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Employing a Single-Screw Expander in an Organic Rankine Cycle with Liquid Flooded Expansion and Internal Regeneration

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Abstract

Positive displacement expanders are proven to be cost-effective in the low to medium power range for Organic Rankine Cycle (ORC) systems. Among the different types of volumetric expanders, the screw-type presents a favorable combination of relatively high internal volume ratio (up to 7) and isentropic efficiency (up to 80%) with respect to the optimal pressure ratio at which sub-critical ORCs operate. In particular, single-screw expanders have shown some potential due to their symmetric and balanced configuration that decreases the loads on the bearings. A comprehensive characterization of this type of machine with two working fluids, i.e., SES36 and R245fa, has been carried out in a previous work [1]. Based on the experimental work, friction losses and internal leakages were found detrimental to the expander performance. As the expander requires lubrication during operation, flooded expansion can be beneficial to reduce such losses as well as to improve the expansion process toward a quasi-isothermal behavior. A thermodynamic cycle model has been developed to evaluate the potential improvements on the thermodynamic performance of organic Rankine cycle with flooded expansion and internal regeneration. A semi-empirical model of the expander is included which accounts for the effects of internal volume ratio. The results from the cycle model have used to design an ORC test setup with an independent lubricant oil loop and internal regeneration. The new test rig will be used validate the trends obtained with the cycle model and to further characterize the single-screw expander. The working fluid employed is R1233zd(E) as a replacement for R245fa.

Keywords: ORCLFE; Single-screw expander; R245fa; R-1233zd(E);

1. Introduction

Low-grade waste heat recovery (80-200 °C) with organic Rankine cycle (ORC) is a well established solution to effectively generate power. Although a wide range of studies exist that address working fluid selection, cycle archi-

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tectures and expander technologies [2–4], there is still room to improve such system as the current thermodynamic efficiency is usually less than 30% of the corresponding Carnot efficiency.

The expansion process in an ORC is bounded between two limit transformations, i.e. adiabatic expansion and isothermal expansion. Since non-negligible heat transfer occurs during the expansion process in a positive displacement machine, the actual expansion deviates from an adiabatic transformation. Theoretically, approaching an isothermal expansion allows to extract more work.

In the medium to low power range (<150 kW), volumetric-type of expanders are cost effective [3]. In particular, screw-type of expanders can potentially reach isentropic efficiency above 80% [3]. As these machines require active lubrication systems, i.e., dedicated lubrication loops (multi-injection ports), the concept of liquid flooded expansion can be explored to achieve two goals: (i) improve the expansion process toward an isothermal to increase the potential power output and favor the use of internal regeneration; (ii) use the flooding medium (typically lubricant oil) to minimize the friction losses. As a result, organic Rankine cycle with liquid flooded expansion (ORCLFE) and internal regeneration is proposed to investigate such benefits. From previous numerical analyses [5,6], it has been shown how positive displacement expanders with larger internal volume ratios are favored for investigating flooded expansion. For this reason, a single-screw expander is considered to show the potential benefits of ORCLFE for waste heat recovery. The characterization of such expander with R245fa and SES36 without significant amount of lubricant oil has been carried out in [1]. In this work, a cycle model has been developed along with a semi-empirical model of the expander to account for the presence of oil, internal volume ratio, heat and friction losses. The cycle model includes also the effect of lubricant oil and working fluid solubility. As a result of the numerical study, an experimental test setup has been designed and built to assess the benefits of a controlled flooded expansion as well as to compare R245fa and its potential replacement R1233zd(E). Lubricant oil ACD100FY [7] is used as flooding medium.

Nomenclature

a_l	liquid volume fraction, -	T	temperature, °C
h	specific enthalpy, J/kg	w	specific work, J/kg
$\dot{m}$	mass flow rate, kg/s	$\dot{W}$	power, W
N_{exp}	expander rotational speed, rpm	y	flooding ratio, -
p	pressure, Pa	η	thermodynamic efficiency, -
$\dot{Q}$	heat rate, W	ϕ	filling factor, -
r_v	specific volume ratio, -		

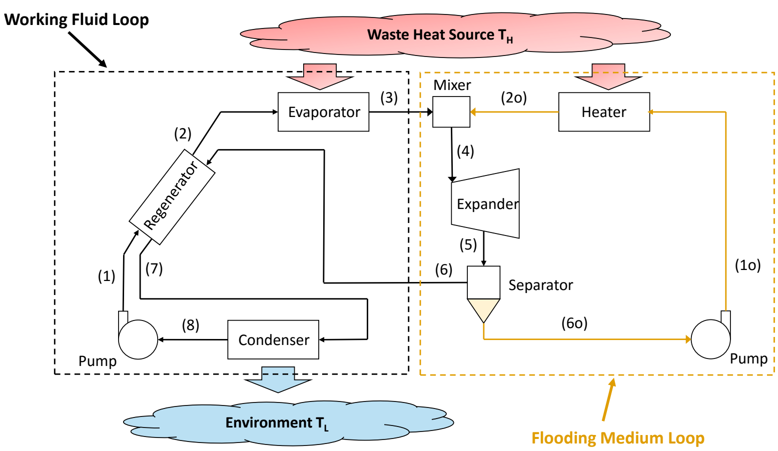

Fig. 1. Schematic of ORCFLE system.