Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 129 (2017) 363–370

Energy Procedia

www.elsevier.com/locate/procedia

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

Converting a commercial scroll compressor into an expander: experimental and analytical performance evaluation

Maurizio Cambi[a], Roberto Tascioni[a,] *, Luca Cioccolanti[b], Enrico Bocci[a]

[a]Marconi University, Via Paolo Emilio 29, 00193 Rome, Italy
[b]Università Telematica eCampus, Via Isimbardi 10, 22060 Novedrate (CO), Italy

Abstract

The development of low cost small scale Organic Rankine Cycle (ORC) has a very interesting potential in generating electricity using low temperature waste heat sources. Moreover, HVAC companies could significantly extend their market if a commercial scroll compressor can be converted into an expander using similar units. Therefore, this work reports experimental test funded by an Italian HVAC company on a scroll compressor modified to work as scroll expander in a non-regenerative cycle and a subcritical fluid regime, aimed at reducing system cost and complexity. The scroll expander has been tested with its fluid R410A in a ORC cycle in order to obtain the isentropic efficiency of the scroll expander (0.5) and the pump (0.4).
On the basis of the experimental tests, a model accomplished by means of MATLAB/CoolProp has been set up to evaluate the performance of the ORC group to achieve 10 kWe as target power output. Four operative fluids have been simulated, i.e. R245fa, R134a, R1234yf, R1234ze, fixing 100°C as evaporating temperature and considering the condenser temperature in the range 20-50°C. The results have showed that R245fa is the most promising working fluid since there is a higher expansion ratio within lower pressure values. As a consequence, not only a lower mass flow rate is necessary, but overall a lower pump consumption is needed, reaching greater overall conversion efficiency (about 6.5% with condensing temperature of 20°C) and power. Thus, a commercial heat pump scroll compressor can be effectively converted into an expander. The fluid selection shows that the most common ORC fluid can be used with relative low performance but at low cost and easy management.

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

Keywords: small scale ORC; ORC model; MATLAB simulation; low temperature operation; working fluid selection

* phone number.: +39-06-37725268;
E-mail address: r.tascioni@lab.unimarconi.it

1876-6102
Peer-review under responsibility of the scientific committee of the IV International Seminar on ORC Power Systems.
10.1016/j.egypro.2017.09.234

1. Introduction

Nowadays, one of the major concerns of our society is the increasing energy demand worldwide. Fossil fuels indeed are limited and the related environmental impact has serious effects on human health, ecosystems and climate. In the last decades, renewable energy technologies such as photovoltaics (PVs) and wind turbines have been widely adopted and energy production from renewables has accounted for about 19.2% of the global final energy consumptions [1] in 2014. Besides PVs and wind turbines one of the most promising technology for power generation are small scale Organic Rankine Cycle (ORC) plants. Such systems can be efficiently fuelled both by renewables or using low temperature waste heat sources thus having a very interesting potential [2].

An Organic Rankine Cycle plant works similarly to a Rankine steam power plant, but it makes use of organic working fluids which are able to condense and evaporate at acceptable temperatures [2]. At present, several manufacturing companies for ORC exist but their products are mainly limited to medium and large scale [3, 4, 5, 6]. Few companies indeed offer products on a small scale i.e. in the order of <50 kWe while <10 kWe ORC systems are limited to prototype units or have not completely entered into the market. On the contrary, industrial and academic research is paying plenty of attention on small scale ORC plants [7, 8]. For example, Li et al. [9] evaluated the influence of heat source temperature and ORC pump speed on the performance of a small-scale ORC system using R245fa as working fluid. Although, the ORC system is able to recover the low grade thermal output from a 80 kWe Combined Heating and Power (CHP) unit, it reached very low performance. On the contrary, Al Jubori et al. [10] focused on the influence of several turbine design features on turbine performance in ORC systems. In particular, this study has shown that a radial-inflow turbine is able to reach higher total-to-total efficiency and power output with respect to axial configuration although it has a higher maximum overall size.

Pie, Li et al. [11] experimentally investigated the performance of a specially designed radial-axial turbine using R123 as working fluid. The test has shown that a turbine isentropic efficiency of 65% and an ORC efficiency of 6.8% can be obtained with a temperature difference of about 70°C between the hot and the cold sides. The same authors [12] evaluated the energetic and exergetic performance of the updated ORC system and the related thermal efficiency at different heat source temperatures. Muhammad et al [13] designed and tested a 1 kWe ORC system using low pressure steam in the range 1-3 bar as heat source. In particular, the authors investigated the effect of superheating on thermal efficiency recording a maximum thermal efficiency of 5.75% and an isentropic efficiency of the expander of about 58.3% at maximum power output.

Although of interest, the limited availability of commercial expanders for small scale ORC systems has hindered their adoption so far. Qiu et al. [14] conducted an expanders market research for ORC-based m-CHP systems concluding that scroll and vane expanders are good choices within the capacity of the 1–10 kW power output. According to this study, Galloni et al. [15] realized and tested a small scale ORC plant with a scroll expander and using R245fa as working fluid in order to exploit low grade heat source in the temperature range 75-95°C. Results showed interesting potential and the best obtained performance were 1.2 kW electric power, 20 kJ/kg specific work and >9% cycle efficiency. Declaye et al. [16] and Oralli et al.[17] showed that a commercially available scroll compressor can be modified to operate in expander mode reaching, e.g., cycle efficiency of 8.5% for evaporating and condensing temperatures of 97.5°C and 26.6°C. These studies remark the importance of the potential application of this conversion using a low grade heat source.

In this work, the operation of a 52 cm^3 commercial scroll compressor converted into an expander has been experimentally investigated using the native working fluid R410A to assess its feasibility to be used in small-scale ORC plants. After that, a numerical model has been developed in order to evaluate the best working fluid and operating conditions to achieve 10 kWe of target power. The paper shows a simplified procedure in order to choose the right organic fluid and estimate the related cycle performance.

2. Methodology

A complete understanding of the performance of a plant can certainly be achieved through an extended field test phase of the real system. Nevertheless, comprehensive experimental investigations to elucidate the influence of the main operating conditions are time and cost consuming. As an alternative, a numerical tool offers the opportunity to