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Research paper

Experimental study on the performance of single-screw expander with different inlet vapor dryness

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HIGHLIGHTS

- A single-screw expander was developed.
- An ORC system prototype with single-screw expander was integrated.
- The performance of the expander with different vapor dryness was obtained.

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ABSTRACT

A single-screw expander with 155 mm diameter screw has been developed. In order to investigate the performance of this prototype with different inlet vapor dryness, an organic Rankine cycle experimental system was built, and experiments were conducted at different inlet vapor dryness by adjusting the mass flow rate of working fluid into evaporator. The results indicated that with the increase of inlet vapor dryness, the power output and expansion ratio were increased , however , the volume efficiency and overall efficiency were decreased. The maximums of power output, expansion ratio, volumetric efficiency and total efficiency of single-screw expander were 5.12 kW, 4.55, 80.5% and 49.5%, respectively.

1. Introduction

Compared with traditional steam Rankine cycle, organic Rankine cycle (ORC) has the same configuration but uses organic media with low boiling points as its working fluid. The organic Rankine cycle, as an effective way of utilizing low and medium temperature energy, has received wide attention of researches [1–5]. There is increasing interest in kW-scale ORC applications since almost 90% of the waste heat is on the scale of 10–250 kW.

The heart of any ORC is the expander, which is one of the key components that limit the cycle efficiency [6]. Turbine expander, as a representative of the velocity-type expanders, has many advantages, but it is generally applied in power cycles with power output greater than 50 kW [7]. And its inherent problems, i.e., water erosion and low efficiency of unit, are unavoidable with saturated vapor for a turbine expander. The volume-type expanders are suitable for the ORC-based waste heat recovery because they are characterized by lower flow rate, higher expansion ratio and much lower rotational speed [8,9]. Moreover, volume-type expanders are particularly suitable for ORCs involving vapor–liquid two phase flow [10–12].

Single-screw expander is a new type of volume-type expanders, which mainly consists of a rotor, two gaterotors and a shell, as shown in Fig. 1. In an action cycle, there are three working processes, i.e., gas suction, gas expansion, and gas discharge, as shown in Fig. 2.

Single-screw expander can be used as the prime mover in a small-sized ORC system. It has many advantages, such as long service life, balanced loading of the main screw, high volumetric efficiency, low noise, low leakage, low vibration and simple configuration, etc. The single-screw expander can achieve 1–200 kW power output, and it works well with diversified kinds of working fluids, such as saturated steam, superheated steam, vapor–liquid two phases or heat liquid [11,13–15].

On the other hand, the selection of working fluid is very important for ORC systems [16,17], because it affects the efficiency

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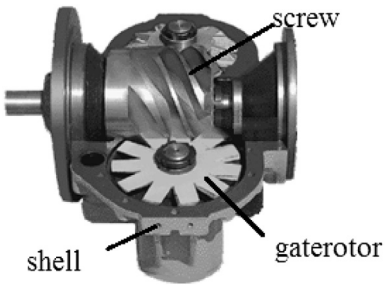

Fig. 1. Configuration of single-screw expander.

of system, the sizes of system components, the system stability and safety, and so on. Many studies on the influence of working fluids with ORC system were reported in the literature [18–21]. Although there are a lot of papers about selection of working fluids, few of them detail the influence of working fluid states on expanders and system performances.

In this study, efforts are made to analyze and explain the Influence of inlet vapor dryness on single-screw expanders. In particular, An ORC system was established with a single-screw expander, which was carefully designed and manufactured by our team. The test was conducted at different inlet vapor dryness for rotational speed of 800 rpm and 1200 rpm of single-screw expander. Power output, flow rate, temperature and pressure were measured, and the performance of the single-screw expander with different inlet vapor dryness was evaluated accordingly.

2. Experimental system

A single-screw expander prototype is adopted in this experimental system. This prototype, shown in Fig. 3, was designed and manufactured by our team. In order to simplify the construction and reduce the friction resistance, packing seal with polytetrafluoroethylene instead of mechanic seal is used as the shaft seal. The balance hole which connects high pressure leakage room with low pressure discharge volume of this expander is drilled on the shell which is different to that drilled on the screw or main shaft. The parameters of this prototype are illustrated in Table 1. Oil in single-screw expander is indispensable for its functions of lubrication and sealing. Oil circulating through the system with working fluid can eliminate the oil cycle, which is usually composed of oil pump, separator, check valve, and so on. This scenario can simplify the experimental system while the system performance becomes worse just a little [22].

Fig. 4 and Fig. 5 respectively show the concept and photo of the experimental system. In this system, R123 is chosen as the working fluid in view of its ability to significantly improve the system performance, and exhaust gas of diesel engine is utilized as heat source. The liquid R123 is pressurized and pumped into an evaporator. Heat is transferred from exhaust gas to R123 in the evaporator. R123 is vaporized under high pressure. Vapor flows into the expander and drives the screw to do work, meanwhile the shaft power is measured by dynamometer. The outlet vapor is condensed to liquid state in a condenser. The liquid flows into a tank and prepares for the next circulation. Pump of the system rotates at rated speed, which is a multistage centrifugal pump of CR5-32 and is provided by GRUNDFOS. In order to adjust the mass flow rate of working fluid into evaporator, a check valve is installed at the bypass of pump. The flow rate pumped into the evaporator is varied in response to valve opening. Bigger valve opening, less flow rate is injected into the evaporator and vapor with higher dryness is gotten; conversely, smaller valve opening results in higher flow rate and lower vapor dryness.

After being evacuated, the experimental system is charged with pure R123. During the test, the heat source maintains steady, namely the mass flow rate of exhaust is fixed at 1135 kg/h and its temperature keeps constant at 681 K. Different working conditions are obtained by adjusting the mass flow rate of working fluid into evaporator. Two series of experiments were conducted at rotational speed of 800 rpm and 1200 rpm of single-screw expander.

Fig. 3. Photo of prototype.

Table 1
The parameters of single-screw expander.

Parameters	Value
Diameter of screw(mm)	155
Groove number of screw	6
Diameter of gaterotor(mm)	155
Tooth number of gaterotor	11
Center distance(mm)	124

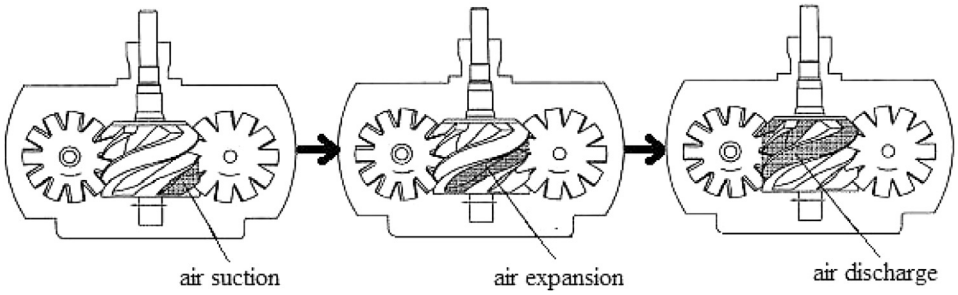

Fig. 2. Sketch of the working principle of single-screw expanders.