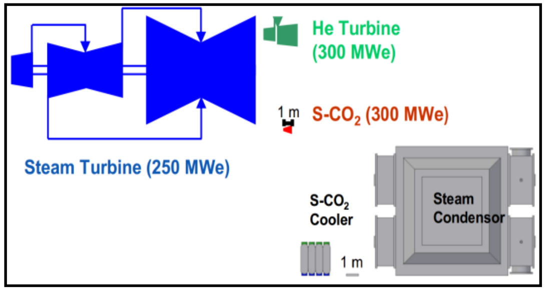
High density, low viscosity

Small expansion ration

⇨ ***Compact turbine, Compact HE***







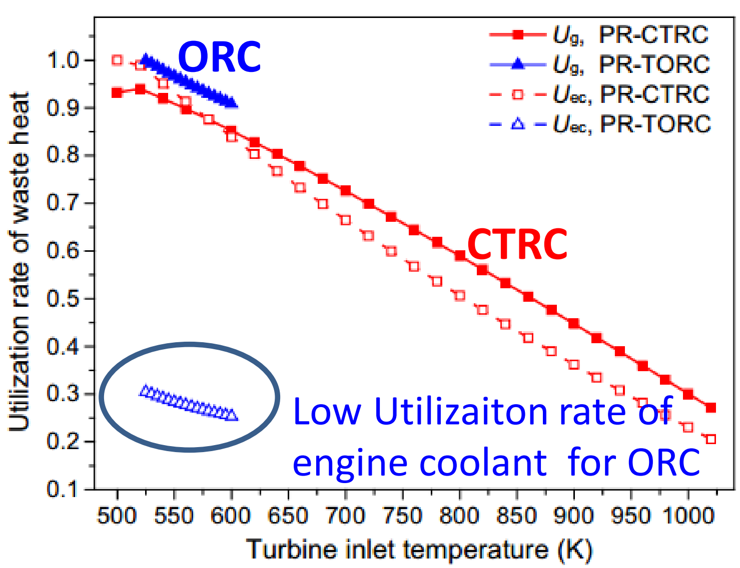
Backgroud-Why CTRC?

CTRC could achieve miniaturization

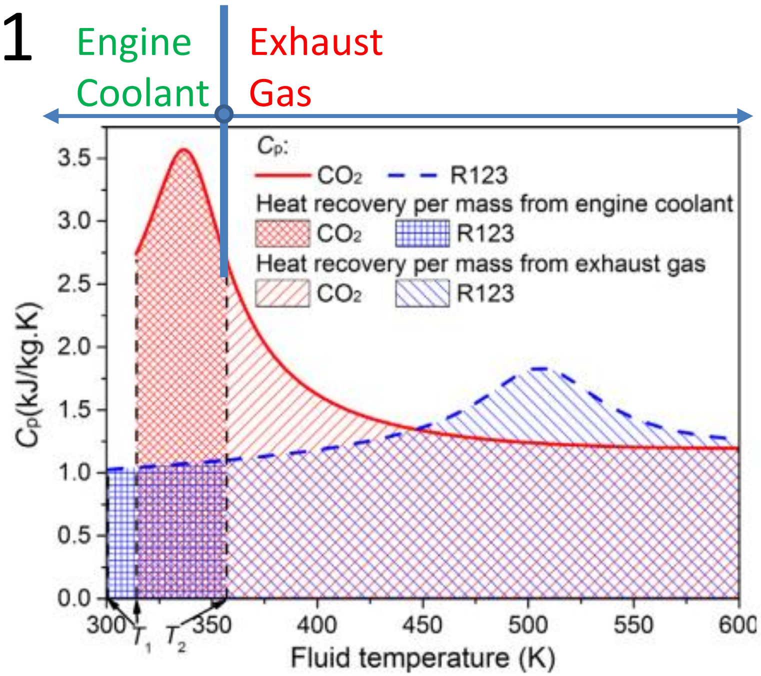
Meet the demand of mobile applications

CTRC could better recover exhaust and coolant energy simultaneously (Applied Energy, 2016, 176:171-182.)

Even both utilization rate of 1

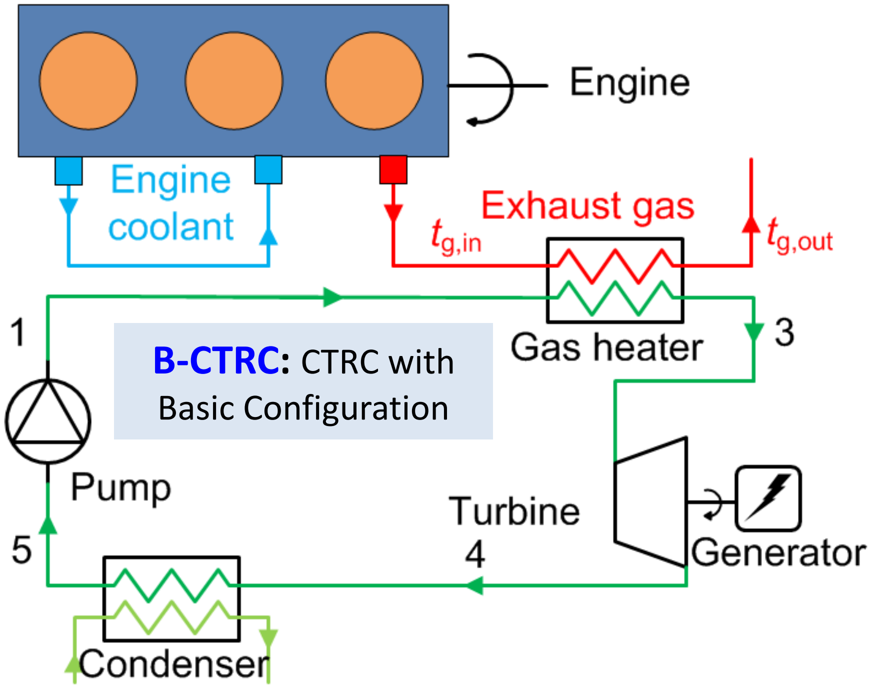


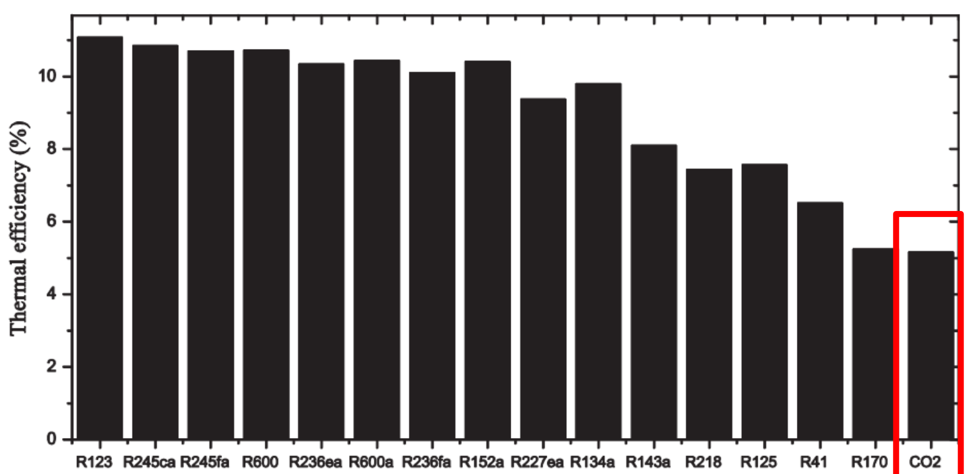
Utilization rate comparison between CTRC and ORC (R123)



Heat absorption capbility between CO_2 and R123

Background-Basic CTRC





Thermal efficiency comparison between CTRC and ORCs

(（Zhang et al. Appl. Eng. 88 (2011) 2740–2754）)

□ B-CTRC Components：

Pump

Gas heater

Turbine & Generator

Condenser

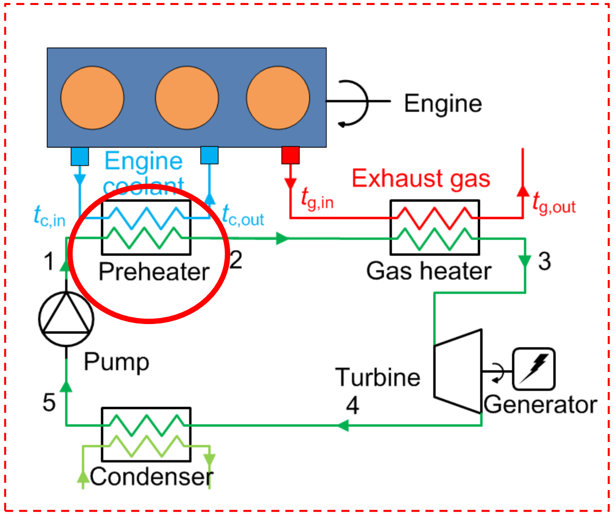
□ Drawback of B-CTRC：

Low thermal efficiency

Low power output

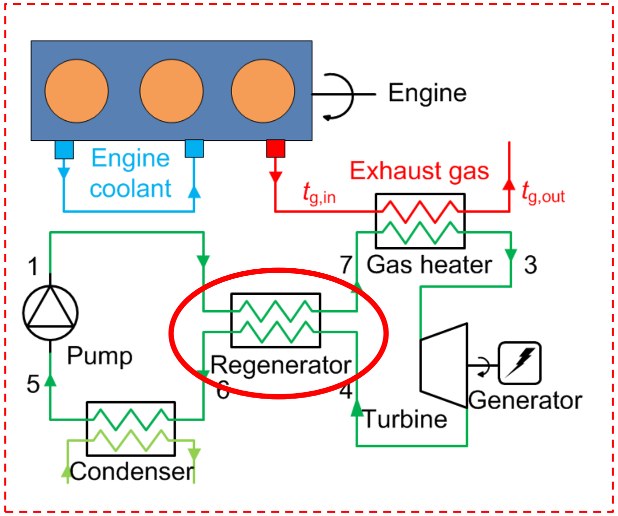
Efficient Solution: Modified Configurations

1. Add energy input from outside: engine coolant as preheat source



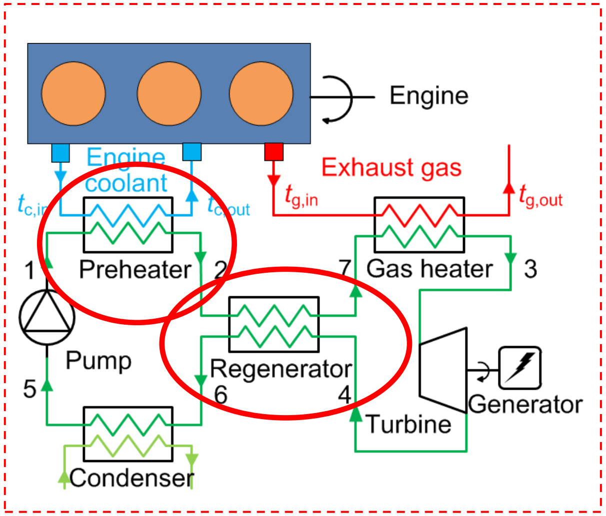
P-CTRC: CTRC with Preheated Configuration

2. Add energy input from inside: high temp. exhaust CO_2



R-CTRC: CTRC with Regenerated Configuration

3. Both of 1 and 2



PR-CTRC: CTRC with Preheated and Regenerated Configuration

Object of study (experimental way):

Compare thermodynamic performance between four CTRC configurations and find improved degree by modified CTRC

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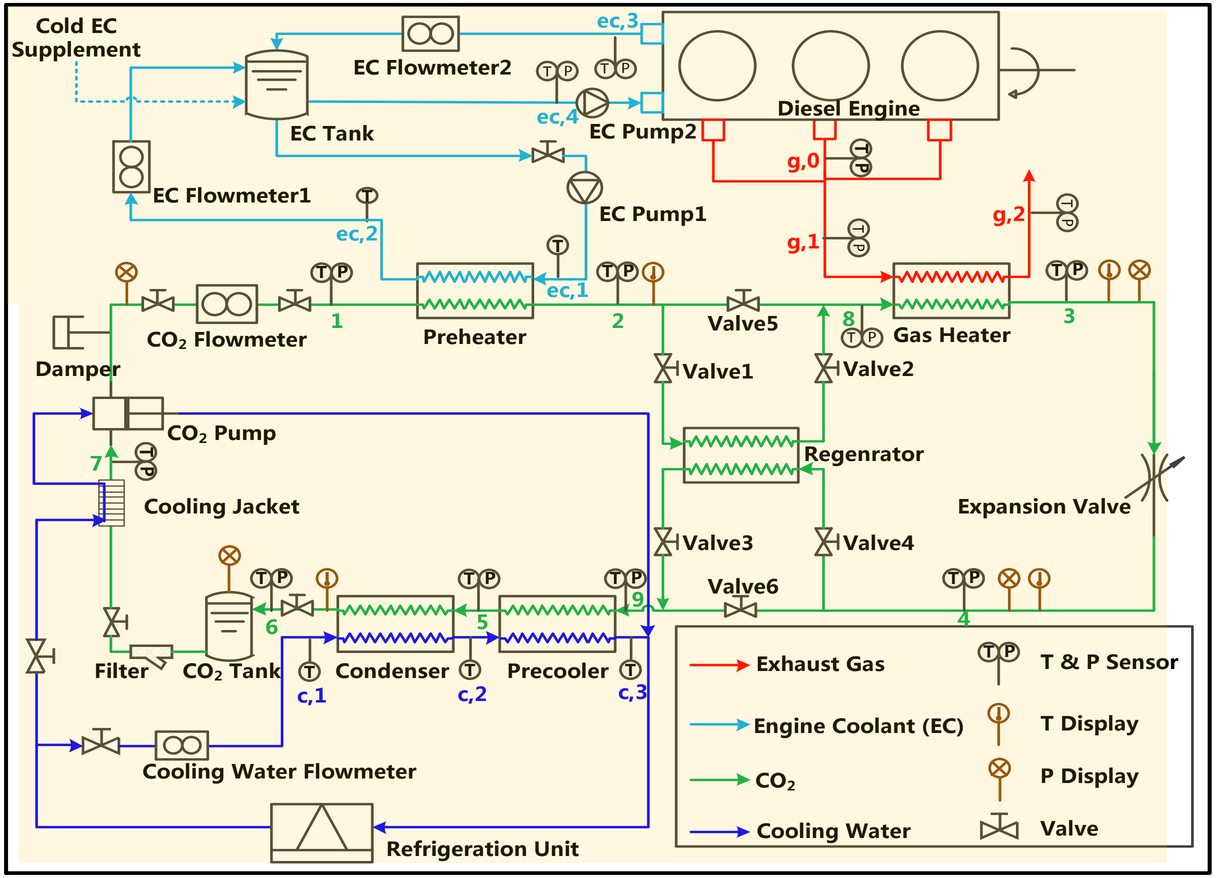
System Layout

Main design parameters：

Power output：4.5kW   Maximum pressure : 11MPa   Maximum temperature : 230℃

Engine coolant system

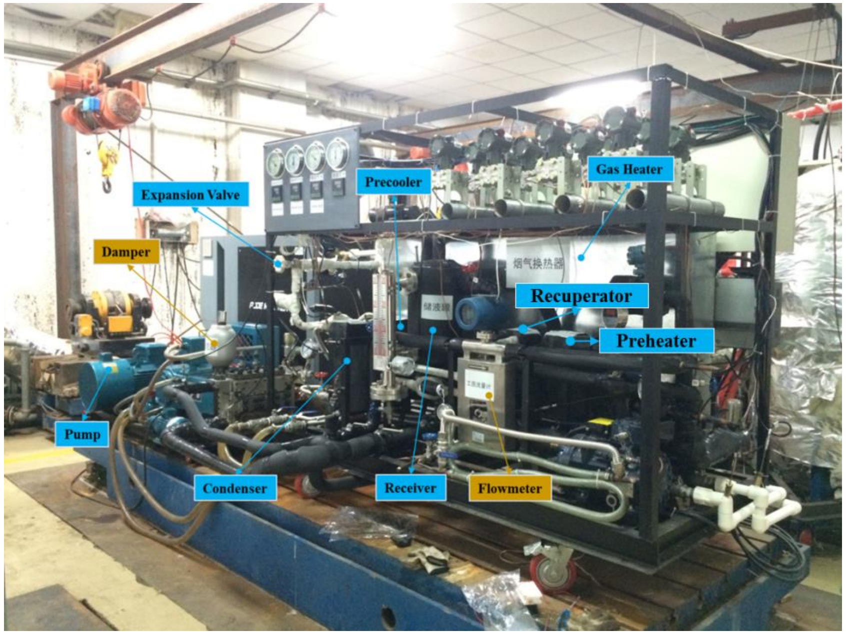


Diesel engine system

CTRC system

System Photos

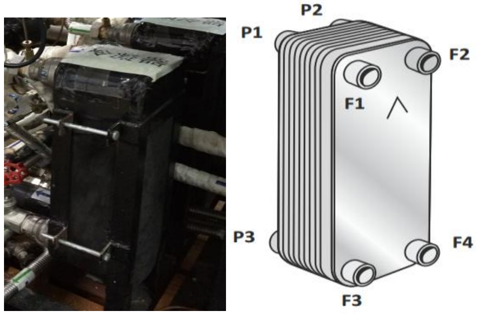
CTRC system



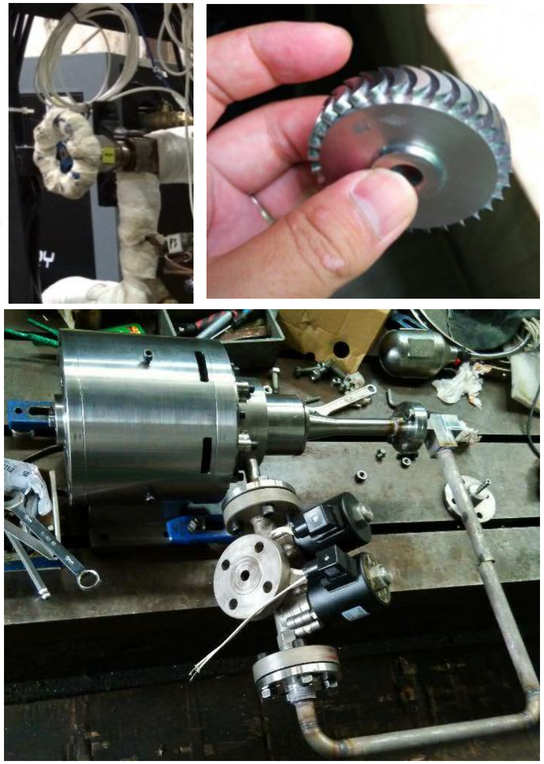
Gas heater

Pump

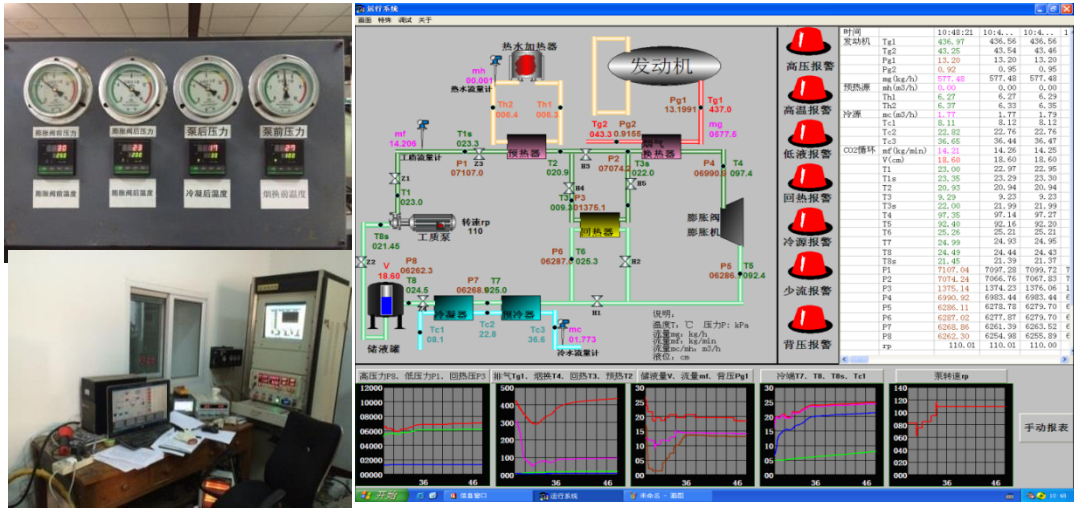
The other HEs



Expansion Valve/ Turbine



Control, Record and Alarm

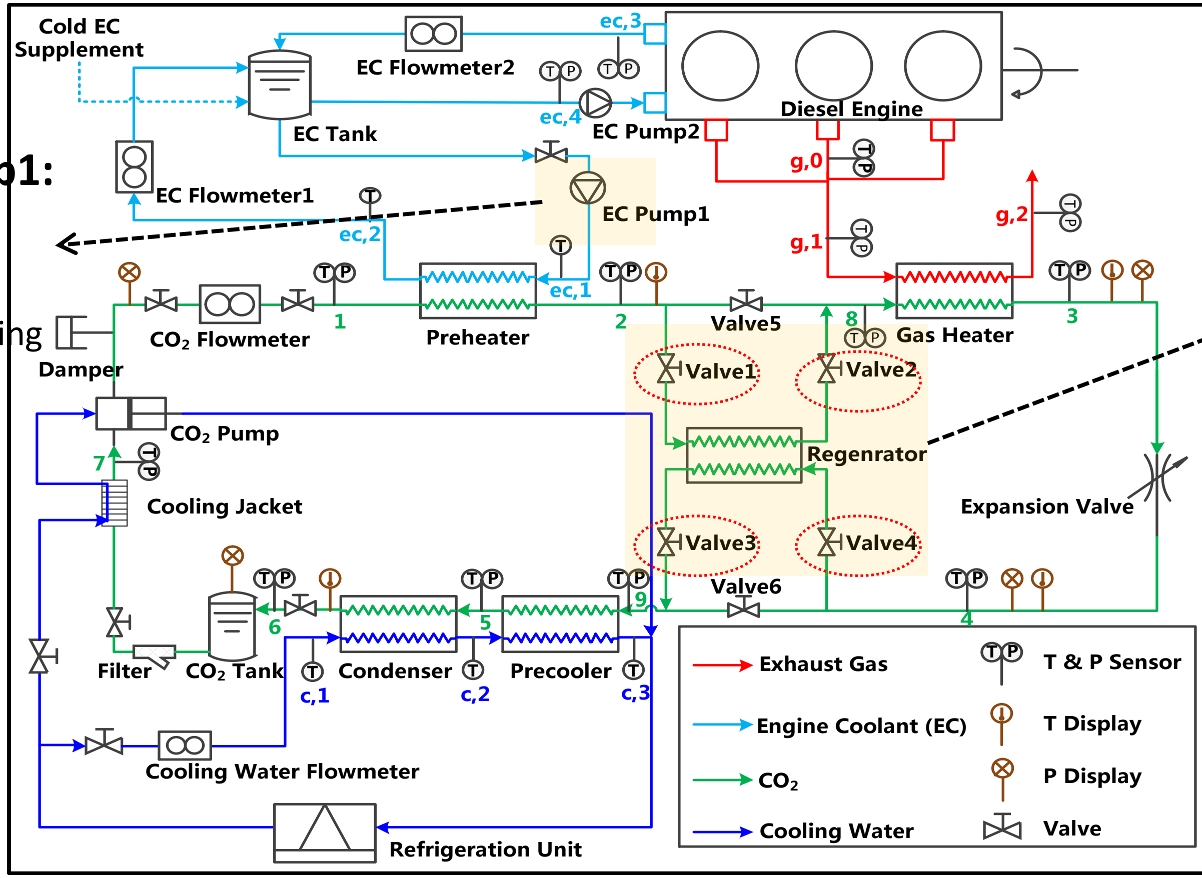


Four CTRC Switch

Control EC Pump1:

On: With Preheating

off: Without Preheating



Control Valve1-4:

On: With IHX

Off: Without IHX

Four CTRC configurations can be tested in this bench:

	B-CTRC	R-CTRC	P-CTRC	PR-CTRC
EC Pump1	Off	Off	On	On
Valve1-4	Off	On	Off	On

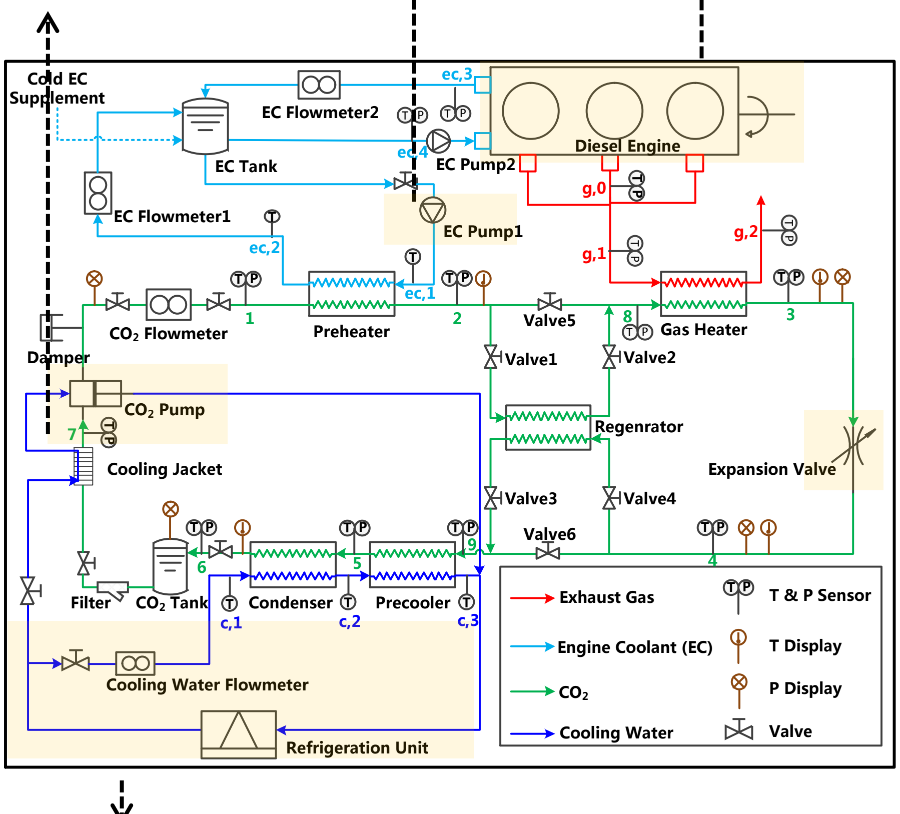
Same Boundary Conditions for Four CTRCs

Heat sources:

1) Same operating conditions of engine (1100rpm,50%load)
2) Same EC temperature (87℃) and EC pump speed (8.75Hz)

Fluid flow rate:

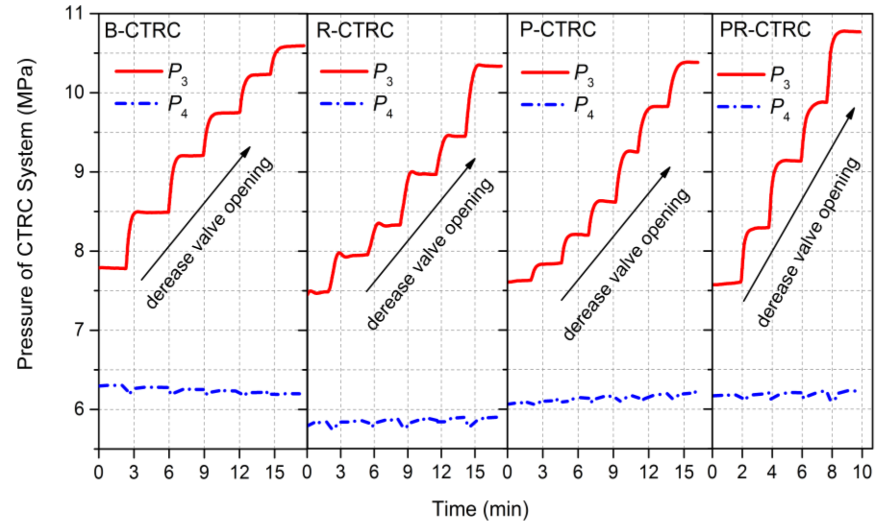
Same pump speed (80Hz)



Cold source:

Same pump speed and similar water temperature control

Operating Conditions for Four CTRCs



High and low pressures

Pressure ratio range:

B-CTRC: 1.23-1.71

R-CTRC: 1.25-1.67

P-CTRC: 1.28-1.75

PR-CTRC: 1.23-1.73

Outline

1. Background

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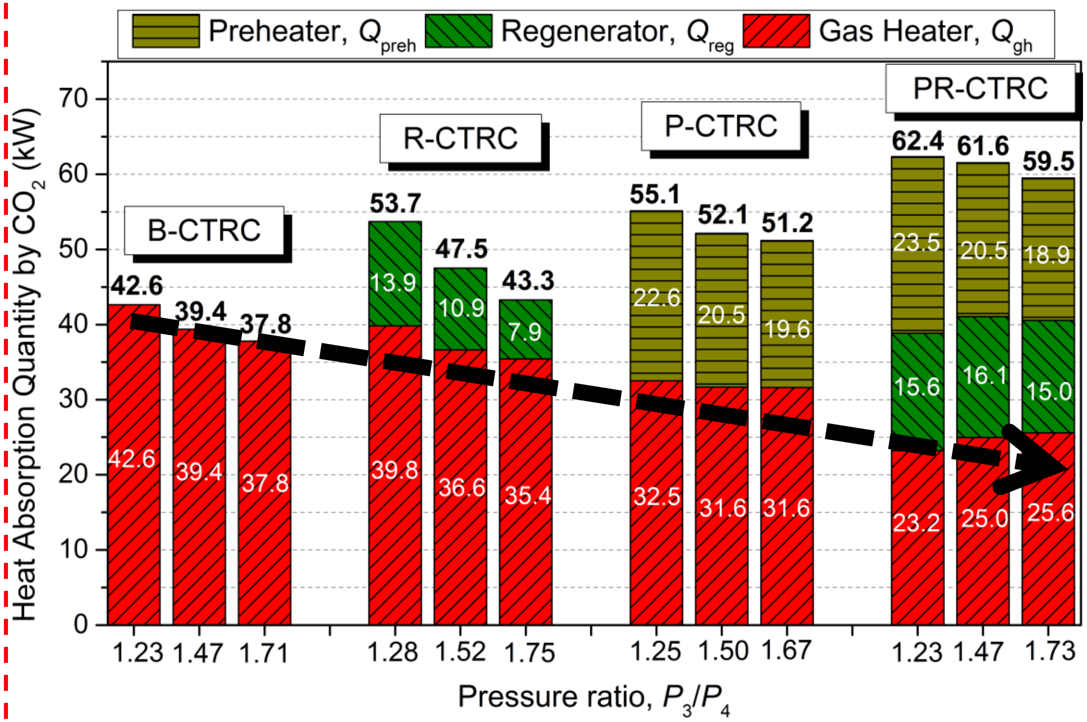
- Energy Input
- Net Power Output (estimation)
- Cooling load

4. Summary

Energy Input

• Heat Absorption Quantity（$Q_{a,total}$）



Versus the B-CTRC, increase of $Q_{a,total}$:

R-CTRC: 18%　　P-CTRC:34%　　PR-CTRC :57%

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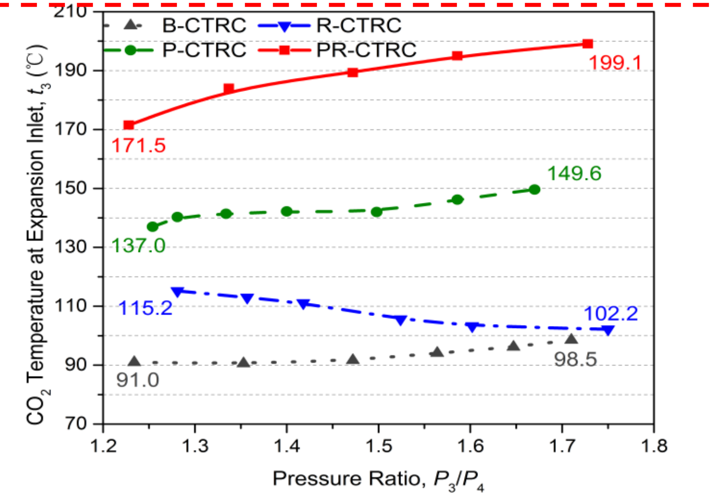
After adding the preheater and regenerator:

1. more energy input, especially the preheater

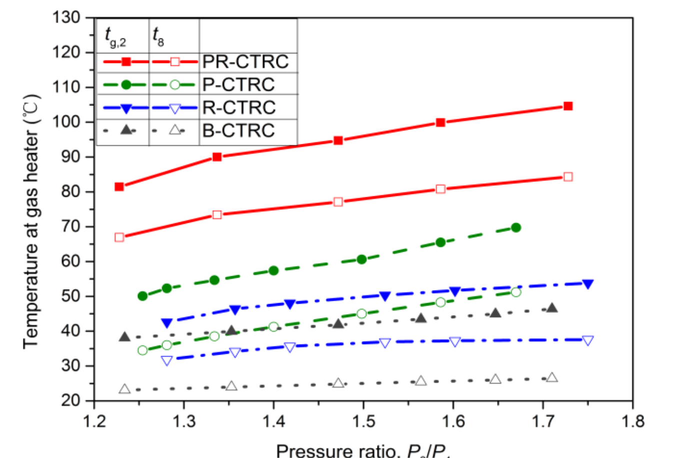
2. affect utilization rate of exhaust gas.

• Maximum Temp. of CO_2



PR-CTRC(199) > P-CTRC > R-CTRC > B-CTRC (99)

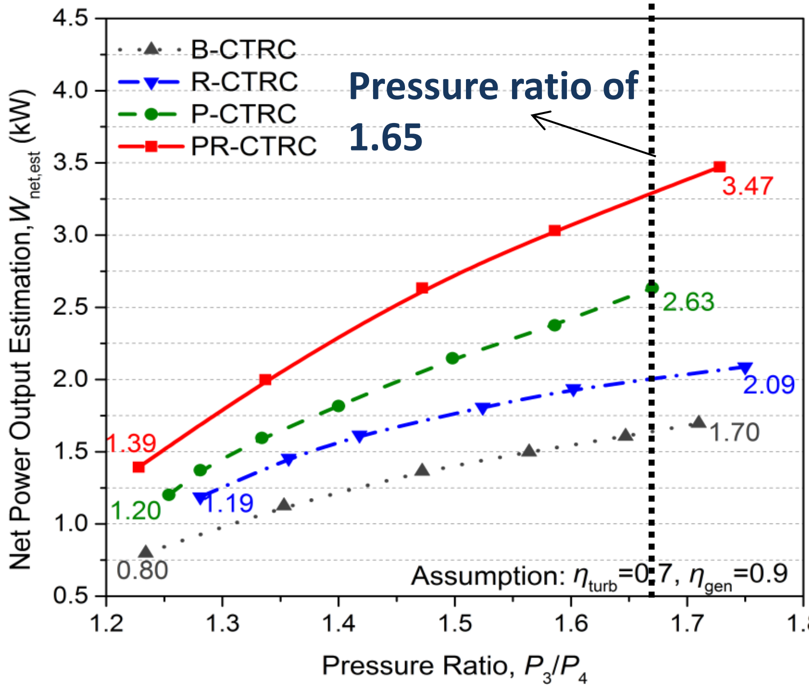
• Inlet Temp. of Gas Heater



Inlet temp. of CO_2 affects final temp. of exhaust gas.

Net Power Output (Estimation)

- **Net Power Output (Estimation, $W_{net,est}$)**



Versus the B-CTRC, increase of $W_{net,est}$:

R-CTRC: 24% **P-CTRC:60%** **PR-CTRC :101%**

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Versus the B-CTRC, increase of $Q_{a,total}$:

R-CTRC: 18% **P-CTRC:34%** **PR-CTRC :57%**

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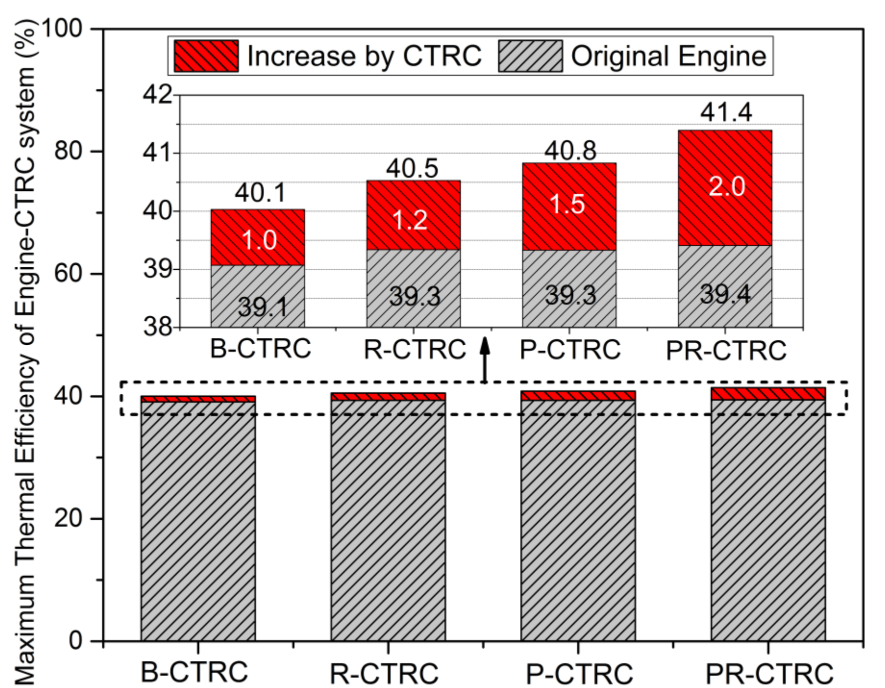
R-CTRC: 1.33 **P-CTRC:1.76** **PR-CTRC :1.77**

- **Efficiency Increase of Engine**



PR-CTRC: increases from **39.4%** to **41.4%**

2.0% absolute increase

After adding the preheater and regenerator:

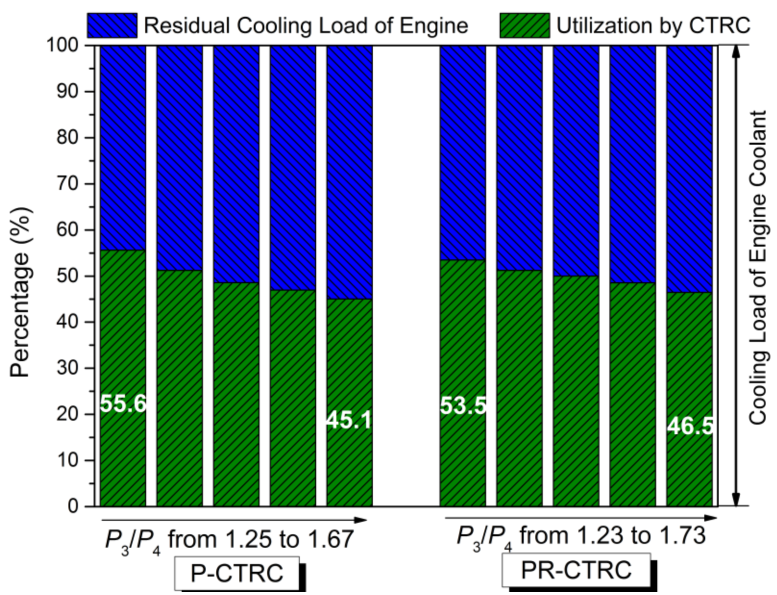
1. about double net power output is achieved;

2. preheater makes more contribution.

Cooling Load of Combined System

Except **output increase**, the **cooling load reduction** of combined system (engine+CTRC) is another benefit after adding preheater or regenerator

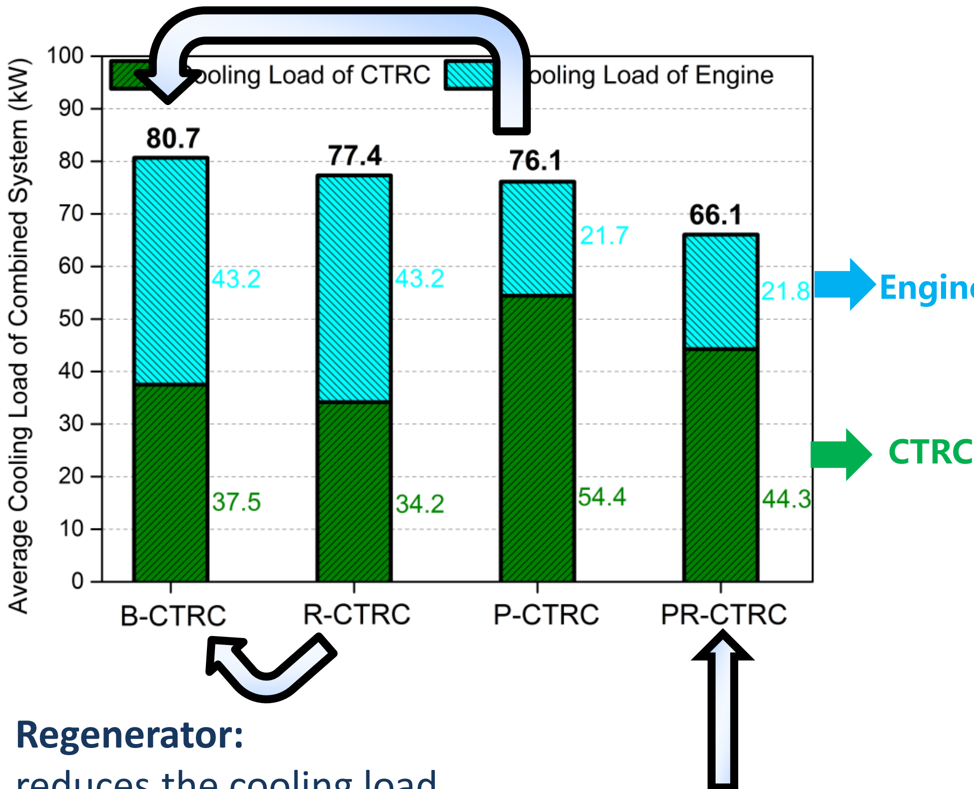
Utilization Rate of Engine Cooalnt



45.1%~55.6%, the residual is still the cooling load of engine.

Cooling Load of Combined System

Preheater:
reduces the cooling load at the **engine side.**



Regenerator:
reduces the cooling load at the **CTRC side.**

Both of them:
the minimum cooling load of combined system

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Summary

By adding a preheater or a regenerator for CTRC system, benefits are achieved as following:

1

- **Compared with the B-CTRC, the PR-CTRC, the P-CTRC and the R-CTRC obtain net power output increase of 101%, 60%, 24%, respectively.**
- **Preheater makes more contributions to output than the regenerator.**
- **The PR-CTRC promotes engine efficiency from 39.4% to 41.4%.**

More Power Output

2

- **Preheater and regenerator has active impact on cooling load of combined system.**
- **Adding both of them, cooling load decreases from 80.7kW to 66.1kW.**

Less Cooling Load

Thank you !

Acknowledgements:

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