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# Liquid and flow boiling heat transfer inside a copper foam

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**Abstract**

This paper presents the experimental measurements carried out during liquid and flow boiling heat transfer of R1234ze(E) and R134a inside a high porosity copper foam. The test section with a 5 pores per linear inch (PPI) foam, is electrically heated from the bottom and it is instrumented with 20 thermocouples to monitor the wall temperature distribution at different imposed heat fluxes, saturation temperatures, vapour qualities, and refrigerant mass flow rates. The experimental measurements were conducted in a new experimental facility built at the Dipartimento di Ingegneria Industriale of the Università di Padova especially designed to study either liquid or two-phase heat transfer processes for electronic thermal management applications.
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## 1. Introduction

The possible use of a low-GWP refrigerant as working fluid would be an important feature for an efficient, eco-friendly, and smart cooling system for electronic thermal management. Over the last several years, much research and development effort has been focused on potential refrigerants possessing low GWPs. Among the fluorinated propene isomers which have normal boiling point temperature data published in the public domain, several have low GWP and normal boiling temperatures relatively close to R134a; among them, R1234ze(E) has a normal boiling temperature approximately 7.3 °C lower than that of R134a. It has a GWP<1 and is being widely considered as a possible replacement for R134a in different applications, including electronic thermal management, air conditioning and refrigeration systems.

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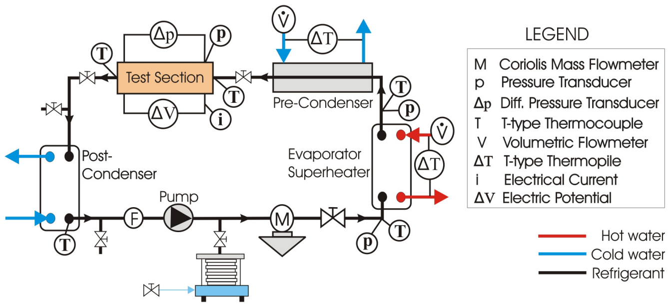


Figure 1. Schematic of the experimental setup.

Boiling is the heat transfer mechanism with the highest heat transfer coefficients, thus it can be used to spread high fluxes to maintain the junction temperature at low values with compact heat sinks. Moreover, new surfaces with microporous coatings, Carbon Nano Tubes (CNTs) coatings, or microstuctured surfaces are now available to enhance the boiling phenomenon. Nevertheless, a lot of work is still needed to deeply understand the boiling mechanism in such surfaces, where a huge number of variables (among those heat flux, saturation temperature, flow pattern, gravity, subcooling, wall surface, and others) are linked together and play important and crucial roles.

By virtue of their interesting multifunctional properties, open-cells metal foams represent promising alternative enhanced surfaces also for flow boiling applications. Nowadays, almost all the research is focused on single-phase flow in metal foams (air or liquid flow) and only few works regard the phase change process. Mancin et al. (2013) carried out a comprehensive work on single-phase heat transfer through metal foams, while a comprehensive review of metal foam heat transfer was proposed by Zhao (2012). Among the few works on flow boiling heat transfer in metal foams the most interesting appear to be: Zhao et al. (2009), Kim et al. (2008), Li and Leong (2001), and Ji and Xu (2012).

However, no one investigated the flow boiling heat transfer of the new low-GWP refrigerant R1234ze(E). This work aims at investigating the heat transfer properties of R1234ze(E) fluid during both liquid and flow boiling inside a copper foam.

## 2. Experimental Setup and Data Reduction

The experimental set up is located at the Heat Transfer in Micro-Geometries Lab (HTMg-Lab) of the Dipartimento di Ingegneria Industriale of the Università di Padova. As shown in Fig. 1, the experimental facility consists of three loops: the refrigerant, the cooling water, and the hot water loop. The rig was designed for heat transfer and pressure drop measurements and flow visualization during either vaporization or condensation of pure refrigerants and refrigerants mixtures inside structured micro-geometries. The facility has a maximum working pressure of 3 MPa, while refrigerant mass fluxes can be varied up to 400 kg $m^{-2}$ $s^{-1}$ in a section of 50 $mm^2$. In the first loop the refrigerant is pumped through the circuit by means of a magnetically coupled gear pump, it is vaporized and superheated in a brazed plate heat exchanger fed with the hot water.

Superheated vapour then partially condenses in a precondenser fed with the cold water to achieve the set vapour quality at the inlet of the test section. The refrigerant enters the test section at a known mass velocity and vapour quality and then it is vaporized by means of a calibrated Ni-Cr wire resistance.

The fluid leaves the test section and passes through a post-condenser, a brazed plate heat exchanger, where it is fully condensed and subcooled. Then, the subcooled liquid is sent back to the boiler by a pump.

A damper connected to the compressed air line operates as pressure regulator to control the saturation condition in the refrigerant loop. As shown in Fig. 1, the refrigerant pressures and temperatures are measured in several locations throughout the circuit to know the refrigerant properties at the inlet and outlet of each heat exchanger.

The refrigerant flow can be independently controlled by the gear pump and it is measured by means of a Coriolis effect flowmeter. The inlet vapour quality to the test section is determined by the heat extracted in the precondenser, which can be controlled by varying water temperature and flow rate. The cold water loop consists of a stabilized

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