International Conference on Applied Energy 2020
Dec. 1 - Dec. 10, 2020, Bangkok / Virtual
Paper ID: 87

Study on Operating Performance of organic Rankine cycle(ORC) System based on GT-SUITE and machine learning

Gege SONG, Xiang LI, Qingzhi YAN Yuting WU *
MOE Key Laboratory of Enhanced Heat Transfer and Energy Conservation, Beijing Key Laboratory of Heat Transfer and Energy Conversion, College of Environmental and Energy Engineering, Beijing University of Technology, Beijing, 100124, China

ABSTRACT

GT-SUITE software was used to build the ORC system simulation model. Based on the simulation model, the effects of single screw expander speed and multistage centrifugal pump speed on system performance were studied. Based on the data obtained by Design of experiment (DOE), using machine learning, a system performance prediction model is constructed. At the same time, the system performance is predicted. The optimal operating performance of the system is determined according to the prediction results. The results show that in the common speed range of single screw expander and multistage centrifugal pump, there is an optimal matching value so that the net power output of the system reaches the maximum, and the optimal expander speed and the optimal pump speed are maintained at lower speed.

Keywords: Organic Rankine cycle; Design of experiment; Operating performance; Machine learning; Optimization;

NONMENCLATURE

Abbreviations	
ORC	organic Rankine cycle
DOE	design of experiment
BPNN	back propagation neural network
Symbols	
N_{p}	Pump speed(r/min)
N_{exp}	Expander speed(r/min)
W_{p}	Pump power input(kW)
W_{exp}	Expander power output(kW)

1. INTRODUCTION

In recent years, the ORC system is considered to be one of the effective ways to improve energy efficiency and reduce pollutant emissions due to its high stability, flexibility and reliability [1,2].

At present, most scholars have optimized the key operating parameters (such as evaporating temperature, condensing temperature, evaporating pressure and condensing pressure) in the ORC system in terms of theoretical calculations [3-5]. In the numerical simulation research of ORC system, some scholars also conducted research [6-7]. However, at present, the combination of numerical simulation and machine learning makes little research on the operating performance of the ORC system.

In this paper, GT-SUITE software is used to model the ORC system, and the rationality of the model is verified through the combination of theoretical calculation and numerical simulation. DOE was used to study the influence of single screw expander and multistage centrifugal pump on system performance. In addition, based on the data obtained by DOE, build a machine learning prediction model. Predict the system performance. Finally, the optimal operating performance of the system is determined based on the prediction results.

2. SIMULATION MODEL OF ORC SYSTEM

The schematic diagram of ORC system is shown in Fig 1. The residual heat enters the evaporator through the connected pipeline to exchange heat with the organic working fluid. The organic working fluid becomes high temperature and high pressure gas and enters the expander for work. The exhaust gas after work is cooled by the condenser. The liquid organic working fluid enters the system again through the pump, so as to start the next cycle.

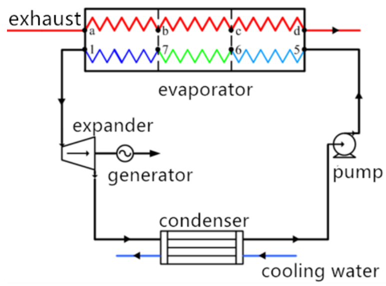

Fig 1 Schematic diagram of ORC system

2.1 Model building

The ORC system constructed in this study consists of a tube-fin evaporator, a plate condenser, a single screw expander and a multistage centrifugal pump [8]. The mass flow of exhaust is 958 kg/h, and the temperature of exhaust is 417 ℃[9].

In the two-phase region on the working fluid side of the evaporator, the Shah_Thome correlation formula was used to predict the surface heat transfer coefficient [10]. On the side of the residual heat source, Shah correlation formula was used to predict the surface heat transfer coefficient [11]. Kandlikar correlation formula was used to predict the surface heat transfer coefficient of the cooling water side of the condenser [12]. On the working fluid side, Yan_Lio_Lin correlation formula was used to predict the surface heat transfer coefficient [13]. The evaporator is built with the "HxGeomGeneral" module; the condenser is built with the "HxGeomPlate" module. The single screw expander is built using the "TurbPosDispRefrig" module. Multistage centrifugal pumps are built using the "PumpMap" module [14]. The completed ORC simulation model is shown in Fig 2.

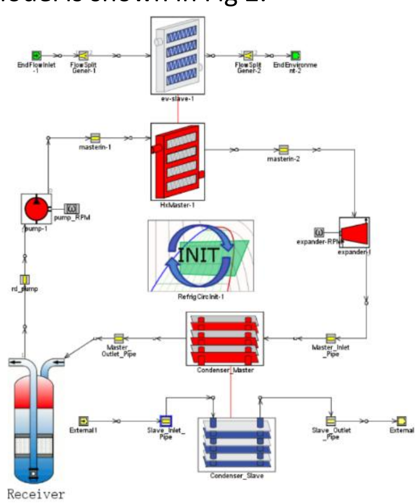

Fig 2 Simulation model of ORC system

2.2 Model validation

In order to ensure the rationality of the ORC system simulation model, this paper uses a combination of theoretical calculation and numerical simulation to verify the rationality of the model. The maximum errors between the calculated and simulated values of the inlet and outlet temperature of the expander are 0.027% and 3.24%, respectively. The maximum errors between the calculated and simulated values of the heat exchange capacity of the evaporator and the condenser are 4.5% and 4.3%, respectively. The maximum error between the calculated value and the simulated value of the pump outlet mass flow rate is 0.14%. There is a good agreement between the calculated value and the simulated value. Therefore, the accuracy of the constructed ORC system simulation model is verified.

2.3. Influence of pump and expander on system performance

Based on the ORC system simulation model, DOE is used in this paper to study the effects of pump speed and expander speed on the net power output of ORC system. And provide training and verification data for machine learning prediction models. The DOE distribution diagram of the data set is shown in Fig 3.

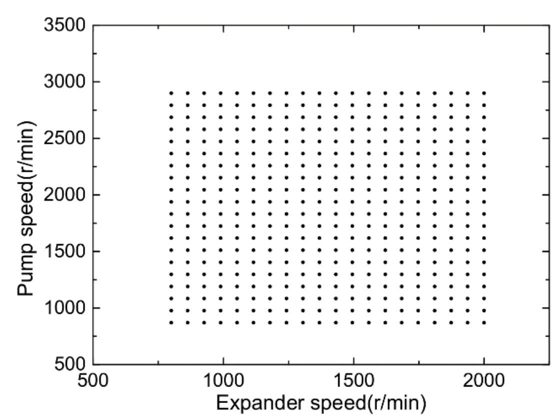

Fig 3 DOE data distribution

In this paper, the commonly used speed range of multistage centrifugal pump (870 r/min-2900 r/min) is selected for DOE analysis [14]. Fig 4 shows the effect of pump speed on the net power output of the ORC system. It can be seen from the figure that under the premise that the speed of the expander is 800 r/min, as the pump speed increases, the net power output of the system shows a trend of increasing first and then decreasing. For a given expander speed, there is an optimal pump speed to match.

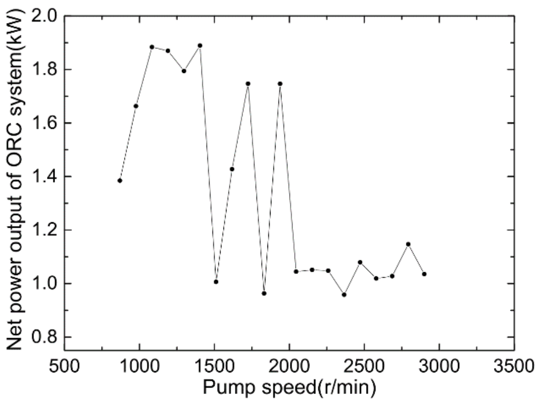

Fig 4 Effect of pump speed on net power output of ORC system

In this paper, the commonly used speed range of single screw expander (800 r/min-2000 r/min) is selected for DOE analysis [9]. Fig 5 shows the effect of the speed of the expander on the net power output of the ORC system. It can be seen from the figure that under the premise that the pump speed is 870 r/min, with the increase of the expander speed, there is a non-linear increasing trend in the early stage of the system's net power output, and the overall presents a non-linear decreasing trend. For a given expander speed, there is an optimal expander speed to match.

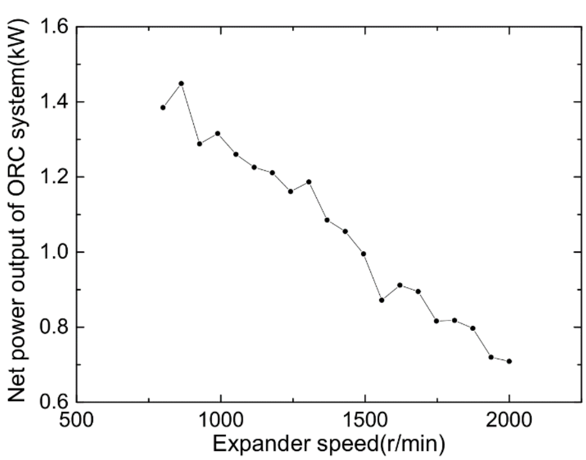

Fig 5 Effect of expander speed on net power output of ORC system

3. MACHINE LEARNING PREDICTION MODEL OF ORC SYSTEM

3.1 Model building

Machine learning can mine hidden rules from a large amount of data and use them for prediction. Based on DOE data, this paper constructs a net power output of ORC system machine learning prediction model through back propagation neural network (BPNN). Select pump speed($N_{\rm p}$) and expander speed($N_{\rm exp}$) as input variables. Select pump power input ($\dot{W}_{\rm p}$) and expander power output($\dot{W}_{\rm exp}$) as output variables. The schematic diagram of BPNN's topology is shown in Fig 6.

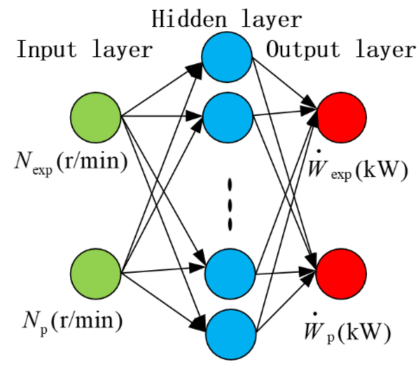

Fig 6 Topological structure schematic of BPNN

Fig 7 is a BPNN regression diagram. It can be seen from the figure that the R-square of the prediction model is higher than 0.8. therefore, the machine learning prediction model has a high generalization ability.

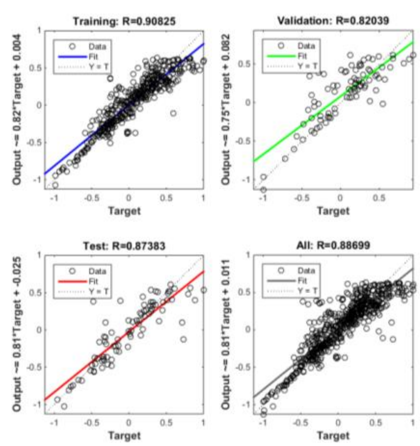

Fig 7 BPNN regression diagram

3.2 The optimization of pump speed and expander speed

The machine learning prediction model predicts and optimizes the expander power output, pump power input and system net power output corresponding to 24684 different combinations of pump speed and expander speed matching. Fig 8 is a graph of the system's net power output prediction and optimization results. It can be seen from the figure that when the pump speed and the expander speed are 1390 r/min and 1080 r/min, respectively, the system has a maximum net power output of 1.734 kW. At this time, the power input of the pump is 0.094 kW; the power output of the expander is 1.828 kW.

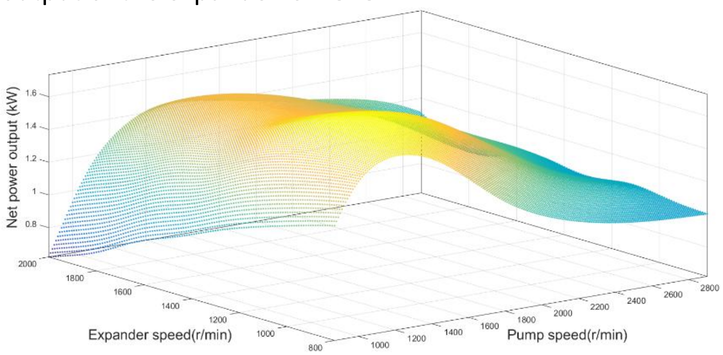

Fig 8 Prediction and optimization results

4. CONCLUSIONS

(1) The changes of pump speed and expander speed in the ORC system directly affect the net power output of the system. In addition, changing the speed of another key component under the premise of ensuring that the speed of any key component of the expander and pump will directly cause the change of the operating performance of the expander and pump, which will lead to the change of the net power output of the system.

(2) By coupling machine learning and numerical simulation, it is feasible to build simulation modeling, performance analysis and prediction on the ORC system. And the accuracy of the ORC system simulation model and the generalization ability of the machine learning prediction model are within the acceptable range.

(3) The optimal matching speed exists in the common speed range of multistage centrifugal pump and single screw expander, which makes the net power output of ORC system reach the maximum. And the optimal pump speed and the optimal expander speed are maintained in a lower speed.

ACKNOWLEDGEMENT

This work was supported by the (Grant No.2017YFB0903603).

REFERENCE

[1] Stoppato A. Energetic and economic investigation of the operation management of an Organic Rankine Cycle cogeneration plant. Energy 2012; 41:3-9.

[2] Guo T, Wang HX, Zhang SJ. Fluids and parameters optimization for a novel cogeneration system driven by low-temperature geothermal sources. Energy 2011; 36:2639-2649.

[3] Gu W, Weng Y, Wang YJ, et al. Theoretical and experimental investigation of an organic Rankine cycle for a waste heat recovery system. Proceedings of the Institution of Mechanical Engineers Part A: Journal of Power and Energy 2009; 223:523-533.

[4] Boretti AA. Transient operation of internal combustion engines with Rankine waste heat recovery systems. Applied Thermal Engineering 2012; 48:18-23.

[5] Wang JF, Yan ZQ, Wang M, Li MQ, Dai YP. Multi-objective optimization of an organic Rankine cycle (ORC) for low grade waste heat recovery using evolutionary algorithm. Energy Conversion and Management 2013; 71:146-158.

[6] Yang XF, Xu JL, Miao Z, Zou JH, Yu C. Operation of an organic Rankine cycle dependent on pumping flow rates and expander torques. Energy 2015; 90:864-878.

[7] Salek F, Moghaddam AN, Naserian MM. Thermodynamic analysis of diesel engine coupled with ORC and absorption refrigeration cycle. Energy Conversion and Management 2017; 140:240-246.

[8] Zhao R, Zhang HG, Song SS, Tian YM, Yang YX, Liu Y. Integrated simulation and control strategy of the diesel engine-organic Rankine cycle (ORC) combined system. Energy Conversion and Management 2018;156 639-654.

[9] Zhang YQ, Wu YT, Xia GD, Ma CF, Ji WN, Liu SW, Yang K, Yang FB. Development and experimental study on organic Rankine cycle system with single-screw expander for waste heat recovery from exhaust of diesel engine. Energy 2014; 77:499-508.

[10] John GC, Johnr T. Convective boiling and condensation. New York: Oxford University Press 1994.

[11] Xie H, Yang C. Dynamic behavior of Rankine cycle system for waste heat recovery of heavy duty diesel engines under driving cycle. Applied Energy 2013; 112:130-141.

[12] Kandlikar S G. A General correlation for saturated two-phase flow boiling heat transfer inside horizontal and vertical tubes. Journal of Heat Transfer 1990;112: 219-228.

[13] Yan YY, Lio HC, Lin TF. Condensation heat transfer and pressure drop of refrigerant R134a in a plate heat exchanger. International Journal of Heat and Mass Transfer 1999; 42:993-1006.

[14] Meng FX, Zhang HG, Yang FB, Hou XC, Lei B, Zhang L, Wu YT, Wang JF, Shi ZC. Study of efficiency of a multistage centrifugal pump used in engine waste heat recovery application. Applied Thermal Engineering 2017;110: 779-786.