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EXPERIMENTAL RESULTS OF A TWO-PHASE EJECTOR: NOZZLE GEOMETRY EFFECTS

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ABSTRACT

An experimental study of a two-phase ejector with R134a as the working fluid is presented in this paper. The main objective is to determine the effects of the divergent section of the nozzle on the ejector performance under various working conditions. For the same conditions of operation, the ejector with a convergent nozzle presents a higher critical primary mass flow rate and a lower critical pressure in comparison to the version with a convergent-divergent nozzle. Globally the ejector with the convergent-divergent nozzle provides a higher entrainment ratio. The nozzle geometry has no impact on the optimal position of the nozzle. The same position giving the best entrainment ratio was found for the two tested nozzles. Unlike the convergent-divergent nozzle, the convergent nozzle has an entrainment ratio almost insensitive to a wide range of primary inlet subcooling. Primary and secondary mass flow rates increase with the subcooling level in a proportional way, resulting in a quasi-constant entrainment ratio.

Keywords: experiments, two-phase, ejector, R134a, nozzle geometry.

1. INTRODUCTION

The use of ejectors in building applications (heat pumps, refrigeration), and other areas (transportation, industrial processes) [1] may be an efficient way to use energy. Typically, an ejector consists of a primary nozzle, a mixing chamber and a diffuser (Fig. 1).

A high-pressure stream (primary flow) expands through the primary nozzle. As a result, a low-pressure zone is created in the mixing chamber inlet where a lower energy flow (secondary flow) is drawn. Primary and secondary flows mix inside the mixing chamber, and if conditions allow, mixing shock waves occur and result in a first pressure increase. The flow resulting from this mixing phase is further compressed in the diffuser.

The geometrical features of an ejector influence performance to various extents, depending on the working fluids, the application and operating conditions. The number of studies on geometry effects of two-phase

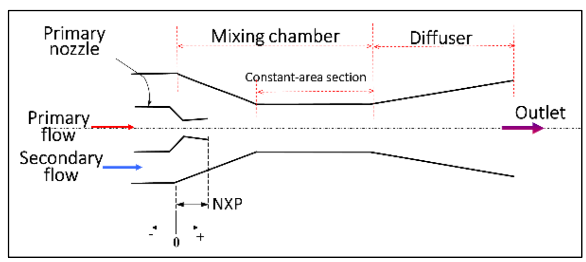

Fig.1. Schematic of an ejector

ejectors are relatively few in comparison to the single-gas type and the lack of reliable CFD modeling does not help to bridge this gap.

Hu et al. [2] tested a two-phase ejector with the refrigerant R410A, in an air-conditioning system. The distance between the nozzle outlet and the constant-area mixing chamber was varied from 0 to 9 mm. An optimal position of the nozzle for the system capacity and performance was found to be 3 mm. The authors also varied the throat diameter from 0.9 to 1.2 mm. The case of 1 mm yielded the best ejector efficiency and system performance.

Palacz et al. [3] investigated the geometry optimization of a two-phase CO_2 trans-critical ejector. Six geometrical parameters were considered: three of them were related to the mixing section and the remainder to the motive nozzle. The results showed that the suction nozzle shape had less significance on the ejector performance than the motive nozzle and the mixing chamber geometries.

Nakagawa et al. [4] investigated the effect of the divergent angle of the primary nozzle, showing that it played an important role in the decompression boiling phenomena of transcritical CO_2.

Baek et al. [5] performed a CFD study to identify geometry parameters affecting two-phase ejector entrainment performance, using R134a. The divergent length of the primary nozzle was tested in the range of 10 mm to 50 mm, the length of 20 mm generated the higher entrainment ratio. The nozzle positioned at 3 mm produced the smallest recirculation zone at the nozzle outlet, providing the higher entrainment ratio.

The main objective of the present study is to investigate experimentally the influence of the primary nozzle geometry on the ejector performance. The experiments were performed on a two-phase ejector using R134a as the working fluid. Two primary nozzles, respectively with and without the divergent were tested under different working conditions in order to assess the impact on the entrainment ratio. The nozzle position relative to the mixing chamber was also investigated.

2. EXPERIMENTAL FACILITY

An experimental installation built at CanmetENERGY and dedicated to testing two-phase ejectors was used to generate the results of this study. The test stand is well equipped with high quality instrumentation, more particularly around the ejector loop. A detailed description of the ejector test bench and measurements uncertainties can be found in a previous paper [6].

The same ejector body was used to test successively two nozzles, represented in Fig. 2. The two nozzles have the same external shape and dimensions. Regarding the internal geometry, they present the same convergent and throat diameter but only nozzle B has a divergent.

The ejector performance indicator presented in the results is principally the entrainment ratio ω (secondary on primary mass flow rates), which measures the ejector capacity to draw the secondary fluid. The uncertainty on this parameter was ±0.8%.

3. RESULTS AND DISCUSSION

The experimental results on the operation and performance of a two-phase ejector with the refrigerant R134a are presented. Two different nozzles, with and without the divergent were used to determine the

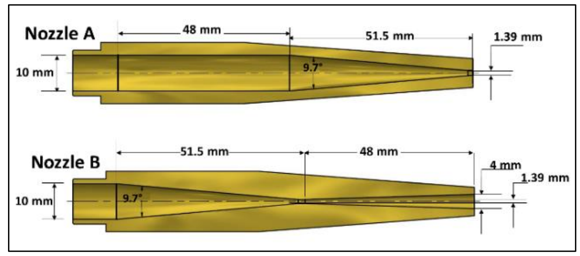

Fig.2. Tested nozzles: (a) nozzle A without divergent section, (b) nozzle B with divergent section

impact of this geometry change on the ejector performance. Various positions of the primary nozzle inside the mixing chamber, and different conditions at the inlet and outlet of the ejector were tested.

In order to cover refrigeration and potential industrial applications, a large range of subcooling (ΔT_{sub}) at the primary inlet (0.5-46 °C) was tested.

The primary nozzle position (NXP) was tested in the range of -10 mm to 44.4 mm. The definition of the NXP used in this paper relies on the sketch drawn in Fig. 1. Two pressures at the primary inlet were used (8.8 bar and 14.9 bar), and the pressure at the ejector outlet was varied in the range of 3-7 bar. During the tests, the entrainment was favoured over the compression, thus the secondary pressure was maintained slightly lower than the outlet ejector pressure. Tests with induced flow were made with the superheat at the secondary inlet around 10 °C.

3.1 Critical flow

As a first result (Fig. 3), the entrainment of the ejector was not considered in order to see the effects of

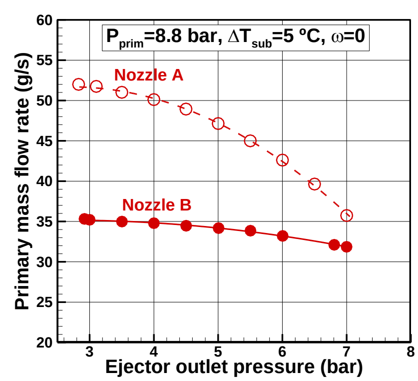

Fig.3. Effects geometry nozzles on critical mass flow rate

the nozzle geometry on the critical mass flow rate. The conditions at the primary inlet were fixed to P_{prim}=8.8 bar and ΔT_{sub}=5 °C, and the ejector outlet pressure was varied. A typical trend of the primary mass flow rate with the outlet pressure was observed: the flow rate increased with the ejector outlet pressure decrease. At

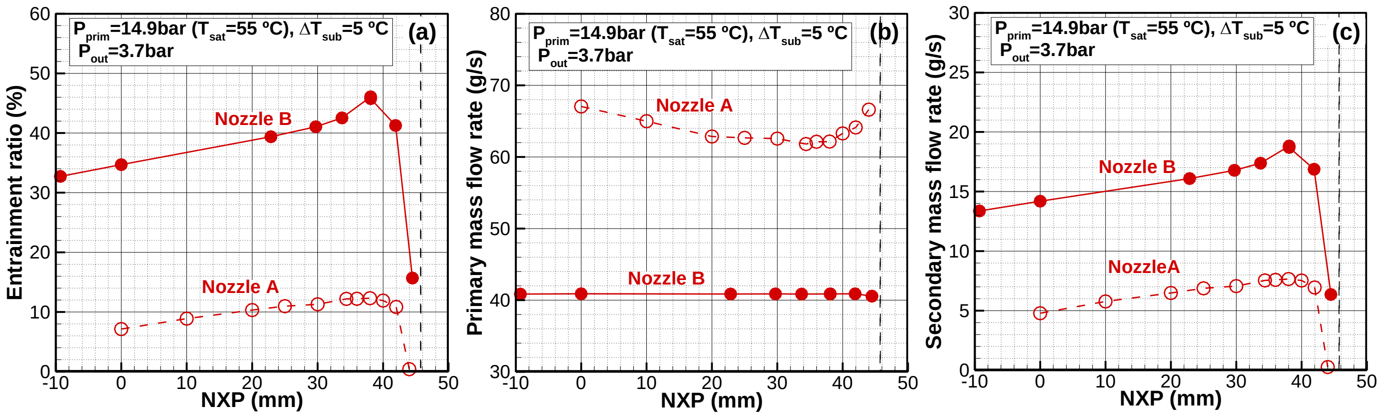

Fig.4. Nozzle geometries and the NXP: (a) entrainment ratio, (b) primary mass flow rate and (c) secondary mass flow rate

low pressures, the critical conditions were reached and the mass flow rate became less sensitive to outlet pressure change. The curves of the two nozzles present different slopes. In the convergent-divergent case, the critical flow condition was attained with a relatively low flow expansion, compared to the convergent nozzle. A similar behaviour was observed in a previous study where the expansion increased by varying inlet subcooling [7]. In addition, Wallis [8] observed that nozzle length influenced the nucleation phenomenon and, consequently the critical flow. Based on these observations it is believed that combined effects of the nozzle geometry and subcooling probably affect the critical conditions and flow flashing along the same mechanisms.

Even with the same throat diameter, a high mass flow rate is always associated with nozzle A with no divergent. At P_{out}≈3 bar, its critical mass flow rate was about 48.5% higher in comparison with nozzle B. This difference in mass flow rate is perhaps due to the phenomenon mentioned above and to the nozzle outlet pressure. The flow in nozzle B expands more than in nozzle A. A higher pressure at the outlet of nozzle A probably helps to better withstand the pressure imposed at the ejector outlet.

3.2 Nozzle exit position

The effect of the nozzle displacement on the entrainment ratio, the primary and secondary mass flow rates for two nozzles geometries is presented in Fig. 4. Primary conditions were fixed at P_{prim}=14.9 bar and ΔT_{sub}=5 °C. The ejector outlet pressure was maintained constant at 3.7 bar, and the secondary inlet pressure was in the range of 3.65-3.8 bar. The position of the primary nozzle was varied from -10 mm to 45 mm. The vertical dashed line in the figure represents the inlet to the mixing zone with constant-area. For the two tested nozzles, the entrainment ratio has the same trend (Fig. 4a), an increase is observed with the NXP until an optimal position where the curve presents a maximum, and beyond this position, a sharp decrease of the entrainment is observed. By moving the nozzle downstream, and close to the zone's inlet, the passageway of the secondary stream flow becomes increasingly obstructed.

The geometry of the nozzles has apparently no effects on the optimal NXP, which is approximately observed at the same position (NXP_{opt}≈38 mm) for both nozzles. For all tested NXP cases, nozzle B (with a divergent) presents the highest entrainment ratio. At NXP_{opt}, nozzle B reached an entrainment ratio close to 0.45; this value decreases by 74% in the case of nozzle A with no divergent.

The entrainment ratio of nozzle A is double penalized with a higher primary mass flow rate (Fig. 4b) and a lower secondary mass flow rate (Fig. 4c) than observed in nozzle B. Explaining the suction mechanism of the secondary flow, due to nozzle geometry may be tricky. The nozzle divergent may affect in different ways the expansion level, the flashing mechanism, the jet's shape and the local flow around the nozzle outlet.

Note that, all the subsequent experiments were performed with the nozzles positioned at the optimal NXP identified previously.

3.3 Primary flow subcooling

Effects of primary inlet subcooling on mass flow rates and the entrainment ratio for two nozzle geometries are reported in Fig. 5. Subcooling was varied from 0.5 to 46 °C, the pressure at the primary inlet was kept constant at 14.9 bar and the ejector outlet pressure was maintained at 3.7 bar.

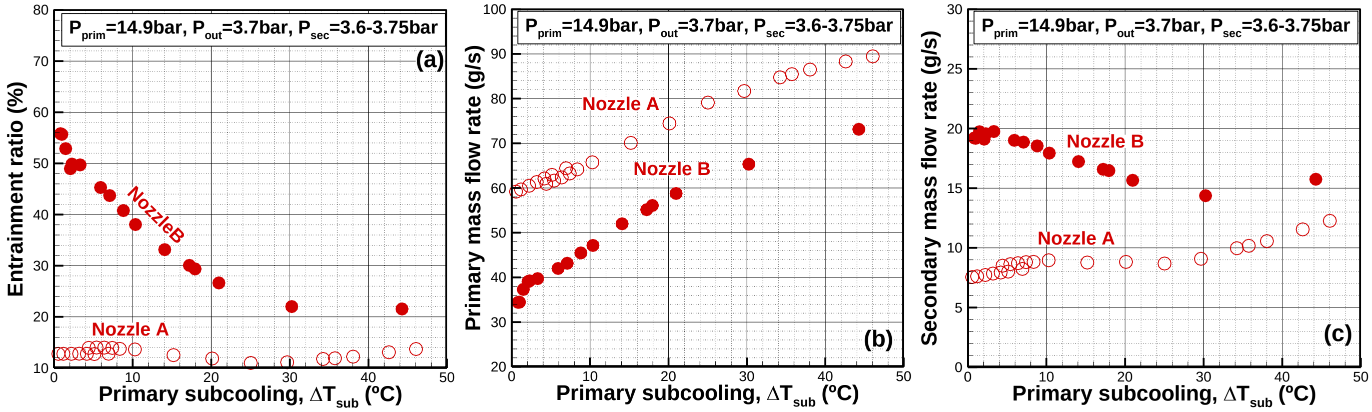

Fig.5. Nozzle geometries and the primary inlet subcooling: (a) entrainment ratio, (b) primary mass flow rate and (c) secondary mass flow rate

The ejector with nozzle B provided a higher entrainment ratio (Fig. 5a) with respect to nozzle A and greatly depended on the primary subcooling level. When the subcooling increased, the entrainment decreased and around ΔT_{sub}=30 °C it remained almost constant. The entrainment ratio with nozzle A (without divergent) was less sensitive to the subcooling level.

For both nozzles, the primary mass flow rate (Fig. 5b) increased with subcooling at the primary inlet. The highest mass flow rate was recorded with the nozzle A.

The ejector with convergent-divergent nozzle B provided a higher entrainment capacity of secondary flow than nozzle A (Fig. 5c). It may be noted in addition that the two nozzles showed an opposite trend in terms of subcooling at the primary inlet. With Nozzle B a decrease of the secondary mass flow rate was observed when subcooling increased up to ΔT_{sub}=20 °C beyond which limit it became nearly constant. On the other hand, Nozzle A showed an increase of the secondary mass flow rate with subcooling, except for ΔT_{sub}=10-30 °C where the entrainment remained almost constant.

Explaining the impact of the nozzle geometries on the entrained flow can be tricky without a complete picture inside the ejector. Among factors that influence the entrainment is the level of expansion in the nozzle.

4. CONCLUSION

An experimental investigation of a two-phase ejector was conducted to determine the effects of the nozzle geometry on performance. The same body of an ejector was used to test two different nozzles separately (convergent, convergent-divergent)

For the tested conditions, the ejector with convergent nozzle presents a higher critical primary mass flow rate and a lower critical pressure.

The results showed that the nozzle geometry has no impact on the nozzle position relative to the mixing section, and the same optimal NXP was found for the two tested nozzles.

Globally the ejector with the convergent-divergent nozzle presents a higher entrainment ratio, with a reduced primary mass flow rate and an increased secondary mass flow rate.

Unlike the convergent-divergent nozzle, the convergent nozzle has an entrainment ratio almost insensitive to a wide range level of subcooling at the primary inlet. The primary and secondary mass flow rates increase with the level of the subcooling in a proportional way, resulting in an almost constant entrainment ratio.

Depending on the two-phase ejector application and the level of the primary flow subcooling, design recommendations can roughly be made:

- A convergent nozzle is preferred for an ejector insensitive to subcooling but a low entrainment ratio is to be expected.

- A convergent-divergent nozzle is preferred to enhance the entrainment ratio, but it is prone to a higher sensitivity to subcooling.

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