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Experimental investigation on the performance of a twin-screw expander used in an ORC system

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Abstract

Organic Rankine Cycle (ORC) is an effective and promising technology to convert low-grade thermal energy to electricity. As a key component in an ORC system, the expander plays a significant role in energy conversion efficiency in the ORC system. In this paper, an ORC experimental system is developed to investigate the performance of a twin-screw expander under various working conditions. Pressure sensors with high sensitivity and accuracy are installed at appropriate locations in the expander casing to monitor the *p-V* (pressure-volume) indicator diagrams which indicates the performance of the expander. The effect of the key parameters such as expander rotating speed, the suction pressure on the expander performance is studied using the experimental data. The results show that high expander rotating speed leads to large suction pressure loss, low volumetric and indicated efficiencies. As the rotating speed increases from 900 rpm to 1900 rpm, the volumetric efficiency decreases by up to 17.2% from 1.004 to 0.831 and the indicated efficiency reduces by up to 27.1% from 0.846 to 0.617. Furthermore, as the suction pressure increases from 550 kPa to 750 kPa the indicated efficiency rises up to a peak value of 0.815 and then falls. The volumetric efficiency does not show significant change as the suction pressure varies.

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Keywords: Organic Rankine Cycle; Heat Recovery; Twin-screw Expander.

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1. Introduction

Due to energy crisis and worldwide environmental problems such as CO_2 emission and global warming, it is essential to improve energy utilization efficiency by generating useful power from low-grade heat sources, such as industrial waste heat, solar thermal and geothermal sources. Organic Rankine Cycle (ORC) is an effective technology to convert the low-grade thermal energy to effective power. This ORC technology has attracted extensive research interest as it is progressively adopted in the application of low-grade heat sources [1]. The ORC system uses organic working fluid instead of water in a traditional steam Rankine Cycle to cater for different temperature ranges and uses different types of expanders to fit various power capacities. Two main types of expanders are normally used in ORC systems: dynamic expanders [2-5] and volumetric expanders. As a main type of positive displacement type expander, twin-screw expanders are widely used in small-to-medium scale ORC units [6].

Much research work has been carried out to investigate the performance of the twin-screw expander in ORC systems. Tang et al. [7] studied the performance of a twin-screw expander and investigated the effect of expander speed and suction pressure. Subiantoro et al. [8] compared the performance of the four new revolving vane expanders. Results showed that some revolving vane expander performance is much better than others. Wang et al. [9] demonstrated that it was possible to apply the single screw technology in the expander field, which had good part load characteristics. Yang et al. [10] performed experimental investigation on the internal leakage of a rotary vane expander prototype to replace the throttling valve to improve the COP of the CO_2 refrigeration cycle.

The *p-V* indicator diagram is often used by researchers to evaluate the performance of compressors and expanders. Wu et al. [11] investigated the effect of super-feed pressure with an economizer on the performance of a twin-screw refrigeration compressor experimentally by analysing the indicated diagrams. Wu et al. [12] further developed a theoretical model to illustrate the *p-V* indicator diagrams and validated the model using experimental data. The results showed that the theoretical model could be used as a powerful tool to evaluate the performance of a twin-screw refrigeration compressor. However, only little research used the *p-V* indicator diagrams to investigate the performance of different positive displacement type expanders. In this paper, the performance of the twin-screw expanders used in the ORC system is studied by using the *p-V* indicator diagrams.

2. Experimental facilities

2.1. The ORC system test rig

Fig. 1(a) shows the schematic drawing of the twin-screw expander experimental system. It consists of a boiler, a twin-screw expander, a condenser, a reservoir, a pump and a lot of piping and valves. Hot water is pumped into the evaporator as heat source. R245fa is used as working fluid due to its safety, stability and high efficiency at a medium heat source temperature [13]. The working fluid R245fa absorbs energy from the hot water in the boiler and expands in the twin-screw expander. The expanded vapor is then cooled and condensed in the condenser by the cold water from a cooling tower. The working fluid pump pumps the condensate from the condenser to the boiler and then next cycle starts. The operating conditions of the ORC system are listed in Table 1.

Table 1. Operating conditions of the ORC system

Parameter	Value
Evaporation pressure of the working fluid, MPa	0.33~0.47
Evaporation temperature of the working fluid, °C	65~78.4
Condensation pressure of the working fluid, MPa	0.14
Designed rotational speed of the expander, rpm	1500
Designed volume ratio of the expander	2.3

Two plate types of heat exchangers provided by Danfoss are used as the boiler and condenser in the studied system due to their compact size and high heat transfer coefficient. The twin-screw expander is coupled with an eddy current dynamometer which provides load automatically. The eddy current dynamometer can be set to measure torque, rotational speed and output power of the twin-screw expander. The centrifugal type working fluid pump (GRUNDFOS,