DOI: 10.18462/iir.nh3-co2.2023.XXXX[DOI Number]

A comparative study to investigate two configurations of a two-stage evaporator in a CO_2 heat pump chiller

Mihir Mouchum HAZARIKA[(a)], Armin HAFNER[(a)], Jan BENGSCH[(b)]

[(a)] Department of Energy and Process Engineering, NTNU
Trondheim, 7034, Norway, e-mail: mihir.m.hazarika@ntnu.no, armin.hafner@ntnu.no
[(b)]SINTEF Ocean
Trondheim, 7465, Norway, e-mail: jan.bengsch@sintef.no

ABSTRACT

This study is carried out to investigate the performance of a CO_2 heat pump chiller that provides heating and cooling simultaneously. For heating applications, hot water is produced at 90°C; while for cooling applications, chilled water is produced at 4°C. The evaporator utilized for chilled water production is a novel two-stage evaporator. Two configurations have been proposed to implement this two-stage evaporator in the CO_2 system. One configuration is termed GFES: the first stage is fed by gravity; the second stage is fed by ejector suction. The other configuration is termed EDES: the first stage is fed by the ejector discharge; the second stage is fed by ejector suction. The primary goal of this study is to compare the performances of these two evaporator configurations and their effects on the system's overall performance. To fulfill this objective simulation models are developed in Modelica. Results show that the COPs are nearly the same for both configurations. In addition, it is observed that the integration of the two-stage evaporator enhances the overall performance as the cooling capacity is shared between the two stages and the suction pressure of the compressor is elevated by utilizing the ejector.

Keywords: Carbon Dioxide, Heat pump, COP, Two-stage evaporator, Ejector.

1. INTRODUCTION

The use of flooded evaporators in the heat pump units enhances the performance. Lorentzen (1968) presented the benefits of using flooded evaporators over dry expansion evaporators. It was reported that the average efficiency of dry expansion evaporators is less than half of the efficiency of flooded evaporators. Karampour and Sawalha (2018) presented that the evaporation temperature can be increased by 3-4 K in CO_2 units, when applying flooded evaporators as compared to dry expansion evaporators. Hafner (2018) and Tosato et al. (2020) presented a new method with two evaporators operated in flooded mode. One evaporator was operated on gravity-fed mode and the other was operated on ejector-supported mode. Based on this concept, Hafner et al. (2022) proposed a novel two-stage evaporator and carried experimental study. Results show the benefit of using this two-stage evaporator.

This study is carried out to investigate the implementation of this two-stage evaporator in a CO_2 heat-pump chiller. This two-stage evaporator is designed to achieve a high-temperature gradient on the secondary fluid side. The basic working principle is that the two stages of the evaporator are operated at different evaporation pressures. To manage the desired evaporation pressures in the two stages of the evaporator, an ejector is utilized in the proposed CO_2 system. In this study, two configurations are demonstrated which show the procedures for implementing the two-stage evaporator in the CO_2 system. In the first configuration (GFES), the first stage of the evaporator is operated on gravity-fed mode at the separator pressure while the second stage of the evaporator is operated utilizing the suction of the ejector's secondary nozzle. In the second configuration (EDES), the first stage of the evaporator is fed with refrigerant discharged from the diffuser of the ejector while the second stage of the evaporator is operated utilizing the suction of the ejector's secondary nozzle. The primary goal of this study is to compare the performances of the two proposed configurations with the two-stage evaporator.

2. MODELLING PROCEDURE

Fig. 1 and Fig. 2 show the two configurations of the heat-pump chiller with the two-stage evaporator. In the first configuration (GFES) (Fig. 1), high-pressure and high-temperature refrigerant (state pt. 2) leaves the compressor and goes to the gas coolers. Then it enters the internal heat exchanger (IHX) (state pt. 3). After IHX, the refrigerant (state pt. 4) enters the primary nozzle of the ejector. The ejector discharge (state pt. 5) is then fed to the liquid separator. A part of the liquid refrigerant from the separator is fed to the first stage of the two-stage evaporator which is operated in gravity-fed mode. The other part of the liquid refrigerant (state pt. 8) from the separator is sucked by the ejector suction nozzle through the second stage of the two-stage evaporator. This is how the two-stage evaporator is operated in the first configuration. In the second configuration (EDES) (Fig. 2), the ejector discharge flow (state pt. 5) is first fed to the first stage of the two-stage evaporator. After that, the refrigerant (state pt. 6) goes to the separator. From the separator, the liquid phase of the refrigerant (state pt. 7) is sucked by the suction nozzle of the ejector through the second stage of the two-stage evaporator. This is how the two-stage evaporator is operated in the second configuration.

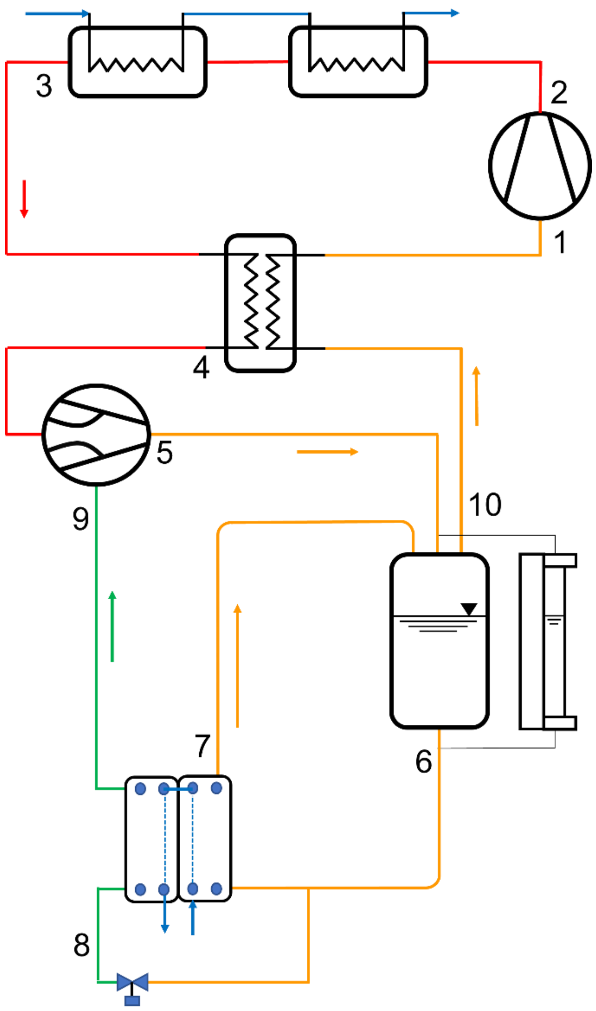

Figure 1: Heat pump chiller with the two-stage evaporator (GFES): first stage fed by gravity; second stage fed by ejector suction

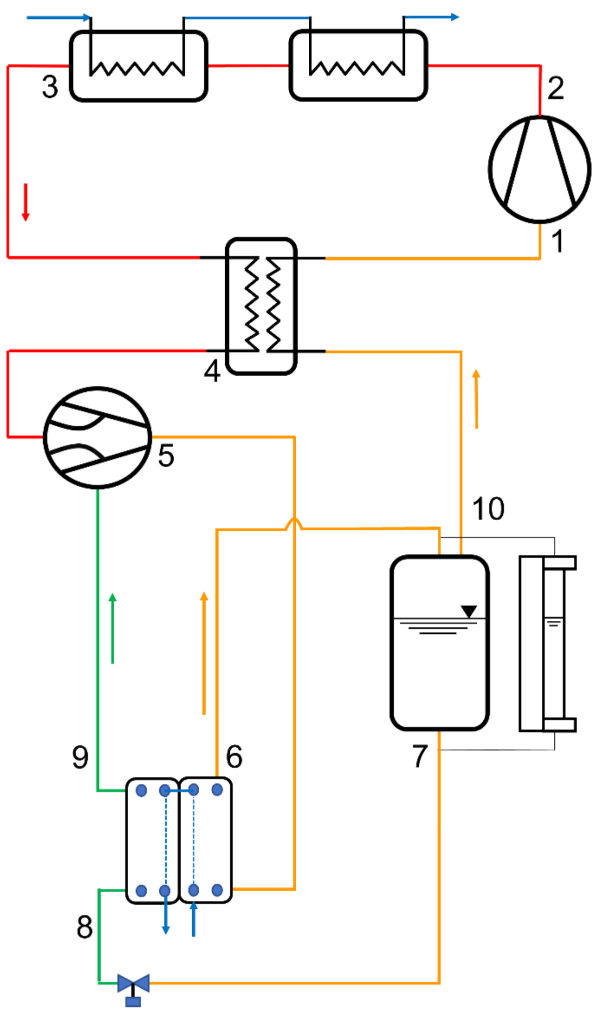

Figure 2: Heat pump chiller with the two-stage evaporator (EDES): first stage fed by ejector discharge; second stage fed by ejector suction

The simulation models for these two proposed configurations are developed in Modelica (Modelica). These models are created by combining the component models using the TIL-library 3.9 (TLK-Thermo Gmbh) which contains the models for components of refrigeration and heat pump systems used in this study. However, these models from TIL-library do not have the appropriate equations to estimate the minor losses, major losses, and the gravity term for the gravity-fed evaporator loop. Hence, these models are upgraded including all the necessary equations to capture the physics of self-circulating flow in the loop (Hazarika et al., 2022). These upgraded models are then used to develop the gravity-fed evaporator loop. Next, the gravity-fed evaporator loop is combined with the ejector-fed evaporator and the other components to complete the simulation model for GFES configuration. Similarly, the complete simulation model is developed for EDES configuration. Dymola 2021 is used as the modeling environment (Dassault Systems). The operating parameters considered during simulation are shown in table 1. The dimensions of the components are presented in earlier publications (Hafner et al., 2022; Hazarika et al., 2022).

Table1. Operating parameters considered during simulation

Discharge pressure (bar)	Gas cooler approach temperature (K)	Compressor frequency (Hz)	Secondary fluid (water) return temperature		Secondary fluid (water) flowrate	
			Gas cooler inlet (°C)	Evaporator inlet (°C)	Gas cooler (kg/min)	Evaporator (kg/min)
120	3	45 to 80	24	15	11.87	48

3. RESULTS AND DISCUSSION

Simulations are carried out to investigate the effect of the compressor frequency on the performances of two configurations of heat pump chiller with the two-stage evaporator.

3.1. GFES configuration

For GFES configuration, the results are presented in this section to analyze the effect of compressor frequency. Fig. 3 shows the change in the supply temperature of the water with the change in compressor frequency. At high frequencies, water is cooled to low supply temperatures. This is due to higher refrigerant flowrate at high frequencies. In addition, the evaporation pressures also decrease with an increase in compressor frequency (fig. 4). That brings the supply temperature of water further down. Cooling capacities for both stages of the evaporator are shown in fig. 5.

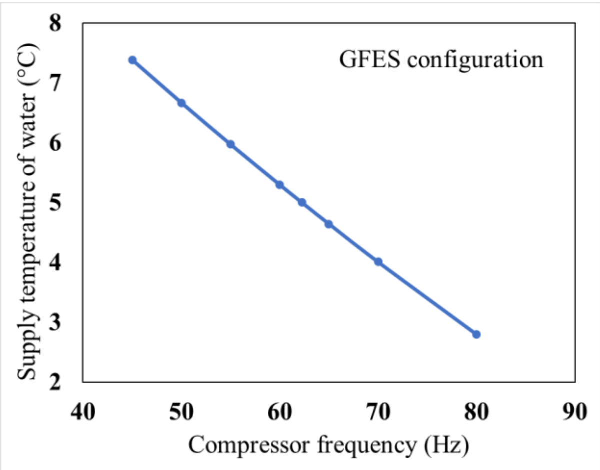

Figure 3: Supply temperature of the water with change in compressor frequency (GFES)

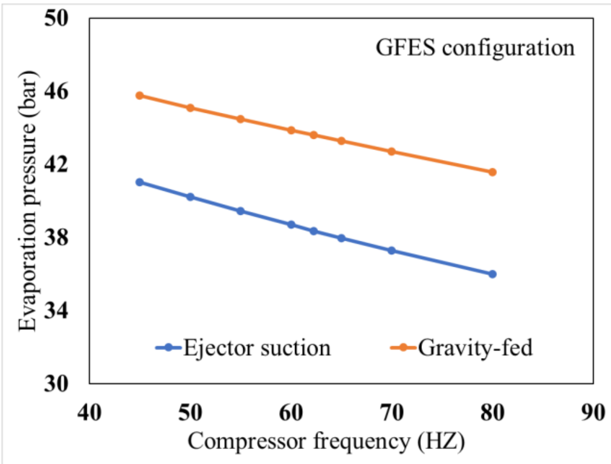

Figure 4: Evaporation pressure with change in compressor frequency (GFES)

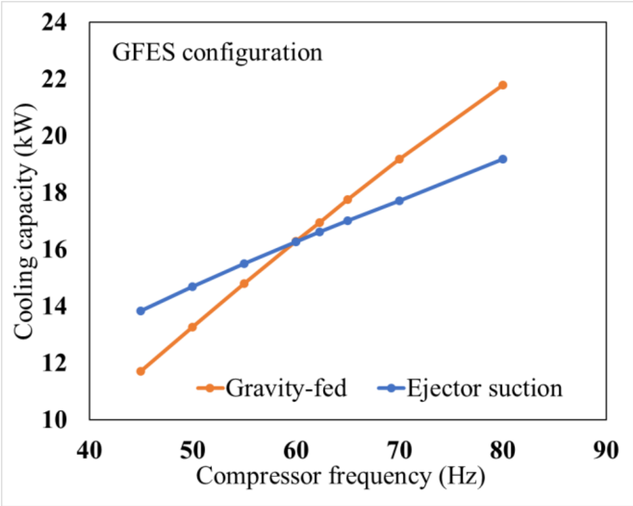

Figure 5: Cooling capacity with change in compressor frequency for both stages (GFES)

3.2. EDES configuration

For EDES configuration, the results are presented in this section to analyze the effect of compressor frequency. Fig. 6 shows the change in the supply temperature of the water with the change in compressor frequency. Like GFES configuration, it is observed that the supply temperature of water decreases for EDES configuration with an increase in compressor frequency. This is due to an increase in refrigerant flowrate and a decrease in evaporation pressure (Fig. 7) with a change in compressor frequency. Cooling capacities for both stages of the evaporator are shown in fig. 8.

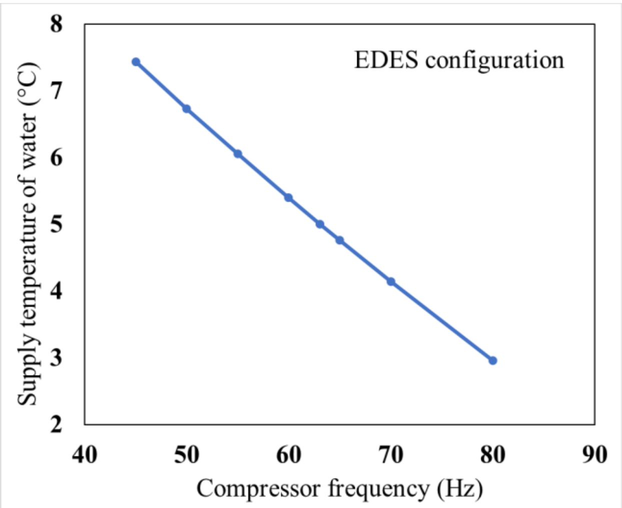

Figure 6: Supply temperature of the water with change in compressor frequency (EDES)

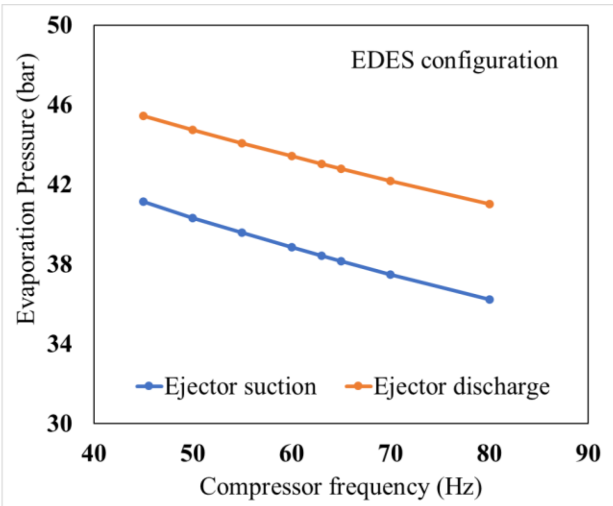

Figure 7: Evaporation pressure with change in compressor frequency (EDES)

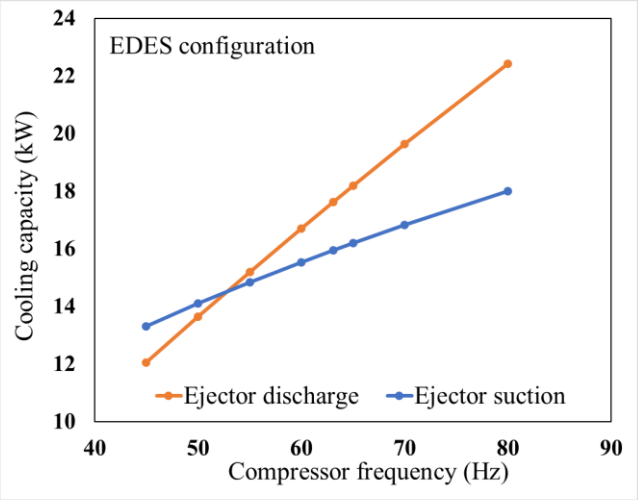

Figure 8: Cooling capacity with change in compressor frequency for both stages (EDES)

3.3. COP of GFES configuration and EDES configuration

This heat-pump chiller is designed to provide heating and cooling simultaneously. Therefore, total COP is estimated considering both heating and cooling capacity. Fig. 9 shows the total COP for GFES and EDES configuration with change in compressor frequency. It is observed that the total COPs are comparable for both configurations. However, a small improvement in COP is observed for GFES configuration compared to EDES configuration. This is because the pressure lift of the ejector is slightly higher for the GFES configuration compared to the EDES configuration.

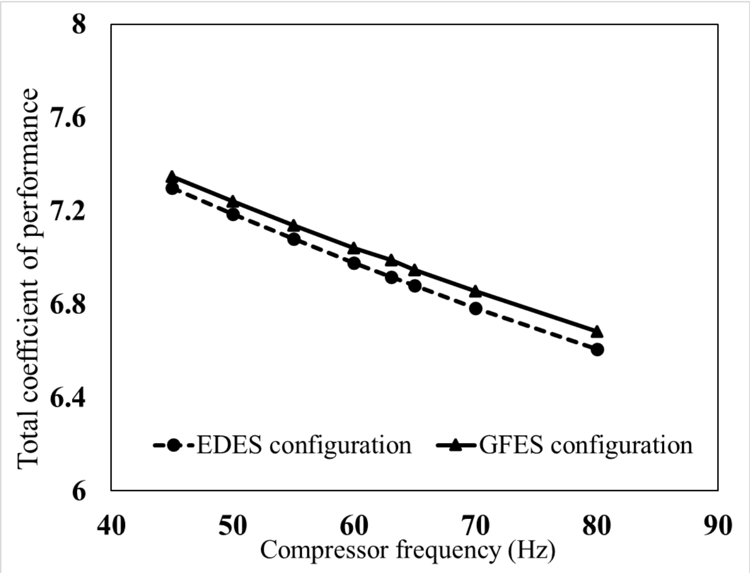

Figure 9: Total COP of GFES and EDES configuration with change in compressor frequency

4. CONCLUSIONS

This study is carried out to investigate the implementation of a novel two-stage evaporator in a heat pump chiller. Two configurations are proposed in this study to integrate the two-stage evaporator. One configuration is termed GFES in which the first stage of the evaporator is fed by gravity and the second stage is fed by ejector suction. The other configuration is termed EDES in which the first stage of the evaporator is fed by ejector discharge and the second stage is fed by ejector suction. Simulations models are developed for these configurations and simulation results are analyzed to compare the two configurations. Compressor frequency is varied during simulations from 45 Hz to 80 Hz (78% increase). With that increase in compressor frequency, the cooling capacity increases for both stages of the two-stage evaporator. For GFES configuration, it is observed that the cooling capacity of the first stage increases by 86% and the cooling capacity of the second stage increases by 38%. For EDES configuration, the cooling capacity of the first stage increases by 86% and the cooling capacity of the second stage increases by 35%. Results are also analyzed to compare the overall COPs of the two configurations. It is observed that the COP of the GFES configuration is slightly higher compared to the EDES configuration. In addition, results show that the integration of the two-stage evaporator enhances the overall performance as the cooling capacity is shared between the two stages and the suction pressure of the compressor is elevated by utilizing the ejector.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support received from the national research project: CoolFish (NFR project No. 294662) funded by the Research Council of Norway.

REFERENCES

Dassault Systems, DYMOLA Systems Engineering. Available online: https://www.3ds.com/products-services/catia/products/dymola/

Hafner, A. 2018. Latest CO_2 refrigeration trends, Proceedings of the Atmosphere Europe event Lago di Garda, Italy, 19-21.11.2018

Hafner, A., Hazarika, M.M., Lechi, F., Zorzin, A., Pardiñas, Á.Á., Banasiak, K., 2022. Experimental investigation on integrated two-stage evaporators for CO_2 heat-pump chillers. in: 15th IIR-Gustav Lorentzen Conference on Natural Refrigerants.

Hazarika, M.M., Bengsch, J., Hafsås, J., Hafner, A., Svendsen, E.S., Ye, Z., 2022. Integration of gravity-fed evaporators in CO_2 based heat-pump chillers, in: 15th IIR-Gustav Lorentzen Conference on Natural Refrigerants.

Karampour, M., Sawalha, S., 2018. State-of-the-art integrated CO_2 refrigeration system for supermarkets: A comparative analysis. Int. J. Refrig. 86, 239–257.

Lorentzen, G., 1968. Evaporator design and liquid feed regulation. J. Refrig. (November December).

Modelica. The Modelica Association. Available online: https://modelica.org/

Tosato, G., Girotto, S., Minetto, S., Rossetti, A., Marinetti, S., 2020. An integrated CO_2 unit for heating, cooling and DHW installed in a hotel. Data from the field. J. Phys. Conf. Ser. 1599.

TLK-Thermo GmbH. TIL Suite Thermal Systems. Available online: https://www.tlk-thermo.com/index.php/en/software/til-suite