COMPUTATIONAL MECHANICS 2021
36th conference with international participation
Srní
November 8 - 10, 2021

Ejector-boosted transcritical R744 refrigeration system

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The conventional refrigeration systems are mainly driven by electricity and are usually categorized by high energy consumption. Transcritical refrigeration systems have been verified to be very energy efficient, reliable, and more attractive, especially as the world becomes more energy-sentient. The properties of CO_2 as a refrigerant have made the transcritical refrigeration systems cost-effective and efficient. In contrast, working at supercritical pressure and high gas cooler outlet temperature leading to significant exergy destruction lies in the throttling process impacting the overall system performance. The use of ejector allows for overcoming the significant exergy destruction lays on the expansion processes of the cooling systems and led to spark improvement in the system performance by recovering some of the expansion work [3]. This study addresses the impact of utilizing the expansion ejector on the CO_2 transcritical refrigeration system by recovering some expansion work and reducing power consumption. The ejector profile was described by a comprehensive experimental study, and its performance was validated with approximation functions by Elbarghthi et al. [1, 2]. In the analysis, the ejector boosted system was compared with the parallel compression configuration representing the baseline system layout. The ejector cartridge type CTM ELP60 by Danfoss was used; it proposed the smallest profile with a motive nozzle throat diameter of 0.71 mm. The schematic diagram of the system supported with an ejector is represented in Fig. 1. The system consists of a base-load compressor, gas cooler, evaporator, and HPV with a metric expansion valve. The system is supplied with a supplementary compressor denoted as a parallel compressor to draw the vapour from the liquid separator to the gas cooler.

In refrigeration systems, the energy efficiency of the cycle can be quantified by assessing the coefficient of performance as the ratio between the cooling capacities into the total gross energy input to the cycle based on the first law of thermodynamic. The analysis was performed at exit gas cooler pressure of 90 bar and temperature of 20°C and 35°C. The cooling system was tested at a -6°C evaporation temperature with an outlet evaporator superheat of 10 K. Semi-hermetic reciprocating compressors manufactured by Dorin type CD1400H and CD380H were incorporated into the analysis presenting the base-load and parallel compressors. The compressor supplier provides polynomial functions to calculate each compressor's mass flow rate and electric power consumption. The calculation considers that the pressure drop in the piping and all heat exchangers are neglected with a totally isolated system. The analysis was conducted at steady-state conditions, and the potential and kinetic energies were not considered.

Fig. 2 represents the impact of the ejector profile on the overall system COP improvement and the reduction of power consumption. The left side shows the COP improvement via different cooling loads at pressure lift of 6 bar and exit gas cooler of 20°C and 35°C. The result revealed a significant COP improvement when running the system with the ejector at low system cooling capacity. The highest COP improvement recorded was 8.5% when implementing

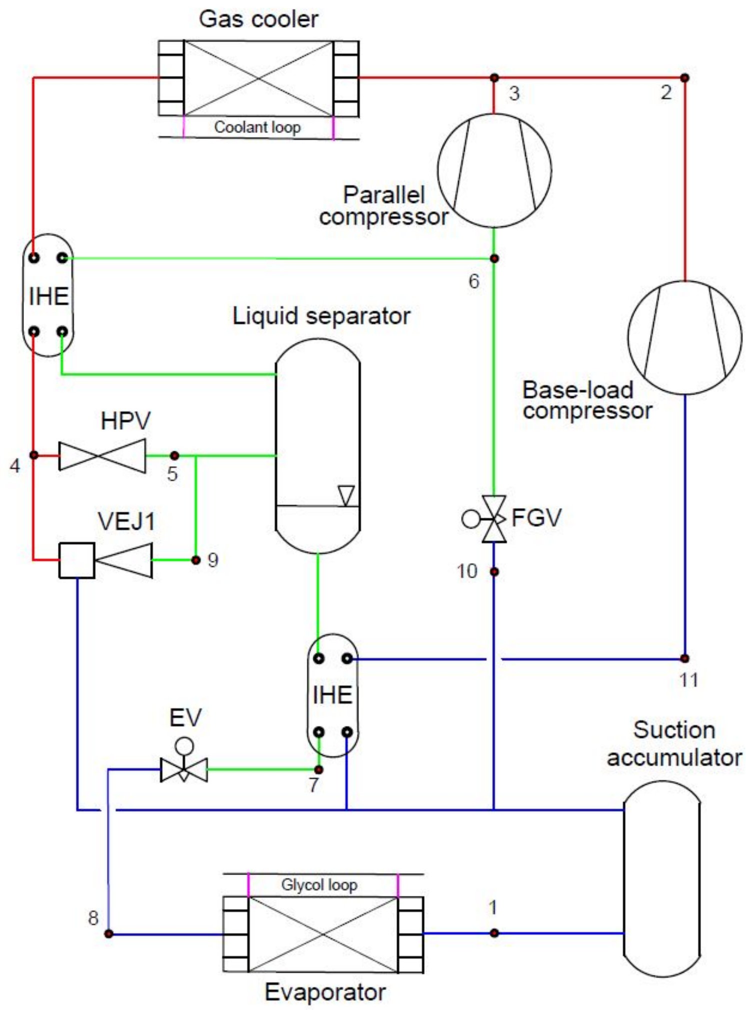
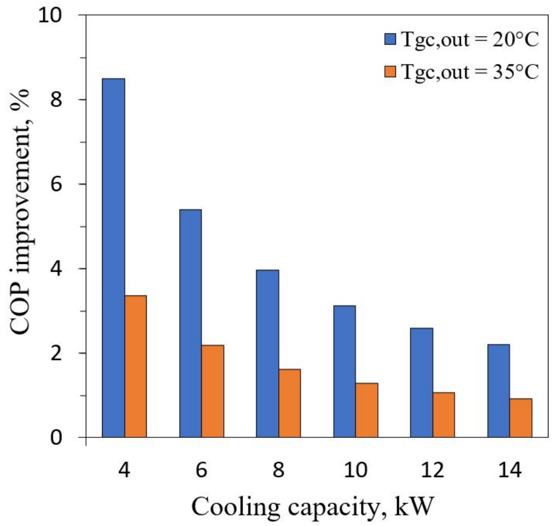


Fig. 1. The schematic diagram of the proposed ejector-boosted cooling system

the ejector comparing with operating in parallel configuration baseline at $T_{gc,out}$ = 20°C while the system improved by 3.36% under the same cooling load of 4 kW at $T_{gc,out}$ = 35°C. As long as the system cooling load increased, the effect of the ejector reduced. For example, COP improvement dropped to less than half when the cooling load grew to 10 kW.

Moreover, implementing the ejector to the system assisted in saving some of the energy needed for the compressors. Based on the result illustrated in the right side of Fig. 2, for the calculation of the power consumption at pressure left of 5 bar and $T_{gc,out}$ = 20°C, the ejector could reduce the input power for the compressors up to 5.3% and 13.45% at the cooling capacity of 10 kW and 4 kW respectively. The peak where the system could reach the highest possible power-saving when utilizing the ejector is a function of the ejector efficiency, which is interpreted as the amount of the total power applied to compress the entrained flow isentropically to the ejector outlet over the maximum theoretical work recovery potential. Therefore, operating with an ejector should be regulated with a specific pressure lift that can improve the system's performance.

In conclusion, applying the ejector in the R744 transcritical refrigeration system as a flashing device will recover the expansion work and reduce the overall input power. It is worth highlighting that understanding the ejector characteristics and the optimum operation conditions will lead to the ideal overall system performance.



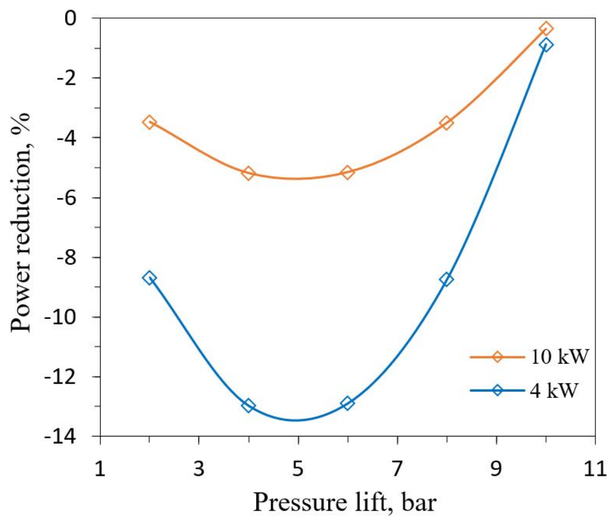


Fig. 2. The impact of the ejector profile on the system: COP improvement versus cooling load (*left side*), and the power reduction as a function of the different pressure lift (*right side*)

Acknowledgement

The work was supported by the Student Grant Competition of the Technical University of Liberec under the project No. SGS-2021-5063.

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