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A Review on CFD Analysis of Ejector Use in Refrigeration System

M.Tech Scholar Nawed Aqbal Khan, Prof. Dr. Ajay Singh, Nitin Barodia
Department of Mechanical Engineering, RITS Bhopal

Abstract- The refrigeration system plays an important role in various applications from households to industries. An ejector refrigeration system is one of the thermal driven refrigeration systems. The cycle of this type of refrigeration system is properly described by the previous works. The thermal driven refrigeration systems are commonly used to reduce fossil fuel usage in electricity production and resolve the global warming problem of carbon dioxide (CO2) production. An ejector refrigeration system has several advantages, including simple design with non-moving parts, low cost of operation, and ease of construction and maintenance. Note that the installation cost of the steam ejector is lower than that of a modern refrigerant ejector. Moreover, water (steam) is the most environmentally friendly substance and cheapest working fluid.

Keywords- CFD analysis, ejector use, refrigeration system

I. INTRODUCTION

The refrigeration system plays an important role in various applications from households to industries. An ejector refrigeration system is one of the thermal driven refrigeration systems. The cycle of this type of refrigeration system is properly described by the previous works (Ruangtrakoon et al., 2011; Ruangtrakoon and Aphornratana, 2019). The thermal driven refrigeration systems are commonly used to reduce fossil fuel usage in electricity production and resolve the global warming problem of carbon dioxide (CO2) production (Sanaye et al., 2019; Yadav et al., 2022). An ejector refrigeration system has several advantages, including simple design with non-moving parts, low cost of operation, and ease of construction and maintenance. Note that the installation cost of the steam ejector is lower than that of a modern refrigerant ejector. Moreover, water (steam) is the most environmentally friendly substance and cheapest working fluid. However, an ejector refrigeration system presents a problem in that the low ejector efficiency (ηej) makes the coefficient of performance (COP) lower than other refrigeration systems. This shortfall encourages many researchers to propose methods to improve the ejector system COP. Generally, the ejector efficiency can be enhanced by increasing entrainment ratio (Rm) and critical condenser pressure (Pcrit) to improve system COP and make the ejector possible in commercial applications. The mass entrainment ratio is a ratio of primary to secondary mass flow rates. The critical condenser pressure is the highest possible condensation pressure, providing the maximum mass entrainment ratio.

The mass entrainment ratio can be improved by designing the proper ejector geometries at the specified operating conditions to increase system COP. Experiments and CFD simulations have been adopted to investigate these appropriate ejector designs. In addition, CFD can assess the ejector performance and reveal the flow phenomena inside the ejector to better understand the entrainment performance and the shear-mixing process. CFD

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simulation has become an important tool to study the ejector refrigeration system. Although CFD simulation is successfully employed to investigate the appropriate ejector design, the theory-based design model is still necessary to obtain the initial ejector design. One of the earliest theory-based design models is the classical 1-D model theory of Keenan (1950). Later, many researchers proposed alternative theory-based ejector design models (Huang et al., 1999; Chen et al., 2013; Petrovic et al., 2018; Kitrattana et al., 2021).

Keenan (1950) assumed constant pressure during the mixing process of primary and secondary fluids for the CPM ejector. After two fluid streams are completely mixed inside the CPM ejector, the presence of normal shock wave results in pressure recovery, thermodynamic loss, and low ejector performance (Chen et al., 2013; Kitrattana et al., 2021). Later, Eames (2002) designed the CRMC ejector to mitigate the thermodynamic loss via a normal shock wave. Due to the diffuser profile used by this method, the velocity and static pressure gradually decrease and increase along the ejector axis, respectively. The flow areas along the CRMC ejector are significantly different from those of the CPM ejector. The CRMC ejector provides two sections, including entrainment region and CRMC method-based diffuser (curved diffuser) (Sutthivirode and Thongtip, 2021). In contrast, the CPM ejector consists of mixing chamber, throat (constant area), and subsonic diffuser. Generally, the ejector area ratios (ARej), which can be defined as a ratio of the cross-sectional area of ejector throat to the cross-sectional area of primary nozzle throat, of these ejectors are different. Due to flow area variation, the significant difference in mass entrainment ratio and condenser pressure (Pcond) of these ejectors encourages some researchers to implement the research based on CRMC ejector design. From the ejector design methods of Keenan (1950) and Eames (2002), the ejector throat diameter and area ratio of the CRMC design are always smaller than those of the CPM ejector under the same working conditions and primary nozzle geometry. The CRMC ejector with a smaller throat diameter provides a lower entrainment ratio and higher critical condenser pressure than the CPM ejector (Kitrattana, 2016; Kitrattana et al., 2017). For the identical area ratio of steam ejector, Kitrattana (2016) and Kitrattana et al. (2017) concluded that the CRMC ejector produced a higher entrainment ratio and identical critical condenser pressure as compared to the CPM ejector. Sutthivirode and Thongtip (2021) also fairly compared these ejectors by using R141b as the working fluid. They confirmed that the CRMC design provided a higher ejector performance than the CPM ejector. However, the critical condenser pressures of these ejectors were slightly different, similar to the previous work on steam ejectors. Due to the advantage in the mass entrainment ratio of the CRMC ejector, many researchers employed CFD to investigate flow and mixing phenomena inside this ejector design (Kumar et al., 2013; Alsafi, 2017; Yadav et al., 2021a). The nozzle exit position (NXP), mixing section length, and diffuser length effects on CRMC ejector performance were numerically investigated (Kumar et al., 2019;

Yadav et al., 2021b). Moreover, Yadav et al. (2021c) represented the supersonic flow inside two-stage CRMC ejector obtained by theoretical and CFD models. Later, Kumar et al. (2022) reported the simulation results that the entrainment of two-stage CRMC ejector was better than that of single-stage ejector.

II. EJECTOR REFRIGERATION CYCLE

The simplest form of a refrigeration cycle (the Carnot cycle) consists of a refrigerant cycling through four components. First, the refrigerant flows through an evaporator where it absorbs energy and changes phase from liquid to vapour. Second, a compressor is used to increase the pressure of the refrigerant. Third, a condenser is used to reject heat from the refrigerant. Fourth, an expansion device is used to decrease the pressure of the refrigerant to the pressure desired in the evaporator where the cycle begins again. In most modern refrigeration systems, a mechanical compressor is used as the second component of the Carnot cycle. Supersonic ejectors can provide an alternative method of providing the required compression. Where conventional vapour compression systems generally use electrically powered mechanical compressors, thermal energy from existing processes can be recovered to drive the ejector. A schematic illustration of an ejector refrigeration system is shown in Fig. 1.

As illustrated in Fig. 1, ejectors generally consist of a primary fluid that flows through a converging-diverging nozzle, exhausts into a chamber in which there are secondary inlets and a single outlet. In regular operation, the primary fluid is vapourized in the generator and accelerated to supersonic velocities in the converging-diverging nozzle. The supersonic primary flow exits the nozzle at low pressure and entrains a secondary flow of vapour from the evaporator. The two streams mix, and a series of shock waves result that reduce the flow to sub-sonic velocities. The combination of the shock waves and of the sub-sonic flow through the diffuser increase the pressure of the flow to that found at the condenser.

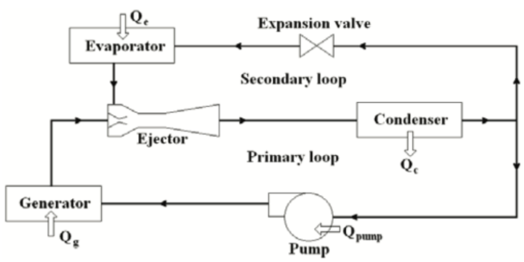

Figure 1: A basic ejector refrigeration cycle

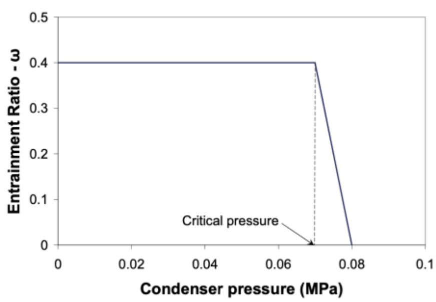

Figure 2: Ejector characteristics

III. PAST STUDIES

Yu et al. (2022) proposed a design method for R1234yf ejectors based on the gas dynamic method and optimizes the geometrical parameters including the area ratio (AR) and nozzle exit position (NXP) to improve its performance through the control variable optimization algorithms. Based on the validated simulation model, the results show that the entrainment ratio increases initially and then decreases with the increase in AR and NXP, respectively; the AR has a significant effect on the shock wave position in the mixing chamber and the NXP can directly influence the expansion state of motive fluid; the ejector performance increases by about 17% over the initial entrainment ratio by the control variable optimization algorithms. This work can guide the R1234yf ejector design and promote the development of the ERS with environmentally friendly working fluids.

Mikielewicz, D., et al. (2023) Supersonic ejectors are broadly utilized in a extend of applications such as aviation, impetus, and refrigeration. The essential intrigued of this think about is to set up dependable hydrodynamics demonstrate of a supersonic ejector, which may be amplified to refrigeration applications. From the early 1900s, Supersonic Ejectors have been utilized in cooling/refrigeration applications. This study shows the results of computational fluid dynamics (CFD) simulations of a supersonic ejector for use in a refrigeration system. The proposed model was applied to a geometry corresponding to an experimental apparatus that operates using R141b, R152a, R134a. The impact of varying operating conditions pressure, velocity, density, the temperature was investigated in the different refrigerants. The results show that CFD is a useful tool in the design of ejectors for refrigeration applications.

Manoj and Lijo (2021) Ejector refrigeration system (ERS) are one of the major methods of refrigeration. It finds its maximum application in industries because it makes use of heat energy as input for refrigeration. ERS is also known as steam jet refrigeration because earlier only steam was used as working fluid. But latest developments offer make use of a variety of working fluids. Recent research results show that there is a large scope for improving efficiency and utility of the system with different working fluids. If suitable working fluid is selected, the ERS can make use of low temperature source like solar energy as input source. A large number of numerical and experimental works are actively going on in the field of ERS. The utilisation of computational fluid dynamics (CFD) software like

ANSYS FLUENT has very much simplified the research activities of ERS. The effect of geometric design modifications of major components like nozzle or throat can be easily studied with the help of CFD software. This paper reviews the recent research and development in the area of ERS.

Riaz et al. (2021) described an ejector model for the prediction of on-design performance under available conditions. This is a direct method of calculating the optimal ejector performance (entrain- ment ratio or ER) without the need for iterative methods, which have been conventionally used. The values of three ejector efficiencies used to account for losses in the ejector are calculated by using a systematic approach (by employing CFD analysis) rather than the hit and trial method. Both experimental and analytical data from literature are used to validate the presented analytical model with good agreement for on-design performance. R245fa working fluid has been used for low-grade heat applications, and Engineering Equation Solver (EES) has been employed for simulating the proposed model. The presented model is suitable for integration with any thermal system model and its optimization because of its direct, non-iterative methodology. This model is a non-dimensional model and therefore requires no geometrical dimensions to be able to calculate ejector performance. The model has been validated against various experimental results, and the model is employed to generate the ejector performance curves for R245fa working fluid. In addition, system simulation results of the ejector refrigeration system (ERS) and combined cooling and power (CCP) system have been produced by using the proposed analytical model.

The detailed ejector geometric optimization can be studied by either experimental works or by computational fluid dynamics (CFD). Zhang et al. (2016) conducted CFD investigation for studying the transport processes in ejectors while focusing on quantifying the energy losses. Scott et al. (2008) employed a CFD analysis for ejector designing refrigeration application and investigated the effect of altering the conditions on the entrainment ratio (ER) and critical pressures.

In the study Elbarghthi et al. (2020) CFD simulation was conducted to model a 2-D axisymmetric supersonic ejector using NIST real gas model integrated in ANSYS Fluent to probe the physical insight and consistent with accurate solutions. HFOs (1234ze(E) and 1234yf) were used as working fluids for their promising alternatives, low global warming potential (GWP), and adhering to EU Council regulations. The impact of different operating conditions, performance maps, and the Pareto frontier performance approach were investigated. The expansion ratio of both refrigerants has been accomplished in linear relationship using their critical compression ratio within 0.30% accuracy. The results show that R1234yf achieved reasonably better overall performance than R1234ze(E). Generally, by increasing the primary flow inlet saturation temperature and pressure, the entrainment ratio will be lower, and this allows for a higher critical operating back pressure. Moreover, it was found out that increasing the degree of superheat for inlet primary flow by 25 K improved the entrainment ratio by almost 20.70% for R1234yf. Conversely, increasing the degree of superheat to the inlet secondary flow has a relativity negative impact on the performance. The maximum overall ejector efficiency reached was 0.372 and 0.364 for R1234yf and R1234ze(E) respectively. Comparing the results using ideal gas model, the ejector entrainment ratio was overestimated up to 50.26% for R1234yf and 25.66% for R1234ze(E) higher than using real gas model.

Suvarnakuta et al. (2020) investigated the performance of the steam ejector used in refrigeration systems to increase operational flexibility and COP. A 2D-axisymetric model of a two-stage ejector (TSE) was developed and its performance was compared to that of the commonly used single-stage ejector. The SST k-omega (k-ω-sst) model was applied as a turbulence model. In the simulation, the TSE was analyzed using generator temperatures between 100 and 130°C and evaporator temperatures between 0 and 15°C, as in a previous study. The CFD simulation results showed that the TSE provided high entrainment ratios up to 77.2% while showing a marginal decrease in the critical back pressure up to a maximum value of

21.9%. Therefore, it can be concluded that the TSE can significantly benefit refrigeration systems requiring high refrigerating capacity while maintaining a slightly low condensing pressure.

Karthick, S. K., (2018) presents the results of computational fluid dynamics (CFD) simulations of a vapor-jet ejector operating with R134a as the working fluid. The impact of varying operating conditions on ejector performance is presented. Also considered in this study is the impact of varying three geometrical parameters on ejector performance: the mixing section length and radius, and the primary nozzle exit radius (representative of the velocity of the motive stream). The results of this study show that CFD is a useful tool in the design and optimization of ejectors for refrigeration devices.

Geng, Lihong, (2019) An ejector refrigeration (ER) system using exhaust waste heat of a heavy vehicle engine is investigated. A program is developed using engineering equation solver software and it is used to make the calculations of the system. The system is taking all the efficiencies of system's components into account. Refrigerants R134a and R245fa are used for the comparative simulation of the system. The pressure at the exit of the pump is varied from 6 to 14 MPa and 3 to 10 MPa for R134a and R245fa, respectively. It can be concluded that COP (coefficient of performance) of the system gradually increases with the increase in pump exit pressure. Results show that, the performance of the system would be higher if R245fa is preferred rather than R134a with the given operating conditions.

IV. CONCLUSION

In conclusion, the review of Computational Fluid Dynamics (CFD) analysis in the context of ejector utilization within refrigeration systems sheds light on the intricate and dynamic nature of the thermal processes involved. The detailed examination of various studies reveals that CFD serves as a powerful tool in understanding the fluid dynamics and heat transfer mechanisms within ejectors, offering valuable insights into their performance and efficiency. Through simulations and analyses, researchers have been able to optimize ejector designs, enhance refrigeration system efficiency, and mitigate operational challenges. The comprehensive exploration of CFD applications underscores its significance in advancing the understanding of ejector-based refrigeration systems, paving the way for more sustainable and energy-efficient solutions in the realm of thermal engineering. As the field continues to evolve, the integration of CFD techniques will likely play a pivotal role in shaping the future of ejector technology within refrigeration, ensuring advancements that contribute to both environmental sustainability and enhanced system performance.

REFERENCES

1. Yu, M., Wang, C., Wang, L., & Zhao, H. (2022). Optimization Design and Performance Evaluation of R1234yf Ejectors for Ejector-Based Refrigeration Systems. Entropy, 24(11), 1632.
2. Mikielewicz, D., Amiri, M., Klugmann, M., & Mikielewicz, J. (2023). A novel concept of enhanced direct-contact condensation of vapour-inert gas mixture in a spray ejector condenser. International Journal of Heat and Mass Transfer, 216, 124576.
3. Manoj, P. J., & Lijo, V. (2021, March). Recent developments in ejector refrigeration system. In IOP Conference Series: Materials Science and Engineering (Vol. 1114, No. 1, p. 012046). IOP Publishing.
4. Riaz, F., Yam, F. Z., Qyyum, M. A., Shahzad, M. W., Farooq, M., Lee, P. S., & Lee, M. (2021). Direct Analytical Modeling for Optimal, On-Design Performance of Ejector for Simulating Heat-Driven Systems. Energies, 14(10), 2819.
5. Zhang, K., Chen, X., Markides, C. N., Yang, Y., & Shen, S. (2016). Evaluation of ejector performance for an organic Rankine cycle combined power and cooling system. Applied energy, 184, 404-412.
6. Elbarghthi, A. F., Mohamed, S., Nguyen, V. V., & Dvorak, V. (2020). CFD based design for ejector cooling system using HFOS (1234ze (E) and 1234yf). Energies, 13(6), 1408.
7. Suvarnakuta, N., Pianthong, K., Sriveerakul, T., & Seehanam, W. (2020). Performance analysis of a

two-stage ejector in an ejector refrigeration system using computational fluid dynamics. Engineering Applications of Computational Fluid Mechanics, 14(1), 669-682.

8. Karthick, S. K., Rao, S. M., Jagadeesh, G., & Reddy, K. P. J. (2018). Experimental parametric studies on the performance and mixing characteristics of a low area ratio rectangular supersonic gaseous ejector by varying the secondary flow rate. Energy, 161, 832-845.
9. Geng, Lihong, Huadong Liu, and Xinli Wei. "CFD analysis of the flashing flow characteristics of subcritical refrigerant R-134a through converging-diverging nozzles." International Journal of Thermal Sciences 137 (2019): 438-445.