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| Department of Mechanical and Structural System Engineering | ID | 079103 | Advisor | Masafumi Nakagawa<br>Kenzo Kitamura<br>Takashi Suzuki |
|---|---|---|---|---|
| Name | Marasigan Ariel Roxas | | | |



| Title | Experimental and Computational Investigation of High-Speed Two-Phase Ejector Using $CO_2$ |
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(800 words)


A long term solution for global warming is now inevitable to mitigate the dilemma of climate change. Two of the most effective solutions are to increase the efficiency of a system or device and to use natural working fluids. These approaches of improving performance while considering environmental effects are the main motivations of this study. The HVAC industry is one of the fields which largely affect the environment such that the shift from fluorocarbon-based to natural refrigerants is inevitable. $CO_2$ is one of the most promising natural alternatives but it yields significant disadvantages when utilized in a conventional expansion system. An ejector can improve the performance of a $CO_2$ refrigeration system by recovering the energy lost during expansion which improves the viability of natural refrigerant $CO_2$. In this research, the use of two-phase ejector for expansion work recovery with emphasis on its application for transcritical $CO_2$ refrigeration was analyzed experimentally and numerically.

The experimental analysis was carried out at different system setup, at wide range of operating pressure and temperature, and for different ejector designs with emphasis on mixing geometry which had a rectangular cross-sectional area. Experimental data were gathered for ejectors with varying mixing lengths and cross-sectional area, and using ejector system with different lengths of internal heat exchanger (IHX). All of the experiments were carried out using gas cooler pressure, gas cooler outlet temperature and evaporator temperature as control parameters. Experimentation was also performed for conventional system with similar setup and operating conditions to calculate the improvement in performance. In all of these experimental investigations, the results have shown the significant effect of motive nozzle inlet pressure and temperature, and the relatively minimal effect of suction inlet condition on the performance of $CO_2$ ejector system. The data has shown that it is beneficial to the performance of the system if the transcritical inlet state of motive nozzle is moved to the left of $CO_2$ *P-h* diagram. The use of IHX significantly improved the performance of the system by allowing a lower motive nozzle inlet temperature. The use of IHX also allowed ejector system to perform more efficiently than conventional system at wide range of operating conditions. On the other hand, the ejectors with mixing length of 5mm and 15mm yielded the lowest and highest ejector efficiency and COP, respectively. The pressure recovery in the ejector with much shorter mixing section did not start until the diffuser. A longer mixing length is needed to improve both pressure recovery and entrainment but a much longer mixing length would have minor change in pressure recovery but it yields significant penalty on entrainment ratio. The experimental results have also shown that a smaller mixing area yields higher efficiency due to its higher pressure recovery and entrainment ratio, but its advantages are limited to lower motive inlet pressure. A larger mixing area is required for higher cooling capacity which can be achieved at higher motive inlet pressure or lower motive inlet temperature but excessive increase in the mixing area considerably decreases the efficiency of the system. The magnitude of motive inlet pressure

where the COP values of 1.5mm-type and 2.5mm-type intersected was directly proportional to the motive inlet temperature. Based on the definition of ejector efficiency used in this study, a more efficient ejector device does not automatically translate to a higher COP of ejector system. In all of the conditions used in this research, the ejector system could provide a maximum COP improvement of up to 35% over conventional system. However, improper sizing of mixing length and mixing area can lower the COP of ejector system by as much as 10%.

The effectiveness of the two-phase ejector is highly dependent on the mixing characteristics of high-speed motive flow and suction flow. The information from experimental data that can be gathered is limited by the complexity of the process inside the ejector. A numerical investigation of this mixing phenomenon was performed at different operating conditions and ejector geometries, and verified with experimental data. The effects of compressibility and mass transfer due to phase change were included. The flow regime was consisted of dispersed droplets in continuous vapor. The numerical results have shown good agreement in comparison with the experimental pressure profile and suction pressure inlet. The pressure recovery profile and its magnitude were largely affected by the motive nozzle inlet conditions while the suction inlet pressure yielded minimal effect on these parameters. The effect of phase change was considerably small while the energy conversion efficiency of the motive nozzle has increased for increasing motive inlet pressure or lower motive inlet temperature which is consistent with the conclusion from experimental analysis. The CFD model has also predicted the presence of recirculation zone which appeared at the diffuser section in most of the cases. The recirculation region has increased for increasing motive inlet pressure or lower motive inlet temperature. The CFD model also predicted larger recirculation zones for ejector with largest mixing area and shortest mixing length which could have contributed on the poor performance of these ejector types when utilized in actual system. This study provides useful information on ejector optimization and offers better understanding of the process taking place inside a high-speed two-phase $CO_2$ ejector. This also contributes in making $CO_2$ as a viable alternative natural refrigerant.