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Utilization of Waste Heat from Intercooled, Reheat and Recuperated Gas Turbines for Power Generation in Organic Rankine Cycles

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Outline

1. Background and Introduction
2. System Description and Modeling
3. Results and Discussion
4. Conclusions

Organic Rankine Cycle (ORC)

- Low and medium temperature
- Low pressure
- Low cost
- Appropriate working fluids
  (pure fluid or mixtures)
- Served as a bottoming cycle
  (Gas turbines, Gas microturbines, Internal combustion engines, Supercritical CO_2 cycle, etc)

Combined Gas Turbine – ORC cycles

- **Small recuperative gas turbines**
  - Exhaust gases 250 ℃ – 300 ℃
  - 45 kW additional power *by Invernizzi et al. (2007)*

- **Limited studies on high efficiency heavy duty gas turbines**
  - Characterized by very high efficiency but low exhaust temperature

  Chacartegui et al. (2009)
  - Modify existing gas turbines by adding intercooled compression and reheat
  - 3% of the efficiency higher than steam combined cycles

- **No studies on the heat recovery from the intercooler**
  - 120 ℃ – 250 ℃ of the intercooler inlet temperature
  - Rejected to the atmospheric air, cooling water or sea water

- **The present study**

  A combined power cycle consisting of a recuperated, intercooled and reheat (ICRH) gas turbine and two ORC bottoming cycles

  a) Three commercial gas turbines are converted

  b) Thermodynamic analysis of each combined cycle

  c) Parametric optimization of bottoming ORC cycles

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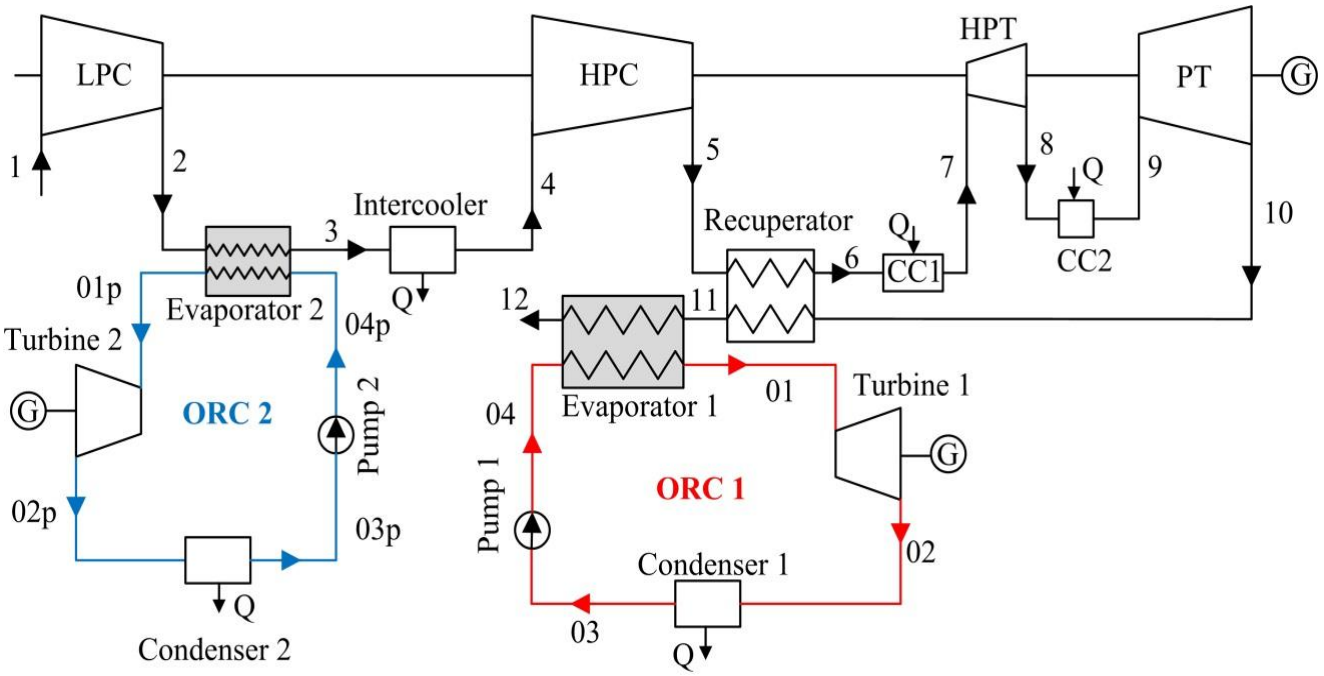
The recuperated ICRH gas turbine with two ORC cycles



The Existing Machines Considered

	GE LM 6000	Alstom GT 24	RR WR 21
PR	29.1	30.0	16.2
TIT(℃)	1260	1260	982
TET(℃)	438	630	356
m_E (kg/s)	127	391	73
Net power (MW)	43.4	179	25.25
Efficiency (%)	41.8	37.5	41.2

Data from Bhargava *et al*. (2002) and Chacartegui *et al*. (2009)

method

The Desired Modifications:

(1) Conversion of existing gas turbine to the ICRH system

(2) Conversion to the recuperated ICRH system

Modified gas turbine main characteristics

Parameter	GE LM-6000	Alstom GT 24	RR WR 21
Power Output (MW)	96.84	249.75	35.76
Overall Efficiency (%)	47.59	47.32	47.5
Turbine Inlet Temperature (℃)	1260	1260	982
Exhaust Temperature (℃)	462	384	307
LPC outlet temperature (℃)	117	211	152
Exhaust Gas Flow (kg/s)	148.7	391	73.1
Overall Pressure Ratio	34.1	31	16.2
LPC Pressure Ratio	2.65	4.48	3.3
HPT Pressure Ratio	3.44	2.03	1.97
LPT Pressure Ratio	-	-	1.64
PT Pressure Ratio	9.88	15.27	4.94

Assumptions

a) Four organic fluids used in ORCs: R123, R245fa, Toluene and Cyclohexane

b) Saturated or superheated working fluid at ORC turbine inlet

c) Saturated liquid supposed at the condenser outlet with a conservative temperature of 40 ℃

d) Values of pinch point in evaporator are not below 2 ℃

Performance evaluation

Net power output

$$\dot{W}_{\text{net}} = \dot{W}_{\text{net, REC ICRHGT}} + \dot{W}_{\text{net, ORCs}}$$

Overall efficiency

$$\eta_{\text{I}} = \frac{\dot{W}_{\text{net}}}{\dot{Q}} = \frac{\dot{W}_{\text{net}}}{\dot{m}_{\text{air}}(h_7 - h_6) + \dot{m}_{\text{mix,1}}(h_9 - h_8)}$$

Power ratio

$$\text{Power Ratio} = \frac{\dot{W}_{\text{net,ORCs}}}{\dot{W}_{\text{net}}}$$

Optimization method

Maximize $\eta_I(T_{e,\,1}, T_{e,2}, \Delta T_E, \Delta T_{\text{sup,1}}, \Delta T_{\text{sup,2}})$

Evaporator temperatures
Pitch point temperature difference
Degrees of superheat

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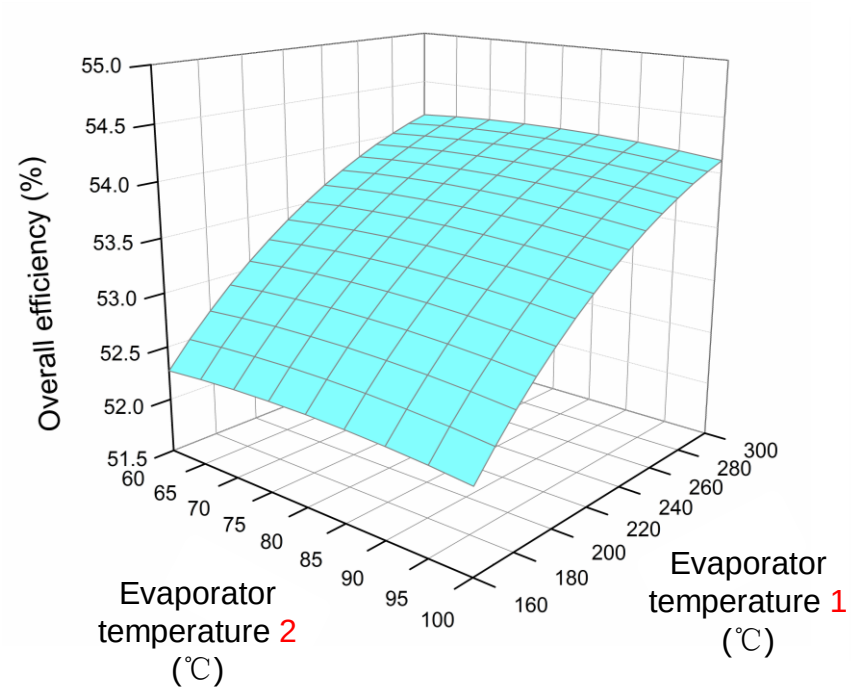
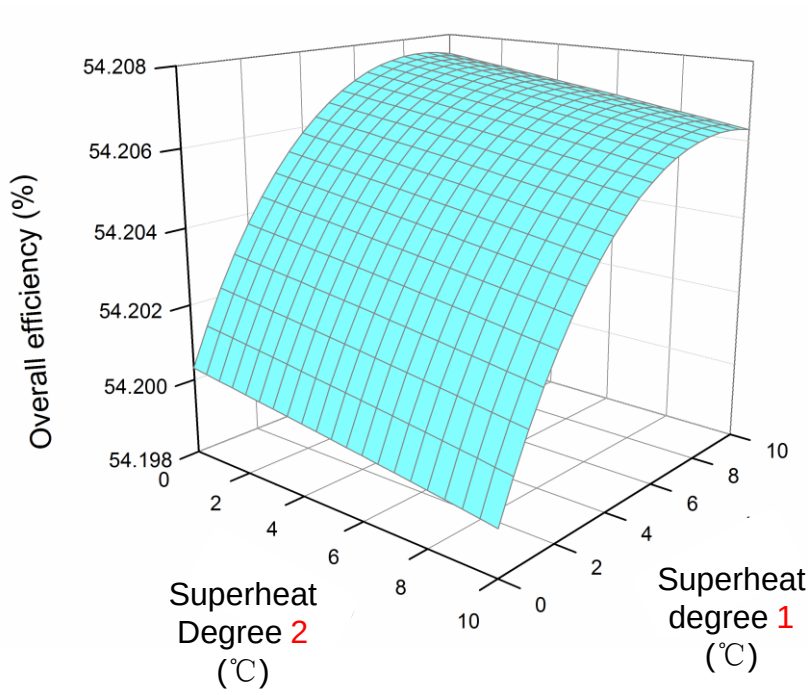
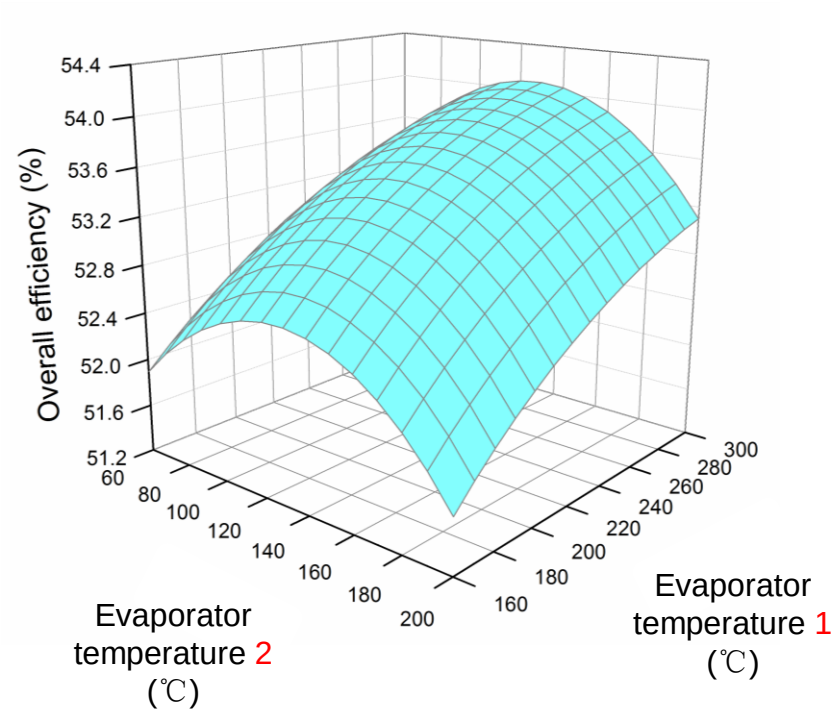
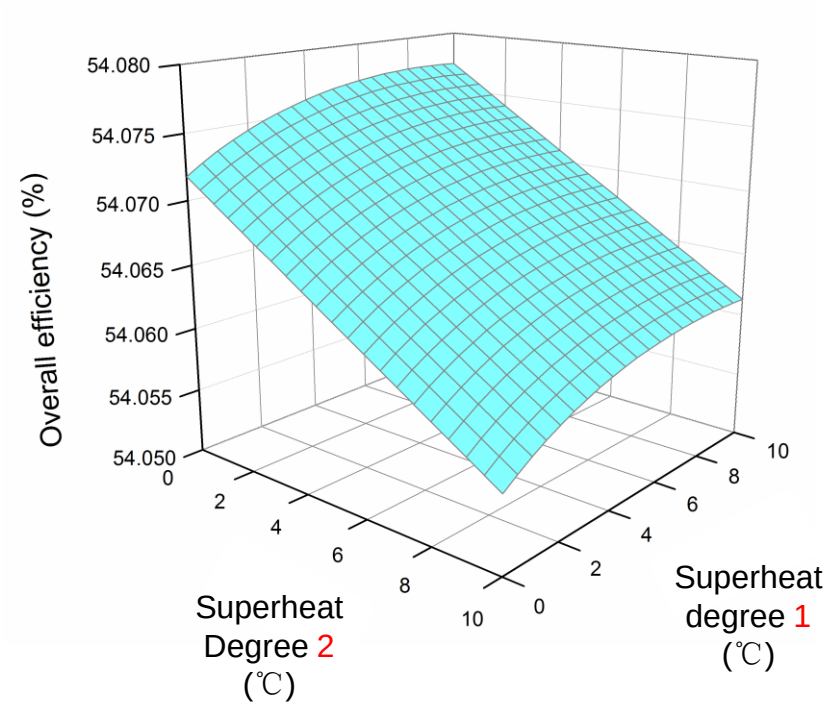
The performance of toluene LM 6000 ORCs combined cycle



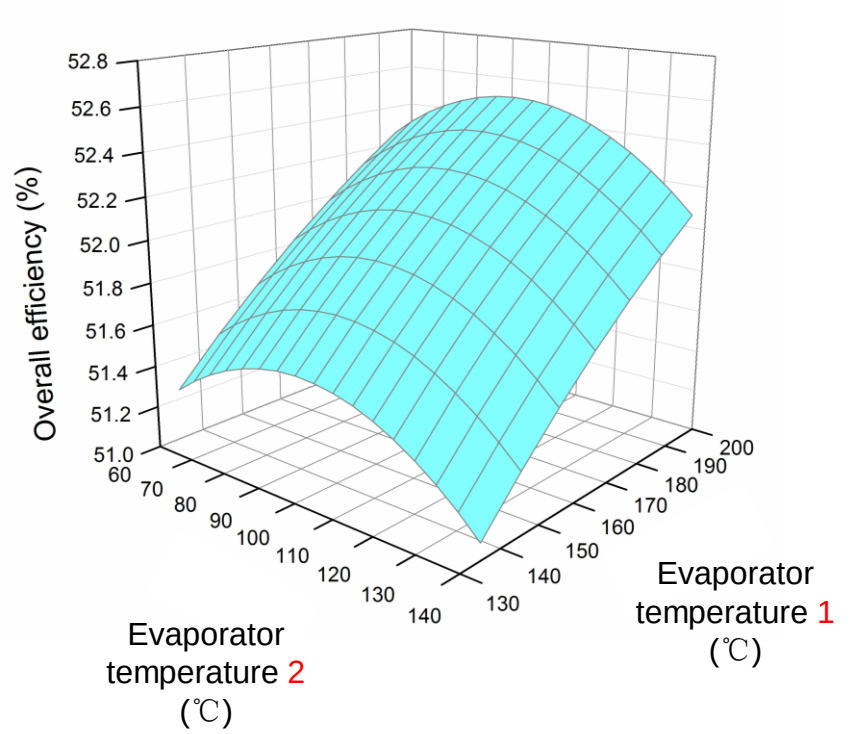


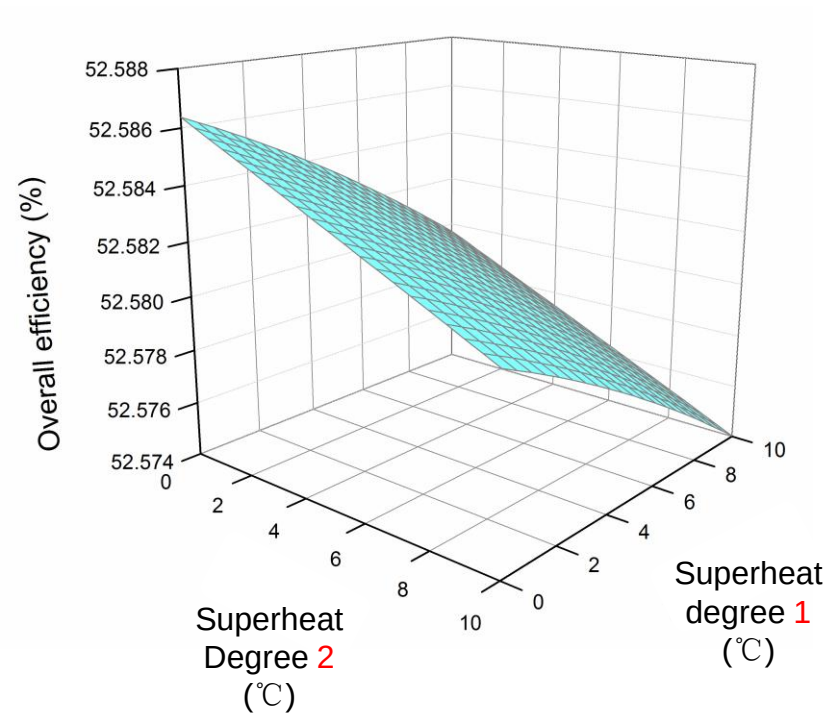
The performance of toluene GT 24 ORCs combined cycle





The performance of toluene WR 21 ORCs combined cycle





The optimization results of modified LM 6000 ORCs combined cycles

Parameter	R123	R245fa	Toluene	Cyclohexane
Overall Efficiency (%)	52.62	51.75	54.81	53.89
Efficiency Enhancement (%)	10.57	8.75	15.18	13.24
ORC 1 Power Output (MW)	9.72	7.95	14.21	12.33
ORC 2 Power Output (MW)	0.52	0.53	0.49	0.49
Overall Power Output (MW)	107.08	105.32	111.54	109.66
Power Ratio (%)	9.56	8.05	13.18	11.69
$T_{e,1}$ (℃)	169.9	140	299.7	263.8
$T_{e,2}$ (℃)	80.3	78.1	80.3	75.6
ΔT_E (℃)	2.3	2.1	2.2	2.9
$\Delta T_{sup,1}$ (℃)	10	8	5.7	1.4
$\Delta T_{sup,2}$ (℃)	0.7	2.1	1.2	3.4
ORC 1 Mass Flow Rate (kg/s)	231.4	215.7	72.8	76.7
ORC 2 Mass Flow Rate (kg/s)	31.6	31.4	12.1	14.1

The optimization results of modified GT 24 ORCs combined cycles

Parameter	R123	R245fa	Toluene	Cyclohexane
Overall Efficiency (%)	52.55	52.13	54.07	52.93
Efficiency Enhancement (%)	11.06	10.17	14.26	11.85
ORC 1 Power Output (MW)	19.83	16.34	28.99	23.13
ORC 2 Power Output (MW)	7.78	9.06	6.63	6.48
Overall Power Output (MW)	277.36	275.15	284.47	279.36
Power Ratio (%)	9.96	9.23	12.48	10.60
$T_{e,1}$ (℃)	175	140	297	225.7
$T_{e,2}$ (℃)	139	129.4	126.1	150.6
ΔT_E (℃)	2.2	2.2	2	2
$\Delta T_{sup,1}$ (℃)	6.6	8.2	4	0.2
$\Delta T_{sup,2}$ (℃)	0.4	0	0.7	0
ORC 1 Mass Flow Rate (kg/s)	477.6	442.7	150.3	161.9
ORC 2 Mass Flow Rate (kg/s)	230.9	280.9	82.1	68.2

The optimization results of modified WR 21 ORCs combined cycles

Parameter	R123	R245fa	Toluene	Cyclohexane
Overall Efficiency (%)	51.77	51.19	52.55	52.62
Efficiency Enhancement (%)	8.99	7.77	10.61	10.76
ORC 1 Power Output (MW)	2.68	2.2	3.3	3.34
ORC 2 Power Output (MW)	0.53	0.56	0.5	0.51
Overall Power Output (MW)	38.97	38.55	39.56	39.61
Power Ratio (%)	8.25	7.21	9.59	9.72
$T_{e,1}$ (℃)	170.6	140	205.8	235.7
$T_{e,2}$ (℃)	98	104	95.3	92.7
ΔT_E (℃)	2.2	2	2	2
$\Delta T_{sup,1}$ (℃)	7.8	5.6	0.9	0.8
$\Delta T_{sup,2}$ (℃)	0	0.4	0.4	2.9
ORC 1 Mass Flow Rate (kg/s)	64.8	61.4	23.4	22.5
ORC 2 Mass Flow Rate (kg/s)	23.9	22	9.2	10.1

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a. ORCs are an interesting and impressing option when combined with high efficiency gas turbines with low exhaust temperatures.

   The toluene ORC combined cycles for each modified gas turbines present a very attractive overall efficiency.

b. The efficiencies of recuperated ICRH gas turbines were improved by about 7.8% to 15.2%.

   The use of different organic fluid in the two bottoming cycles may further improve the combined cycle efficiency.

c. The heavy duty gas turbines like modified LM-6000 and GT 24 are not preferable to be used in combined cycles.

   Gas turbine with relatively small power like WR 21 is more suitable to combine bottoming ORCs with reasonable mass flow rate of the organic fluid.

d. The ORC 2 yielded about 0.5 and 0.53 MW on average of the power output for LM-6000 and WR 21 gas turbine combined cycles, respectively.

Thank You!

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