Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 129 (2017) 487–494

Energy Procedia

www.elsevier.com/locate/procedia

IV International Seminar on ORC Power Systems, ORC2017
13-15 September 2017, Milano, Italy

Experimental Investigation and CFD Analysis of Heat Transfer in Single Phase Subcooler of a Small Scale Waste Heat Recovery ORC

Tryfon C.Roumpedakis[a]*, Spiros Chapaloglou[a], Platon Pallis[a], Aris-Dimitrios Leontaritis[a], Konstantinos Braimakis[a], Sotirios Karellas[a†] , Panagiotis Vourliotis[a]

[a]*National Technical University of Athens, Heroon Polytechneiou 9, 15780 Zografou, Greece*

Abstract

In the present work, a detailed investigation of the single phase heat transfer mechanism in a novel subcooler of an experimental small scale waste heat recovery Organic Rankine Cycle (ORC) unit is presented. The ORC unit is operating with R134a and is designed to utilize the waste heat from the jacket water of marine diesel auxiliary internal combustion engines (ICEs). The ORC unit produces 3.7 kW_{el} net electrical power at a cycle pressure of 25 bar and an expander inlet temperature of 82 °C. The application of subcooling in such systems is common practice, so as to ensure the cavitation-free operation of the pump.

The subcooler is designed to achieve a certain level of subcooling and at the same time minimize the pressure losses on both the refrigerant and the cooling water side. A theoretical CFD model is developed to predict its operation. Based on the experimental results, a new heat transfer correlation is proposed for the single phase heat transfer inside a corrugated tube. The accuracy of the new correlation is compared with existing ones from the literature. Meanwhile, the results of the correlation are validated by the experimental data collected from the respective ORC unit, reducing the theoretical calculations maximum relative error from 2.98% to a 1.88%.

Peer-review under responsibility of the scientific committee of the IV International Seminar on ORC Power Systems.

Keywords: Organic Rankine Cycle; Subcooler; Waste Heat; Heat Transfer; CFD

1. Introduction

* Corresponding author. Tel.: +30-210-7724406; fax: +30-210-7723663.
E-mail address: roumpedakis.t@gmail.com

1876-6102
Peer-review under responsibility of the scientific committee of the IV International Seminar on ORC Power Systems.
10.1016/j.egypro.2017.09.166

Nomenclature

A	Total outer surface of corrugated tube [m^2]
A_{fin}	Fin surface [m^2]
A_i	Inner surface of corrugated tube [m^2]
A_{to}	Surface of bare tube without fins[m^2]
a_i	Mean heat transfer coefficient of R134a side [W/m^2K]
a_m	Mean heat transfer coefficient of water side [W/m^2K]
a_v	Virtual heat transfer coefficient of water side [W/m^2K]
C	Constant [-]
d_i	Tube inner diameter [m]
d_o	Tube outer diameter [m]
Nu	Nusselt number [-]
Pe	Peclet number [-]
Pr	Prandtl number [-]
Re	Reynolds number [-]
U	Overall heat transfer coefficient of subcooler [W/m^2K]

Greek symbols

η_{fin}	Fin efficiency [-]
λ	Thermal conductivity of fluid [W/m K]
λ_t	Thermal conductivity of tube material [W/m K]

The ORC is a rapidly developing technology that can be powered by several medium and low grade heat sources including waste heat [1-3], low temperature geothermal resources [4-6], solar thermal energy [7-9] and biomass [10-13]. The commercially available systems based on ORC technology nowadays range from few kW_e up to 2.2 MW_e, even though the commercially available expansion devices used in such applications start from 1kW_e [14, 15].

Over the past two decades, several investigations have been carried out on both theoretical [16, 17] and experimental level [18-22]. As it has been identified, the ORC pump has a significant impact on the overall system efficiency and its operation has to be closely optimized for ensuring a cavitation free-operation [23-25]. Cavitation consists on the formation of vapor bubbles in a liquid stream at the region where the pressure falls below its vapor pressure [26, 27]. Hence, cavitation occurs in the lowest pressure region in a system, which is the suction line of the pump [28, 29]. One of the main solutions for a cavitation-free operation is the application of subcooling before the pump's inlet [17, 30]. Dumont et al. [31] based on experiments on a plunger type pump, specified the necessary level of subcooling to be at least 10 K. From previous experiments, Leontaritis et al. [32] concluded that a minimum subcooling of 2 K is required for the smooth operation of the diaphragm pump that was used. However, as was shown by Landelle et al. [33], the level of subcooling has a negative effect on the overall ORC system's efficiency and thus a more thorough investigation is required to estimate the optimal operating conditions of the subcooler.

In this study, the operation of the custom-made subcooler in an experimental small scale ORC unit for marine applications (Marine ORC), developed in the National Technical University of Athens (NTUA), Greece, is investigated. The system consists of a single stage subcritical Organic Rankine Cycle with R134a as the working medium. Heat is provided to the system by a natural gas boiler, which is used to simulate the jacket water from the marine diesel auxiliary internal combustion engines (ICEs). The goal of the experiments is the investigation of the single phase heat transfer regime inside the subcooler. Based on the results, a new semi-empirical single phase heat transfer correlation is proposed for the R134a and is subsequently experimentally validated. In addition, a CFD model is developed to further determine the accuracy of the proposed semi-empirical heat transfer correlation.

2. Experimental setup

The Marine ORC is powered by waste heat from the jacket water of marine diesel auxiliary ICEs (average inlet/outlet temperature of 90/85 °C). The unit produces 3.7 kW_e net electrical power at a cycle pressure of 25 bar and an expander inlet temperature of 82 °C. Regarding the system configuration, which is also presented in Fig. 1, a