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Heat Transfer and Fluid Flow Characterisation of a Direct Evaporation Micro-Scale ORC-Evaporator to Identify Guidelines for an Improved Design

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Extended Abstract

The application of micro-CHP systems to the residential sector represent a relevant opportunity for needed energy and economic savings as well as GHG emissions reduction [1]. Even though CHP systems use mainly fossil fuels, these systems could play an important role during fossil fuels phase out period by increasing primary energy savings and reducing the load and losses on the electric grid infrastructure due to the decentralized electricity production, and afterwards by replacing fossil fuels with biofuels/synthetic fuels.

Within the technologies available, Rankine based micro-CHP systems, particularly ORC, are recognized as an adequate technology for this purpose, due to its efficiency, simplicity, heat to power ratio and its potential ability to retrofit wall hang boilers [1]. Additionally other key issues like system response time, size, weight, thermal fluid degradation and cost need to be addressed in residential applications. All these aspects are strongly influenced by the primary energy delivery method (direct or indirect working fluid evaporation) which in turn affect the evaporator design and operation [1]–[3].

Although direct evaporation is an important aspect of the ORC system and subject of research efforts in other contexts, namely waste heat recovery of internal combustion engines, it has not been extensively studied in the context of micro-CHP systems for residential applications.

In this paper, we contribute to the development of a direct evaporator to be applied in a micro-CHP ORC system. To this end we started with a first prototype that was experimentally characterized for a wide range of practical steady state operating conditions. Moreover, the present study also provides some design guidelines for further improve the HEX design.

To study the heat transfer and fluid flow phenomena the direct evaporator prototype was tested on a ORC micro CHP system test rig that uses R-245fa as the working fluid [4]. Furthermore, a detailed physical steady state model regarding the combustion process and heat transfer mechanisms has been developed and empirically calibrated [4]. In order to capture the phase change region, the working fluid domain is discretized, and the calibration procedure consisted of measuring the temperature on several locations along its path and comparing them against the model results.

The experimental direct evaporator prototype was tested for thirteen (1 to 13) operating conditions. In this paper we analysed in detail the operating conditions (2, 3, 5). The referred evaporator is in fact a heat exchanger (HEX) with three zones: pre-heater, evaporator, and super-heater. In this paper, we present a detailed characterization of the fluid flow and heat transfer parameters for each zone.

The evaporator prototype, from here after, referred to as heat exchanger (HEX) to avoid any confusion, consists of a cross flow multipass HEX in an overall counter flow arrangement. The HEX has stainless-steel tubes with an internal diameter of 22.1 mm and an external diameter of 25.4 mm, the external surface was extended by applying copper fins.

The main purpose of this paper is to identify the key issues of the evaporator operation. To this end the data gathered from the model analysis was used to define the relevant HEX operating parameters in the three zones: pre-heater, evaporator, and super-heater (e.g., Reynolds number, heat flux), and so that to identify design guidelines.

The result analysis show that more than 2/3 of the total HEX thermal power occur in the evaporator zone, and the remainder occur in the preheating zone, having the superheating zone a marginal contribution. Despite that, the results also reveal that the preheating zone surface constitutes more than 2/3 of the total HEX area, and the evaporator zone approximately 1/3 of the total area, again having the superheater a marginal area.

The paper also presents some guidelines that will be used to design a new and improved direct evaporator prototype. These guidelines clearly indicate that efforts made towards decreasing evaporator size should be directed to the preheating zone.

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