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A study on lubricant oil supply for positive-displacement expanders in small-scale organic Rankine cycles

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A B S T R A C T

Positive-displacement expanders, which are widely used in small-scale ORCs (Organic Rankine Cycles), need reliable LOS (Lubricant Oil Supply) to get well lubrication and sealing. In the present paper, the characteristics of two traditional LOS schemes are examined. Moreover, a modified one is proposed. Analyses of those elements that lead to work loss of lubricant oil supply have been carried out for all the three LOS schemes. The work loss of lubricant oil supply, which is caused by the employment of lubricant oil pumps, pressure drop in lubricant oil separator and other components contributing to work loss, is evaluated by a definition of WLLS (Work Loss Factor of Lubrication Oil Supply). Based on the thermodynamic model of ORC established, the calculation methods of WLLS are presented. Through analyses of LOS schemes and calculation of WLLS in two typical ORCs, it was found that the traditional LOS schemes either can not work reliably, or might cause up to 11.5% and 9.5% power decrease. The values can be reduced by half in the proposed LOS scheme, which can also work reliably. Accompanied with the advantages, the defects of the new scheme were also investigated.

1. Introduction

One of the approaches to alleviating the problems of energy shortage and environmental pollution is making full use of low grade heat, such as solar energy, geothermal energy, biomass energy and industrial waste heat. In order to convert low grade heat into work, a lot of attention has been paid to ORC (Organic Rankine Cycle) in recent years [1–3]. Solar thermal power plants [4,5], geothermal power plants [6–8] and biomass power plants [9] have been developed through constructing ORC systems. In addition, waste heat recovery is another application of ORC with great potential [10–13]. Compared to traditional Rankine cycle, organic fluids, such as R123, R245fa, R600a, are adopted as working media in ORCs instead of water [14–17].

In an ORC system, expander is a critical component which limits the system efficiency. Expanders can be generally categorized into two types [14,18]:

- The turbo type, such as axial or radial turbo expanders [19–21].
- The positive-displacement type, such as screw expanders [22,23], scroll expanders [24–26], rotary vane expanders [27], rolling piston expanders [28] and reciprocal piston expanders [29].

Positive-displacement expanders are good substitutes for turbo machines at low power output due to its relatively high efficiency, high pressure ratio, low rotate speed and tolerance of two-phase fluids [14]. However, reliable LOS (Lubricant Oil Supply) is essential for positive-displacement expanders to lubricate the bearings, mechanical seals and meshing surfaces, as well as block the leakage channels [14]. Therefore researches on LOS for positive-displacement expanders in ORCs are of great significance.

A lot of experimental studies have been carried out on ORC systems with focus laid on evaporating temperature, condensing temperature, expander performances and system efficiency. Zhou et al. [30] built an ORC system using R123 as working medium, simulate flue gas as the heat source, a reversely operating scroll compressor as the expander, and achieved 645 W of output power with 57% of the expander adiabatic efficiency and 8.5% of the cycle efficiency. In the ORC system, a lubricant oil separator at the outlet of the expander and an oil pump were employed for lubricant oil supply. However, they didn't mention the work consumed by the oil pump or how the pressure drop in oil separator influenced the system, nor made other comment about the LOS. In another paper [31], a scroll expander was also adopted in an experimental ORC

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Nomenclature

c_p	specific heat at constant pressure [kJ·(kg·K)$^{-1}$]
h	enthalpy [kJ·kg^{-1}]
p	pressure [Pa, kPa, MPa]
Δp	pressure drop in lubricant oil separator [kPa]
t	temperature [°C]
T	thermodynamic temperature [K]
v	specific volume [m^3·kg^{-1}]
x	the mass of lubricant oil supplied for 1 kg pure working fluid [kg·kg^{-1}]
w	work [kJ·kg^{-1}]
w_{op}	pumping work of lubricant oil for 1 kg pure working fluid [kJ·kg^{-1}]
$w_{ol,pd}$	work loss due to pressure drop in lubricant oil separator [kJ·kg^{-1}]
$w_{ol,ih}$	work loss due to invalid heat absorbed by lubricant for 1 kg pure working fluid [kJ·kg^{-1}]
$q_{ol,\ ih}$	invalid heat absorbed by lubricant for 1 kg pure working fluid [kJ·kg^{-1}]

Greek symbol

λ	Work Loss Factor of Lubricant Oil Supply [-]
η	efficiency [−]

Subscripts

1	inlet state of the expander
2	outlet state of the expander
4	outlet state of the circulating pump
e	expander
p	circulating pump
oil	lubricant oil
op	oil pump
v	evaporation
c	condensation

Abbreviations

ORC	Organic Rankine Cycle
LOS	Lubricant Oil Supply
WLLS	Work Loss Factor of Lubricant Oil Supply

system, which used R245fa and an electric boiler as the working fluid and the evaporator, respectively. The cycle efficiency reached 8.8%, and the expander adiabatic efficiency was about 70%. In the ORC system, there was no lubricant oil separator or oil pump, and the working fluid was always mixed with the lubricant oil. However, there was still no comment about this LOS scheme. A rolling piston expander was developed by Zheng et al. [28] and applied in ORC condition. R245fa was adopted as the working fluid and a hot-water boiler was employed to supply the low temperature heat. The maximum of expander power was about 0.35 kW, and the expander isentropic efficiency reached 43.3%, which gave the ORC a stable efficiency of 5%. However, the LOS scheme for the expander was unknown. In conclusion, to the authors' knowledge, no paper has specially investigated LOS for positive-displacement expanders in ORC systems.

This work examines two traditional and a proposed LOS schemes for positive-displacement expanders in ORCs with focus laid on the work loss of lubricant oil supply. The work loss of lubricant oil supply is caused by the employment of lubricant oil pumps, the pressure drop in lubricant oil separator and other components which make contributions to work loss, and will be evaluated here by a definition of WLLS (Work Loss Factor of Lubrication Oil Supply).

2. LOS schemes

2.1. LOS Scheme A

The configuration of LOS Scheme A for positive-displacement expanders in ORCs, which was adopted by Zhou el al. [30], is shown in Fig. 1. In Scheme A, a lubricant oil separator is located between the expander and the condenser, where the lubricant is separated and extracted from the mixture of working fluid and lubricant oil discharged by the expander. Because the pressure of the separated lubricant oil is low, a lubricant oil pump is required to deliver the lubricant back to the expander.

LOS Scheme A works reliably because the oil pump can convey lubricant oil to the bearings, mechanical seals and meshing surfaces in the expander. However, it is relatively complex, and the problem of leakage probably gets more serious because of the adoption of oil

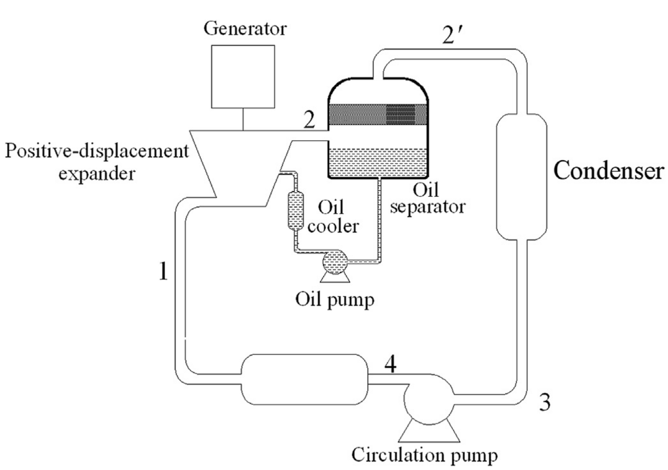

Fig. 1. Supply system of lubricant oil in Scheme A.

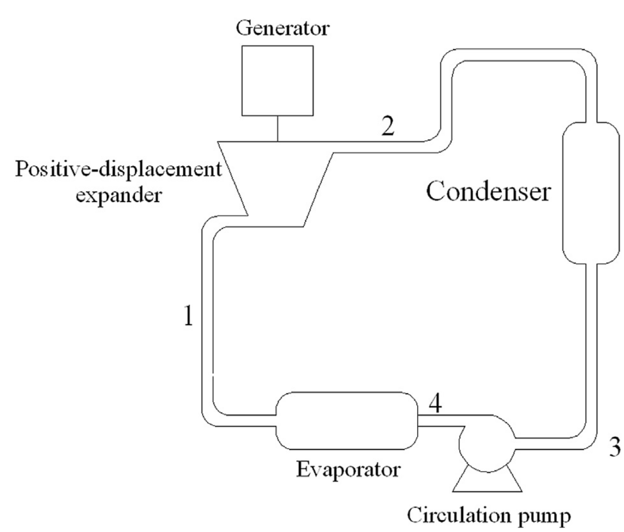

Fig. 2. Technological process of Scheme B.