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# Carbon dioxide flow boiling in a single microchannel – Part I: Pressure drops

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ABSTRACT

Carbon dioxide two-phase flow pressure drops have been investigated in a single horizontal stainless-steel micro-tube having a 0.529 mm inner diameter. Experiments were carried out in adiabatic conditions for four saturation temperatures of −10; −5; 0; 5 °C and mass fluxes ranging from 200 to 1400 kg/m$^2$ s, for inlet qualities up to unity. Measurements have been compared to the predictions of well-known methods. The Müller-Steinhagen and Heck correlation and the Friedel correlation gave the best fit as well as the homogeneous model when the liquid viscosity is used to represent the apparent two-phase viscosity. Further, an analysis based on the homogeneous model has not shown any clear appearance of the laminar or the transition regimes in any given range of Reynolds number. The apparent viscosity of the two-phase mixture was found larger than the liquid viscosity at low vapour qualities, namely at the lowest temperatures. Hence, a new expression to determine the equivalent viscosity was suggested as a function of the reduced pressure. Lastly, the Chisholm parameter from the Lockhart–Martinelli correlation was found lower than expected and also mainly dependent on the saturation temperature.

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## 1. Introduction

In the field of vapour compression systems, environmental concerns regarding ozone depletion and global warming first led to international agreements (Montreal protocol and its amendments) for a progressive phase out of the ChloroFluoroCarbons (CFC) and HydroChloroFluoroCarbons (HCFC) synthetic refrigerants due to their Ozone Depletion Potential (ODP). Introduced in the nineties, the substituting HydroFluoroCarbons (HFC) have a zero ODP. Still, they are powerful greenhouse gases identified by the Kyoto protocol (1997). In Europe, HFC have been subjected to a restricted use since 2006 [2]. In particular, in the area of Mobile Air Conditioning (MAC), HFC having a Global Warming Potential (GWP) higher than 150 will be banned for new vehicle models by January 2011 [3].

Thanks to its zero ODP and unitary GWP, the "old" carbon dioxide refrigerant first received a renewed interest as an alternative natural working fluid for MAC systems [4] where leakages of refrigerant occur due to the use of open compressors and porous hoses. Moreover, $CO_2$ is neither flammable nor toxic and allows the design of compact systems [5]. $CO_2$ is also a well-known substance that offers a long term environment friendly solution (no harmful decomposition in the atmosphere). In the last 10 years, two other obvious applications also appeared. The first is the commercial refrigeration (supermarkets) which is also a quite emissive sector due to the long circuits needed in the conventional direct expansion systems. In this field, $CO_2$ can be used as a secondary fluid or as a refrigerant in the low temperature refrigeration cycle of a cascade system. The second application is the hot water production with a heat pump. This takes advantage of the temperature glide occurring during the cooling of the supercritical $CO_2$. The use of such thermodynamic water heater devices for domestic purposes has been already developed in Japan with the Ecocute project and other industrial applications are also investigated.

A sustainable use of vapour compression systems does not only require reduced direct emissions of greenhouse gases but also reduced indirect emissions due to the energy consumption. This point is particularly important for the $CO_2$ which is not thermodynamically, or theoretically, an ideal refrigerant due to its low critical temperature (close to 31 °C). However this disadvantage can be, for practical purposes, compensated by highly favourable thermophysical properties, leading namely to outstanding heat transfer coefficients compared to traditional fluids. Accordingly, there is a need to develop components specifically dedicated to $CO_2$. Namely, an appropriate design of the evaporator is one of the key towards efficiency, which requires a better knowledge of the heat transfer and pressure drop characteristics of the $CO_2$ fluid.

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