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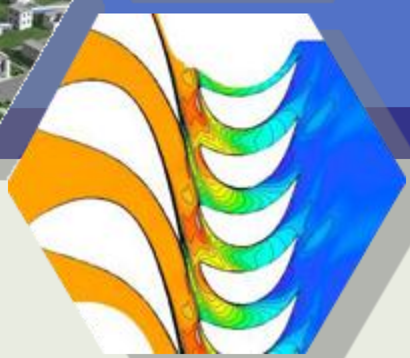
Thermodynamic Analysis and Comparison of an ORC-OFC Combined Power Generation System



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1.Introduction

Damages to environment resulted from overuse of fossil energy contributed to '**energy saving and emission reduction**' as an important strategy for developments of many regions. More and more attentions have been paid to the utilization of industrial waste heat and renewable energy.

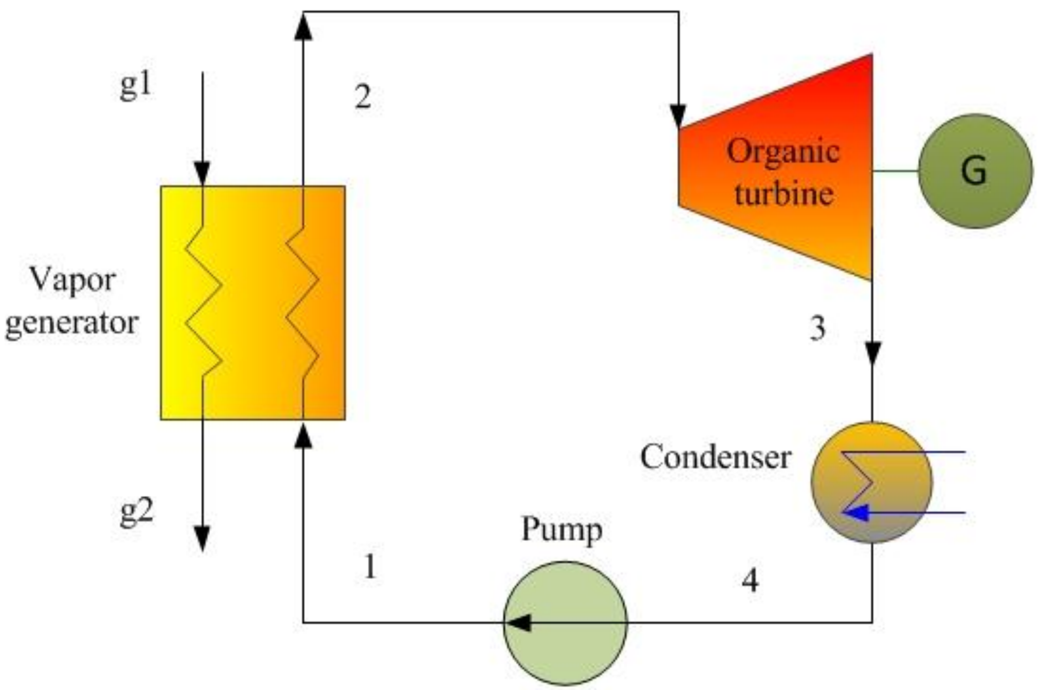
Potential power generation cycle: **Organic Rankine cycle (ORC)**

ORC's disadvantage: **Temperature mismatch between heat source and working fluid**

Two methods: **1. Zeotropic mixtures working fluid**

2. Transcritical or supercritical cycle

1.Introduction



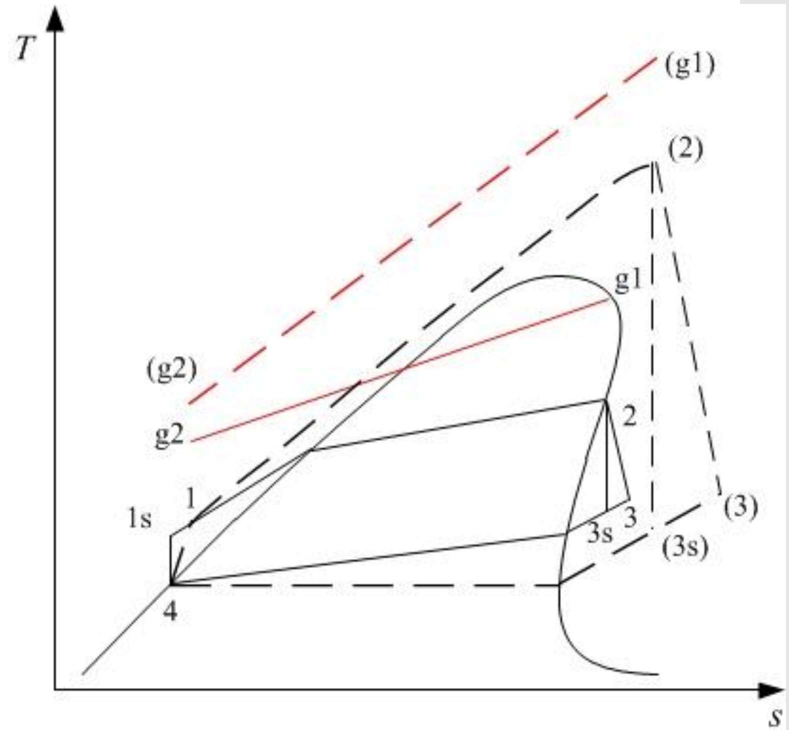


Figure 1: Schematic diagram and *T*-*s* diagram of organic Rankine cycle (ORC)

1.Introduction

Tony Ho *et al.* (Energy 42 (2012) 213-223) proposed Organic Flash Cycle (OFC).

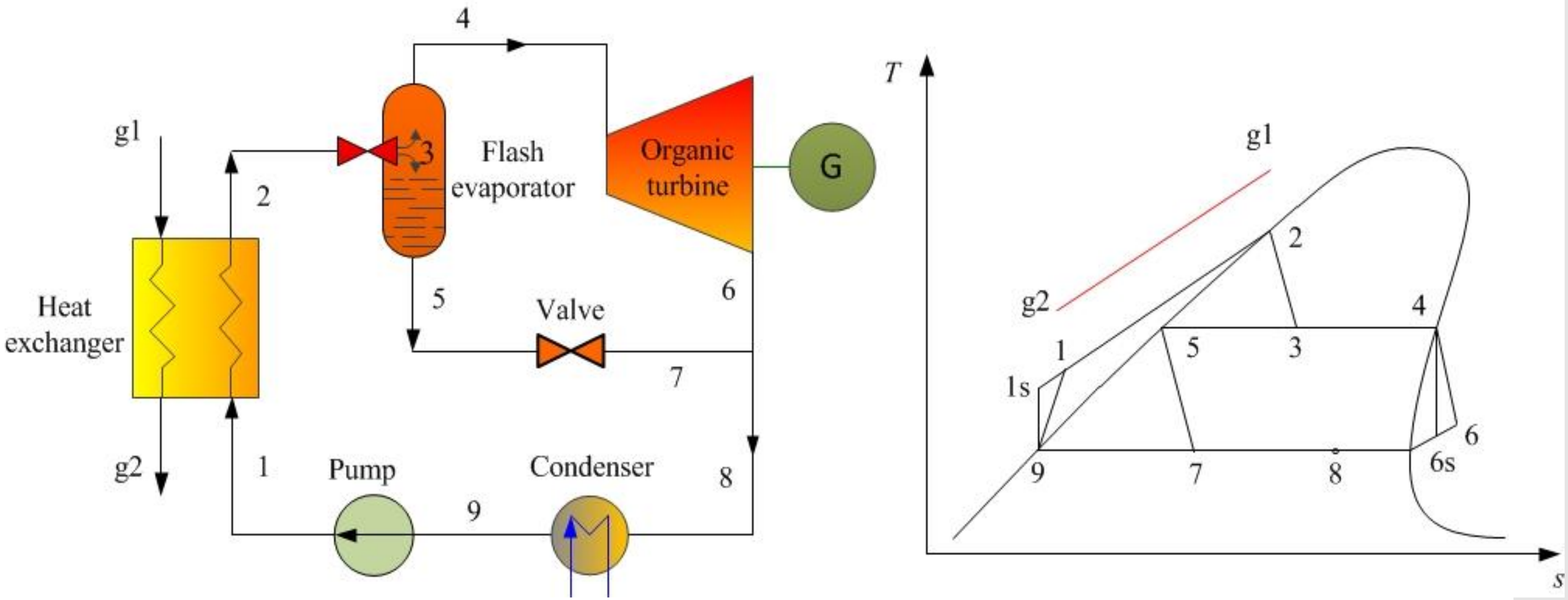


Figure 2: Schematic diagram and *T*-*s* diagram of organic flash cycle (OFC)

2. System Description

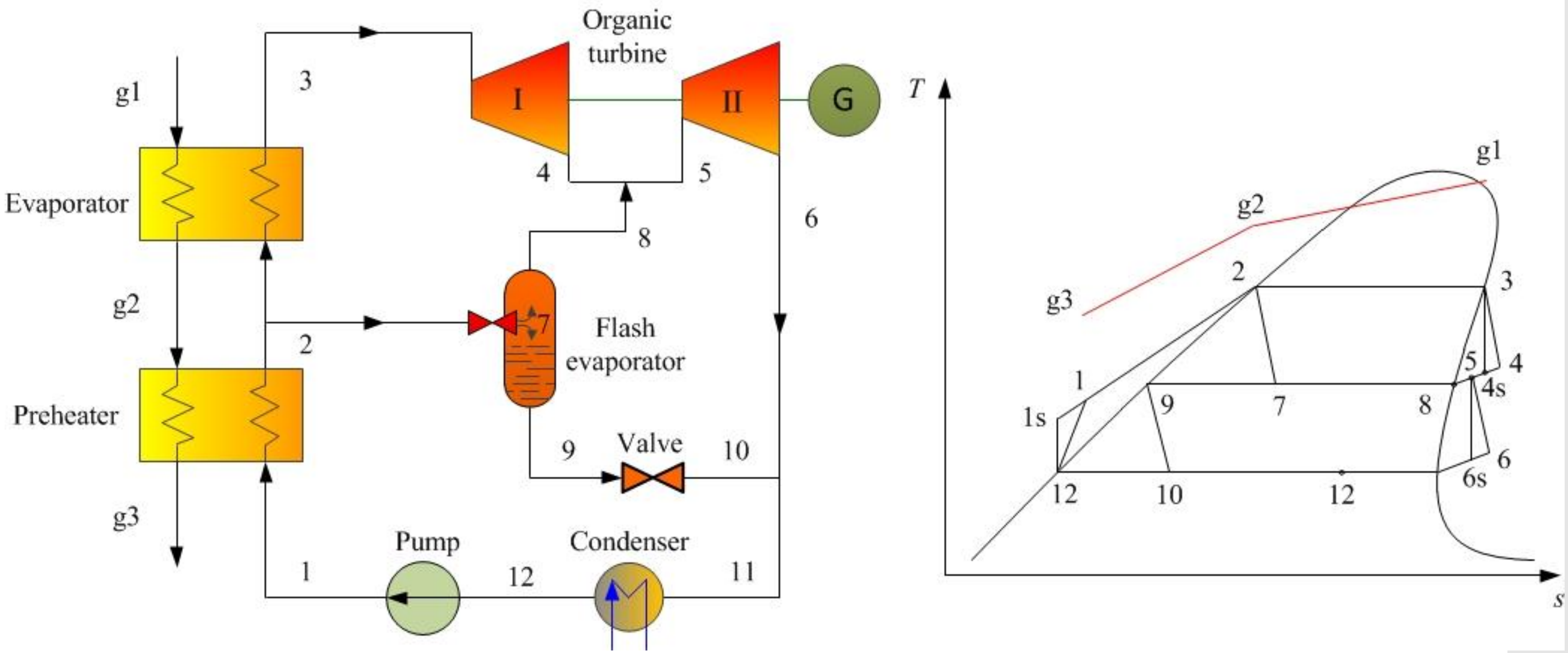


Figure 3: Schematic diagram and *T*-*s* diagram of ORC-OFC combined power generation system

Advantages

— **This new system, improving the issue of ORC that the existence of pinch point temperature difference in vapor generator makes the heat source exhaust temperature high, could decrease the heat source exhaust temperature, driving more working fluid to generate power.**

3. Mathematical Model and Performance Criteria

Some assumptions are made as follows.

1) The system reaches a steady state.

2) The pressure drops in preheater, evaporator, flash evaporator, condenser and connection pipes are neglected.

3) There is no heat transfer between the equipment of system and the environment.

4) The working fluids at the outlet of preheater and the evaporator are saturated liquid and saturated vapor, respectively.

5) The vapor stream and the liquid stream separated from flash evaporator are saturated vapor and saturated liquid, respectively.

6) The streams at the condenser outlet are saturated liquid.

7) The turbine and the pump have a given isentropic efficiency respectively.

8) The flow across the valve is isenthalpic.

3. Mathematical Model and Performance Criteria

Performance Criteria: **Exergy efficiency η_{exg}**

$$\eta_{\mathrm{exg}} = \frac{W_{\mathrm{net}}}{E_{\mathrm{in}}}$$

where,

W_{net} — Net power ouput of system, $W_{\mathrm{net}} = W_{\mathrm{tb,I}} + W_{\mathrm{tb,II}} - W_{\mathrm{p}}$

E_{in} — Exergy input to system, $E_{\mathrm{in}} = m_{\mathrm{hs}}[(h_{\mathrm{g1}} - h_0) - T_0(s_{\mathrm{g1}} - s_0)]$

4. Parametric Analysis

Table 1 Simulation conditions of combined ORC-OFC system

Term	Value	Unit
Working fluid	R245fa	/
Ambient temperature	20	℃
Ambient pressure	101.3	kPa
Heat source (hot air) temperature	150	℃
Heat source (hot air) pressure	150	kPa
Mass flow rate of heat source	10	kg s^{-1}
Organic turbine isentropic efficiency	80	%
Pump isentropic efficiency	70	%
Pinch point temperature difference	10	℃

4. Parametric Analysis

Table 2 Thermodynamic parameters of each node of the system

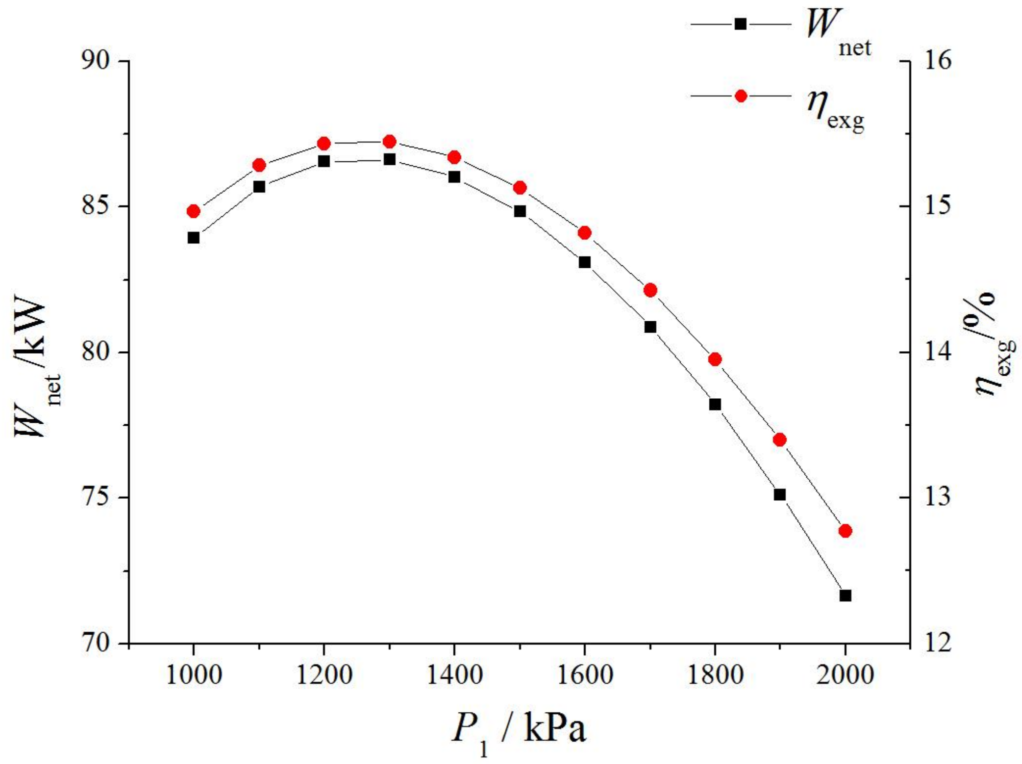
State	t/℃	P/kPa	h/kJ kg^{-1}	s/kJ kg^{-1}K^{-1}	Quality	m/kg s^{-1}
1	34.14	1500.00	245.00	1.1515	0	5.11
2	107.85	1500.00	352.34	1.4635	0	5.11
3	107.85	1500.00	478.62	1.7950	1	2.61
4	86.88	800.00	469.66	1.8012	1	2.61
5	85.53	800.00	468.07	1.7968	1	3.30
6	52.11	200.00	447.27	1.8129	1	3.30
7	80.54	800.00	352.34	1.4697	0.2782	2.50
8	80.54	800.00	462.10	1.7800	1	0.70
9	80.54	800.00	310.04	1.3501	0	1.80
10	33.35	200.00	310.04	1.3669	0.3586	1.80
11	33.35	200.00	398.76	1.6564	0.8375	5.11
12	33.35	200.00	243.59	1.1501	0	5.11
g1	150.00	150.00	428.15	7.1280	/	10.00
g2	117.85	150.00	395.25	7.0471	/	10.00
g3	64.07	150.00	340.44	6.8963	/	10.00

4. Parametric Analysis

Table 3 System performance of combined ORC-OFC system

Term	Value	Unit
Power output of organic turbine I	23.35	kW
Power output of organic turbine II	68.68	kW
Power consumption of pump	7.20	kW
Net power output of system	84.83	kW
Exergy input	560.69	kW
Exergy efficiency	15.13	%

4. Parametric Analysis



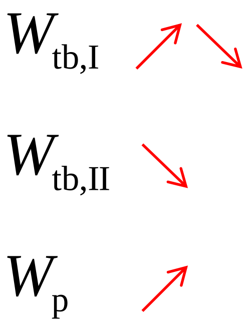
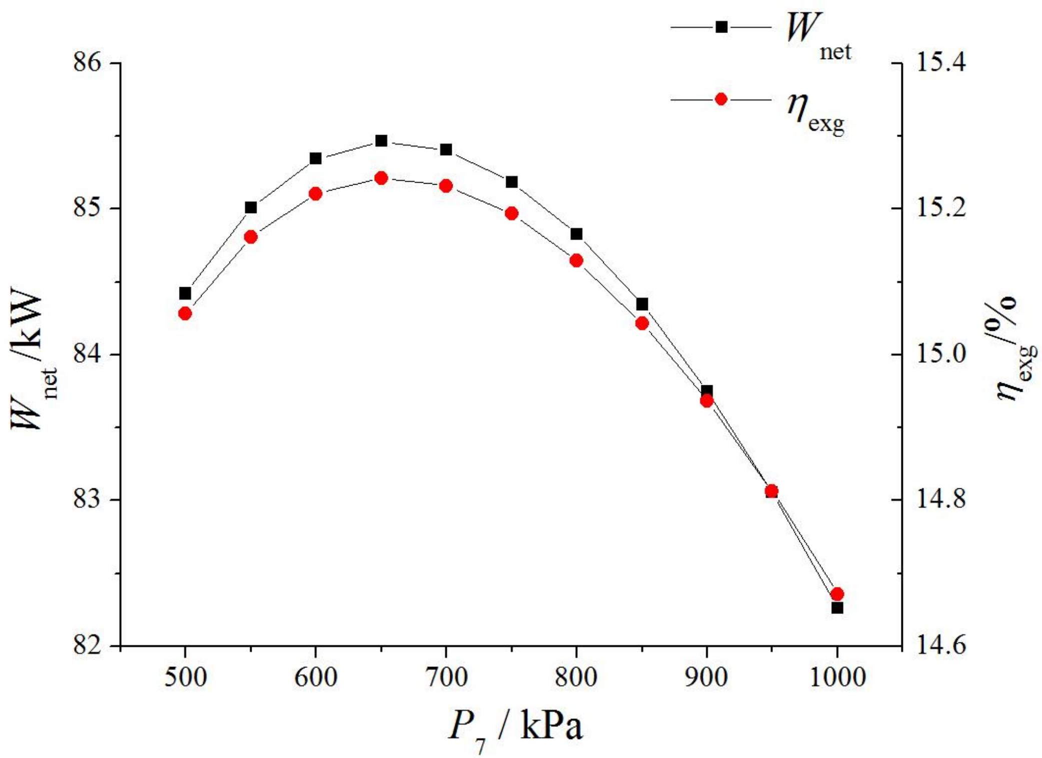


Figure 4: Effect of evaporation pressure on net power output and exergy efficiency

4. Parametric Analysis



$W_{tb,I}$ ↘

$W_{tb,II}$ ↗

W_p →

Figure 5: Effect of flash pressure on net power output and exergy efficiency

5. Optimization and Comparison

- **Objective function: Exergy efficiency (η_{exg})** **Method: Genetic Algorithm (GA)**

Table 4: Ranges of optimization parameters for different systems

System	Thermodynamic parameters needing optimization	Range
ORC-OFC	Evaporation pressure/ kPa	[500,2800]
	Flash pressure/ kPa	[300,2500]
ORC	Evaporation pressure/ kPa	[500,2800]
OFC	Preheating pressure/ kPa	[500,2800]
	Flash pressure/ kPa	[300,2500]

Table 5: Operation parameters of GA

Term	Value
Population size	100
Crossover probability	0.8
Mutation probability	0.01
Stop generation	200

5. Optimization and Comparison

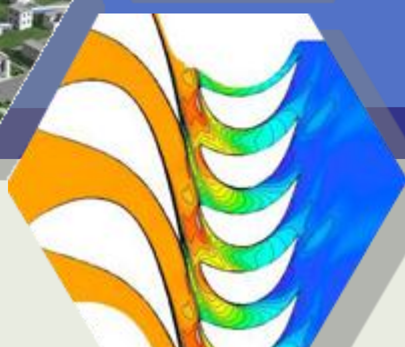
Table 6: Comparison results

Term	ORC-OFC	ORC	OFC
Evaporation/Preheating pressure / kPa	1289.5	1033.2	2800
Mass flow rate of fluid entering evaporator / kg s^{-1}	3.00	3.50	/
Flash pressure / kPa	596.56	/	1132.0
Mass flow rate of fluid entering flash evaporator / kg s^{-1}	4.05	/	6.61
Mass flow rate of saturated vapor generated in flash evaporator / kg s^{-1}	1.20	/	3.63
Condensation pressure / kW	200	200	200
Heat source exhaust temperature / ℃	44.17	73.15	44.93
Power output of organic turbine / kW	I: 33.45 II: 68.51	84.44	92.69
Power consumption of pump / kW	8.33	3.16	18.60
Net power output of system / kW	93.63	81.28	74.09
Exergy input / kW	560.69	560.69	560.69
Exergy efficiency / %	16.70	14.50	13.21

- **ORC-OFC combined power generation system shows the best performance**

6. Conclusions

- ORC-OFC shows great potential because of the following advantages:
  1) Dropping heat source exhaust temperature
  2) Driving more working fluids for power generation
  3) Avoiding high power consumption of pump like that in OFC
- Optimal evaporation pressure
  Optimal flash pressure
  } ORC-OFC: $W_{\mathrm{net,max}}$, $\eta_{\mathrm{exg,max}}$
- ORC-OFC combined power generation system shows best performance through comparisons with ORC and OFC under same conditions.



Thank you