Enhancement of refrigeration system performance by refrigerant capillary injection in evaporator

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Abstract. In this paper, the enhancement of refrigeration system performance by refrigerant capillary injection in evaporator was experimentally investigated. An experimental bench was developed in order to compare the performance of a refrigeration system operating in conventional throttling and capillary injection modes. The temperature distribution in the evaporator and the compressor electrical consumption were determined, showing that in the capillary injection mode, the refrigeration system was more stable, its time to reach the steady state was reduced by 62.5 % and its COP was enhanced by 9 %.

1. Introduction
The growing need of cooling, refrigeration and air conditioning requires an increasing use of refrigeration systems. It is therefore primordial to reduce the electrical consumption of these refrigeration systems by enhancing and optimising their performance and efficiency.

In this context, numerous research works are being conducted on the integration of ejectors and the adoption of field synergy principle in refrigeration systems [1, 2]. By replacing the standard expansion valve by an ejector expansion in refrigeration cycle, Lucas and Koehler [3] experimentally found a COP enhancement of 17 % for CO₂, whereas Hassanain et al. [4] numerically found a COP enhancement of 87.5 % for R134a. Kim et al. [5] introduced a real time control optimal method for heat rejection pressure of a CO₂ refrigeration system with an internal heat exchanger. Bilir Sag et al. [6] experimentally showed that, when the ejector was used as an expander in the refrigeration system, the COP and the exergy efficiency were higher by 7.34-12.87 % and 6.6-11.24 % than in the basic refrigeration system, respectively.

In this work, an experimental study on the enhancement of refrigeration system performance by refrigerant capillary injection in evaporator is conducted. The experimental setup of the refrigeration system is first introduced. The experiments carried out and the results obtained are then presented and analysed.

2. Experimental setup and procedure
The experimental setup (Fig. 1) mainly consists of a compressor (Danfoss, model NL7.3MF), an air-cooled condenser (M3 Technology, model 783670-1), an accumulator, a filter drier (Emerson, model EK 053), a Coriolis mass flow meter (U-ideal, model DMF-1), a throttling capillary tube, a bypass valve (Swagelok), a liquid separator, a test section, a power analyser (Yokogawa, model WT500) and an a data acquisition system (Yokogawa, model MX100).
Prior to the experiments, the refrigerant (R134a) is first perfectly degassed, while the loop of the refrigeration system is put under vacuum, and then released in the accumulator.

When the refrigeration system is turned on, the liquid R134a leaving the accumulator passes through the filter drier, the mass flow meter, the throttling capillary tube/bypass valve, the liquid separator and the test section. The vapour R134a leaving the test section passes through the compressor and the condenser before returning in the accumulator.

The test section is a copper evaporator consisted of 3 horizontal circular cross-section tubes, placed in parallel in a vertical plan with a gap of 50 mm and connected to a cylindrical distributor of inner diameter 20 mm. The tubes have an inner diameter of 10 mm, an outer diameter of 12 mm and a length of 1400 mm. These tubes are heated with the environment air, maintained at 20 °C using a temperature controlled chamber, by natural convection. A capillary tube of inner diameter 1.6 mm, outer diameter 3.2 mm and length 1600 mm is coaxially inserted in each evaporator tube (Fig. 2). 12 holes are spread along this tube and the positions of two adjacent holes are staggered by 90°. The diameters \(d\) and the axial positions \(x\) of the holes in the 3 capillary tubes are chosen as follows:

- Tube 1: \(d=0.5\) mm; \(x=380, 460, 540, 620, 720, 820, 920, 1020, 1140, 1260, 1380, 1500\) mm;
- Tube 2: \(d=0.5\) mm; \(x=420, 540, 660, 780, 880, 980, 1080, 1180, 1260, 1340, 1420, 1500\) mm;
- Tube 3: \(d=0.8\) mm; \(x=420, 540, 660, 780, 880, 980, 1080, 1180, 1260, 1340, 1420, 1500\) mm.
T-type thermocouples are implemented at different points of the loop (Fig. 1). 12 T-type thermocouples are evenly implemented along the wall of each evaporating tube. The axial distance between two adjacent measuring points is 120 mm and the direction is clockwise staggered by 90°. Absolute pressure transducers (Shanghai Pulse, model MK-131) are implemented at the inlet and the outlet of the compressor, the throttling capillary tube and the evaporator in order to measure the pressure jump/drop inside them. The measurements ranges and uncertainties of the sensors are reported in Table 1. All data are collected using a power analyser and a data acquisition system consisted of a data logger, an interface card and a computer.

| Sensor                     | Measurement | Range       | Uncertainty |
|----------------------------|-------------|-------------|-------------|
| Mass flow meter            |             | 0-500 kg.h⁻¹ | ±0.2 %      |
| T-type thermocouple        |             | −30-80 °C   | ±0.5 °C     |
| Absolute pressure transducer|            | −0.1-1 MPa  | ±0.5 % (FS) |

The experiments are carried out using 2 modes: the conventional throttling in the loop and the capillary throttling (i.e. injection) in the evaporator. In the 2 modes, the same pressure of 0.8 MPa is imposed at the compressor outlet. In the first mode, the throttling capillary tube (inner diameter 1.2 mm, outer diameter 1.8 mm and length 950 mm) is used with the bypass valve closed to reduce the pressure at the evaporator inlet. In the second mode, the bypass valve is opened and the capillary tubes with holes spray the liquid R134a at high pressure (i.e. speed) into the evaporator tubes, forming a turbulent flow and enhancing thus the heat transfer. The temperature distribution in the evaporator and the compressor electrical consumption in the 2 modes are determined and compared.

3. Results and discussion

![Figure 3](image-url)

**Figure 3.** Evolutions over time of the evaporator tube 1 temperatures in (a) conventional throttling and (b) capillary injection modes.

Fig. 3 shows the evolutions over time of the evaporator tube 1 temperatures in conventional throttling and capillary injection modes. As can be seen, the temperatures in the capillary...
injection mode are more stable and their fluctuations are inconspicuous, while in the conventional
throttling mode, the temperatures reach a minimum at 180 s, then increase and reach a maximum
at 280 s with a relative amplitude of 2.7 °C before decreasing again and hitting a plateau. In
addition, the time needed to reach the steady state is 800 s in the conventional throttling mode,
while it is only 300 s in the capillary injection mode, reducing thus this time by 62.5 %. These
aspects are due to the fact that in the conventional throttling mode, the liquid refrigerant needs
a certain time to move from the throttling capillary tube to the evaporator and flows in an
inhomogeneous way in the evaporator tubes, while in the capillary injection mode, the liquid
refrigerant reaches the evaporator in a shorter time and is sprayed in an homogeneous way in
the evaporator tubes.

![Figure 4](image_url)

Figure 4. Evolutions over time of the compressor electrical consumption in conventional
throttling and capillary injection modes.

Fig. 4 shows the evolutions over time of the compressor electrical consumption in conventional
throttling and capillary injection modes. As can be noticed, the compressor electrical
consumption in the conventional throttling mode fluctuates and reaches an almost constant
value of 436 W at 800 s, while in the capillary injection mode, it remains at a constant value of
400 W after running for 70 s, enhancing thus the COP by 9 %.

4. Conclusions
An experimental study conducted on the enhancement of refrigeration system performance
by refrigerant capillary injection in evaporator was presented. An experimental bench
was developed in order to compare the performance of a refrigeration system operating in
conventional throttling and capillary injection modes. The results showed that the refrigeration
system was more stable, efficient (steady state time reduced by 62.5 %) and economical (COP
enhanced by 9 %) in the capillary injection mode than in the conventional throttling mode.

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