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EXPERIMENTAL INVESTIGATION ON START-UP PERFORMANCE OF A 315 KW ORGANIC RANKINE CYCLE SYSTEM

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1. Introduction

To explore a 315 kW ORC apparatus start-up method of matching R134a flux with heat source temperature.

An experimental apparatus was set up to measure and calculate the electrical power, turbine back pressure, heat exchangers pressure drop and exergy loss during the start-up process.

The ORC system operation mode and control strategy during the start-up process can be developed.

2.1 Description of the ORC apparatus

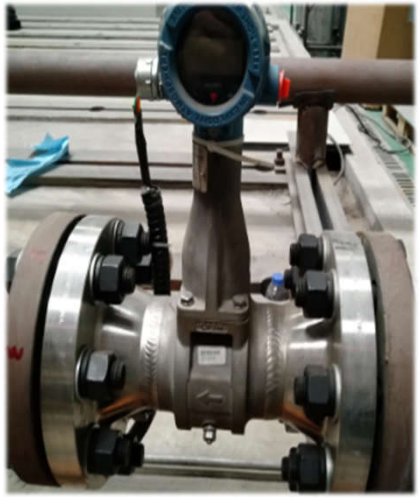
Low temperature waste heat: between 90 ℃ and 150 ℃
Working fluid: R134a ORC loop: generating electricity
Heating loop :simulating the waste heat
Cooling loop condensing turbine outlet R134a gas

- Variable frequency pump
- Preheater
- Two evaporators
- Two condensers
- Radial-flow turbine
- Storage tank
- Tubes
- Valves and sensors

2.2 Control strategy and measurement

The measuring range and accuracy of the measuring equipment used in the experiment






	Pressure Sensor	Temperature Sensor	R134a flowmeter	Water flowmeter
Range	0-2.5 MPa	0-100 ℃	0.08-1.237 m^3/min	0-10 m^3/min
Accuracy	±0.25%	±0.25%	±0.963%	±1%

3.1 The main research parameters of this study

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Electrical power: The power output from the frequency converter to the power grid, measured by the power analyzer.
Turbine back pressure: The turbine outlet pressure sensor to measure its value
Pressure drop of the heat exchanger: Pressure sensors at the inlet and outlet of evaporator and condenser

3.2 The formula for calculating

The formula for calculating the exergy loss:

$$I_{pp} = T_0 \cdot \dot{m} \cdot (s_1 - s_6) \qquad I_{ev} = T_0 \cdot \dot{m} \cdot (s_3 - s_1 - \frac{h_3 - h_1}{T_H})$$

$$I_{tb\&qv} = T_0 \cdot \dot{m} \cdot (s_4 - s_3) \qquad I_{cd} = T_0 \cdot \dot{m} \cdot (s_5 - s_4 - \frac{h_5 - h_4}{T_L})$$

The total exergy loss of the system:

$$I_{sys} = I_{pp} + I_{ev} + I_{tb\&qv} + I_{cd}$$

Exergy loss rate of each device:

$$i_j = \frac{I_j}{I_{sys}}$$

The net power generation efficiency:

$$\eta_{sys} = \frac{W_G - W_{pp}}{Q_{ev}}$$

4.1 System start-up process

Ensuring the superheat

Effective cavitation margin

PID control

Temperature of heat source

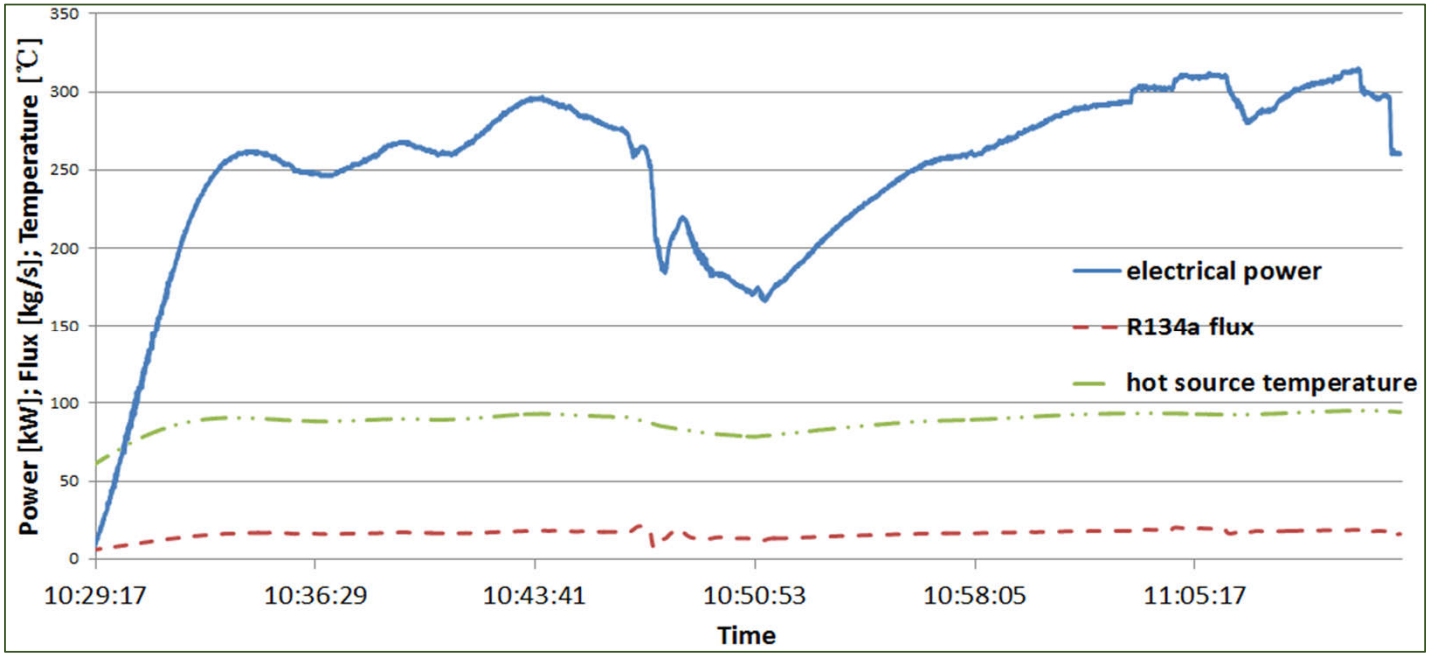
Frequency of working fluid pump

Make the system run steadily

The apparatus experimental condition

Experimental condition	Test1 (1.30)	Test2 (2.18)	Test3 (3.21)
Average temperature of cold source at condenser inlet(℃)	11.9	5.6	9.0
Average flux of cold source at condenser inlet(t/h)	365.6	333.2	391.1
Average flux of hot source at condenser inlet(t/h)	201.8	203.1	206.3

4.1 System start-up process



At the beginning, the temperature of heat source rises gradually, and when the frequency of working fluid pump increases, the motor starts to generate electricity.
In this process, the working fluid pump aims to control the superheat at the evaporator outlet within a certain range, and adjusts with the change of heat source temperature.

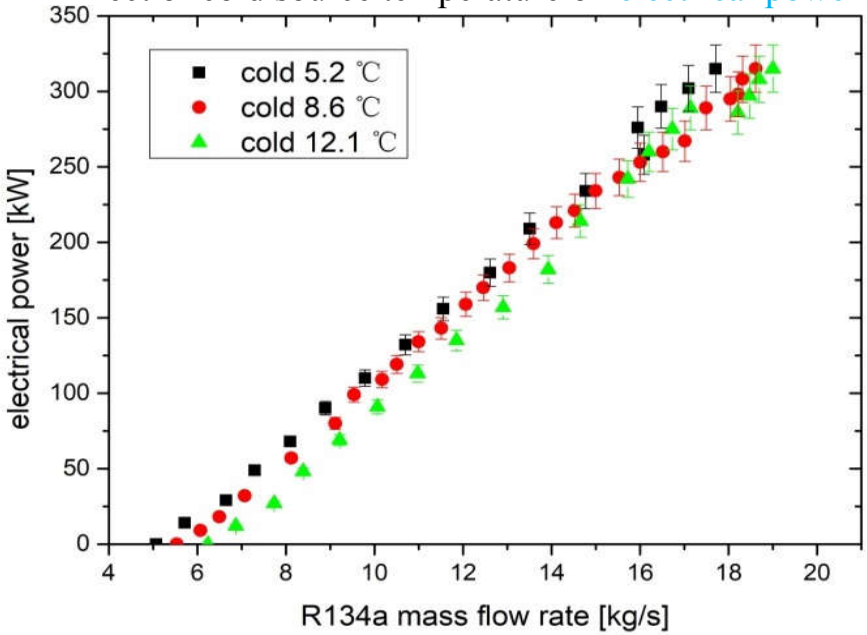
4.2 Effect of cold source temperature

The apparatus experimental parameters at 315 kW

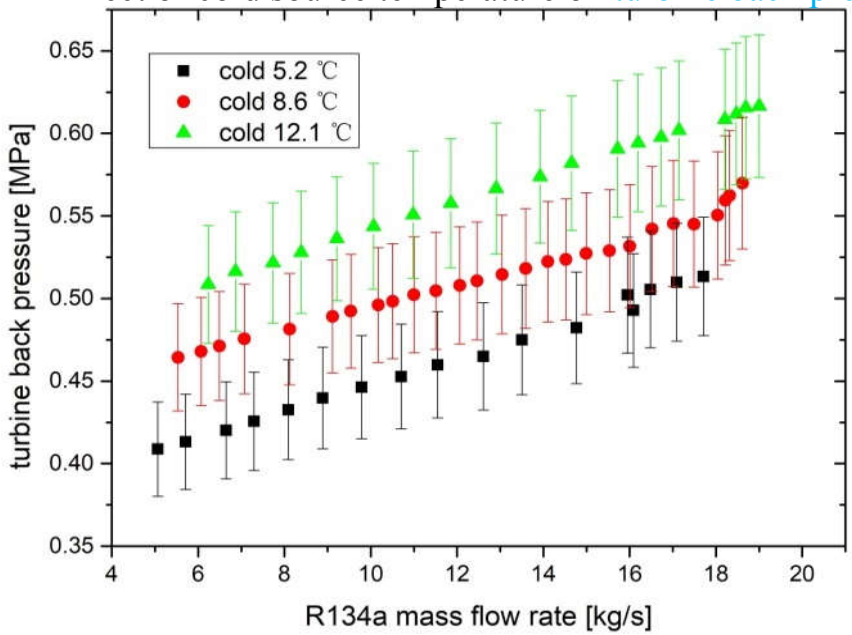
Experimental parameters	Test1 (1.30)	Test2 (2.18)	Test3 (3.21)
Temperature of cold source at condenser inlet(℃)	12.1	5.2	8.6
R134a flux(kg/s)	19.0	17.7	18.6
Frequency of working fluid pump(Hz)	50	48	49
System power consumption(kW)	45.0	39.8	42.4
Temperature of hot source at evaporator inlet(℃)	96.9	94.2	95.2
Net power generation efficiency(%)	6.3	6.5	6.2

4.2 Effect of cold source temperature

Effect of cold source temperature on electrical power



Effect of cold source temperature on turbine back pressure



Temperature of the heat source ↑
Mass flow rate ↑ → **Back pressure and electrical power ↑**

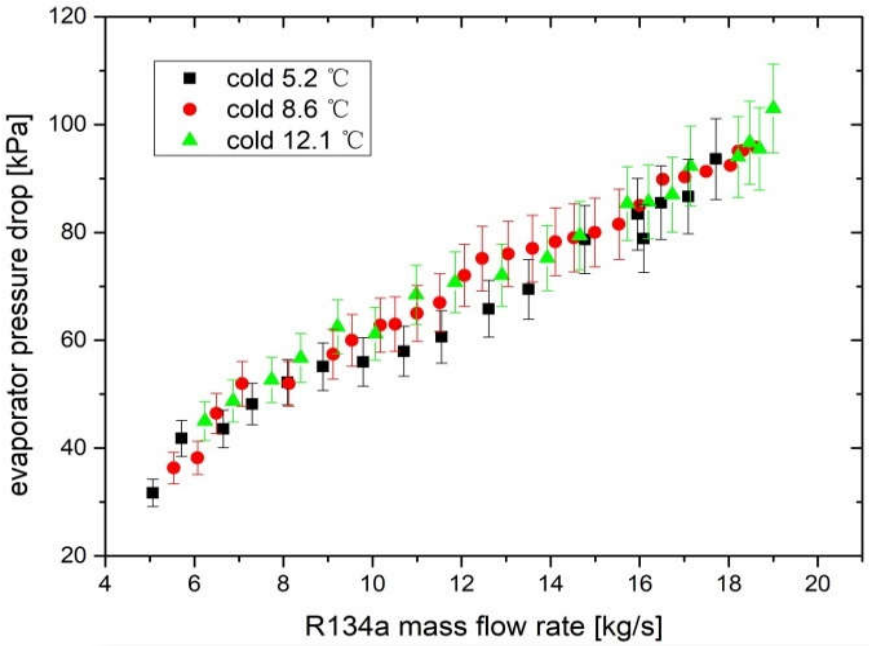
Cold source temperature↓ → **Turbine back pressure ↓**

The lowest temperature of the cold source = 5.2 ℃.

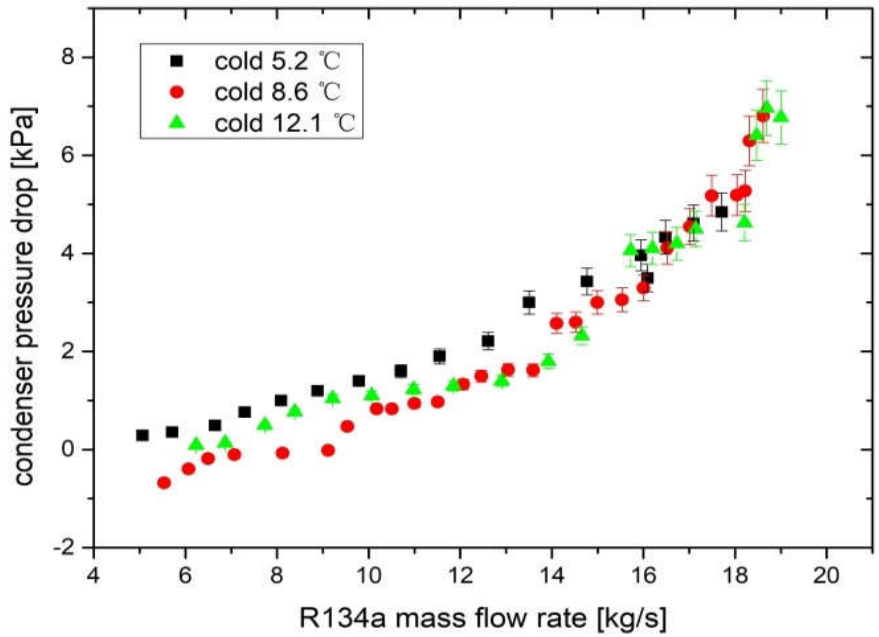
The required working fluid flow rate=17.7 kg/s. **The net power generation efficiency**=6.5%

4.2 Effect of cold source temperature

Effect of cold source temperature on evaporator pressure drop



Effect of cold source temperature on condenser pressure drop



R134a flow rate: 1 kg/s ↑

Evaporator pressure drop: 4.9 kPa ↑

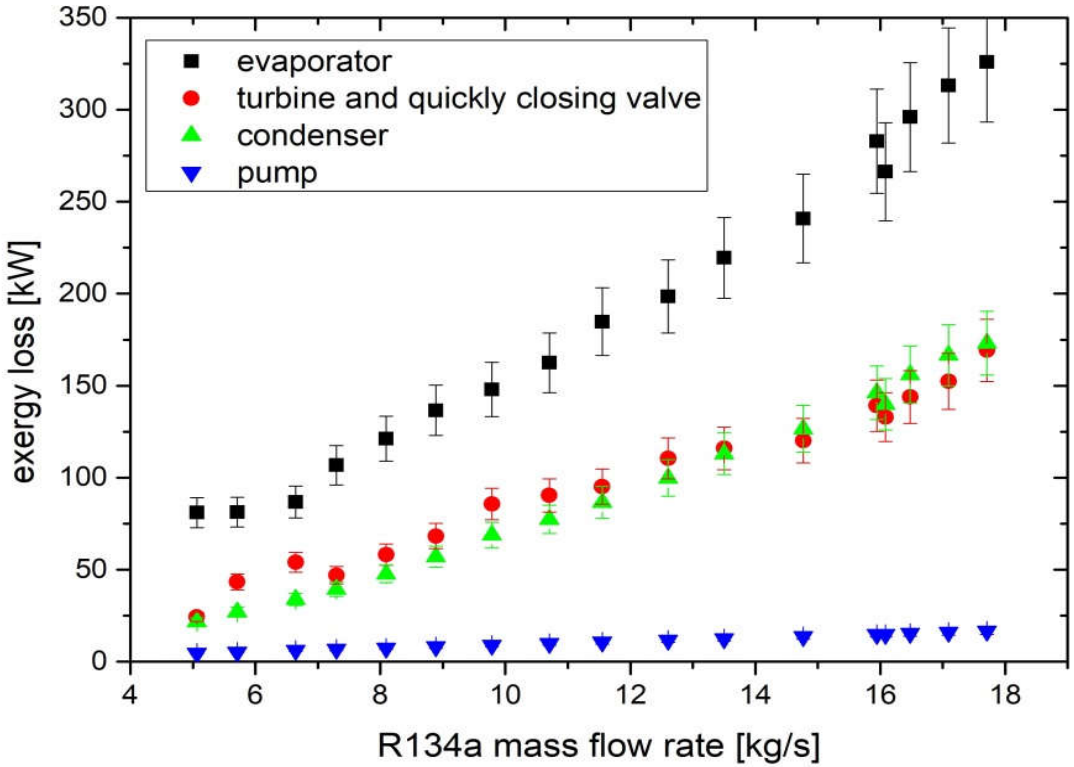
Condenser pressure drop: 0.5kPa ↑

Average flow velocity of working fluid : Evap > Cond

The layout of the evaporator

Pressure loss

4.2 Effect of cold source temperature



Effect of R134a mass flow rate on exergy loss under the cold source temperature of 5.2 ℃

R134a flux ↑

Exergy loss of each equipment ↑

The quickly closing valve uses a three-eccentric butterfly valve has a large pressure loss.

4.2 Effect of cold source temperature

Exergy loss of each equipment at 315 kW under the cold source temperature of 5.2 ℃

	Evaporator	Turbine and quickly closing valve	Condenser	Pump	Total ORC system
Exergy loss(kW)	325.9	169.2	173.1	16.5	684.7
Exergy loss rate(%)	47.6	24.7	25.3	2.4	100

The evaporator exergy loss accounts for nearly 1/2 of the system exergy loss.
The turbine ,the quickly closing valve and the condenser each account for about ¼.
The exergy loss of the evaporator occupying the largest part of the system exergy loss.
The exergy loss of the working fluid pump occupies a small part of the system exergy loss.

5. CONCLUSIONS

- *It is feasible to gradually increase the working fluid flow rate according to the change of heat source temperature during the start-up process.*
- *In the three tests introduced in this paper, the maximum net power generation efficiency is 6.5%.*
- *The evaporator exergy loss accounts for nearly half of the total in the tests during the start-up process.*
- *In the case of the same R134a flux, the pressure drop of the evaporator, condenser and the exergy loss of each device in the ORC system increase at the same time with the increase of cold source temperature.*

REFERENCES

Bracco R. , Clemente S. , Micheli D. , Reini M., 2013, Experimental tests and modelization of a domestic-scale ORC (Organic Rankine Cycle), *Energy*, vol. 58, no. 58:p. 107-116.

Landelle, A. , Tauveron, N. , Haberschill, P. , Revellin, R., Colasson, S. , 2017. Organic Rankine cycle design and performance comparison based on experimental database. *Applied Energy*, S0306261917303884.

Lee, Y. R. , Liu, L. W. , Chang, Y. Y. , & Hsieh, J. C. ,2017, Development and application of a 200, kw, orc generator system for energy recovery in chemical processes. *Energy Procedia*, vol. 129:p.519-526.

Mazzi, N. , Rech, S. , Lazzaretto, A. ,2015, Off-design dynamic model of a real organic Rankine cycle system fuelled by exhaust gases from industrial processes. *Energy*, vol. 90:p. 537-551.

Mohamad, A. S. , Soheil, M. A. S. , Aghajani, D. M. ,2018, Waste heat recovery from a 1180 kw proton exchange membrane fuel cell (PEMFC) system by recuperative organic Rankine cycle (RORC). *Energy*, vol. 157:p.353-366.

Sellers Christopher. ,2017, Field operation of a 125kW ORC with ship engine jacket water. *Energy Procedia*, vol. 129:p.495-502.

Shao, L. , Ma, X. , Wei, X. , Hou, Z. , Meng, X. ,2017, Design and experimental study of a small-sized organic Rankine cycle system under various cooling conditions. *Energy*, S0360544217306588.

Steven, L. , Sergei, G. , Bruno, V. , Michel, D. P. ,2018, Experimental results of a small-scale organic Rankine cycle: steady state identification and application to off-design model validation. *Applied Energy*, vol. 226:p. 82-106.

Tartière, T. , Astolfi, M. ,2017, A world overview of the organic Rankine cycle market. *Energy Procedia*, vol. 129:p. 2-9.

Yang, S. C. , Hung, T. C. , Feng, Y. Q. , Wu, C. J. , Wong, K. W. , Huang, K. C. , 2017, Experimental investigation on a 3 kw organic Rankine cycle for low-grade waste heat under different operation parameters. *Appl. Therm. Eng.*, vol. 113:p. 756-764.

Zhang, H. H. , Xi, H. , He, Y. L. ,Zhang, Y .W. ,Ning, B. , 2019, Experimental study of the organic rankine cycle under different heat and cooling conditions. *Energy*, vol. 180:p. 678-688.

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