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Design of Ejector Parameters and Geometry for Ejector Expansion Refrigeration System- A Review

#1Akshay R. Ghotkar, #2Prof. Nitin V. Sali

1akshayghotkar2@gmail.com
2nvsali@rediffmail.com

#12Mechanical Engineering Department, Shivaji University, Kolhapur,
Government College of Engineering, Karad, Maharashtra, India

ABSTRACT

From last few decades, the use of efficient ejector in refrigeration systems has been paid a lot of attention. This paper presents literature studies on recent development in ejector cooling system and also the enhancement of the coefficient of performance. Some of researches have conducted and categorized in simulation and mathematical modelling of the ejector, geometrical parameters and operation conditions optimization. Most of the experimental work which have been done in last two decades are insufficient compared with simulation modelling results. Hence, there is need of more experimental studies and big scale work in order to come out with good results in real application.

Keywords—working fluid, cooling system, operating conditions ejector design, area ratio-geometry,

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I. INTRODUCTION

The ejector show in fig.1 is a component that expands a high-pressure primary liquid refrigerant to absorb a secondary vapour refrigerant at a pressure slightly above the low pressure reached by the primary substance. In this refrigeration cycle, the two-phases of refrigerant are identical, so both flows mix together, and there is pressure increase due to the change of the flows momentum. An ejector is made up of two components a motive nozzle and a body. The nozzle is having convergent divergent shapes with a throat that defines the primary refrigerant mass flow rate. The role of the nozzle is to create a low-pressure flow of liquid refrigerant with high momentum, so it converts the pressure potential energy into kinetic energy.

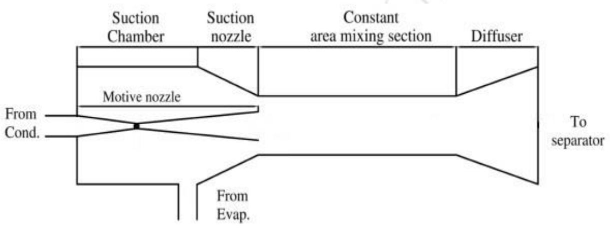

Fig. 1 Ejector Geometry

Fig. 2 shows a basic vapour compression refrigeration system. It mainly consists of a compressor, an evaporator, a condenser, expansion device, ejector and separator. In this system, high pressure (primary fluid) liquid refrigerant flows through the motive nozzle of the ejector and entrains vapour from evaporator at low pressure (secondary fluid). The primary and secondary fluid then mix in the mixing section and recover a pressure in the diffuser.

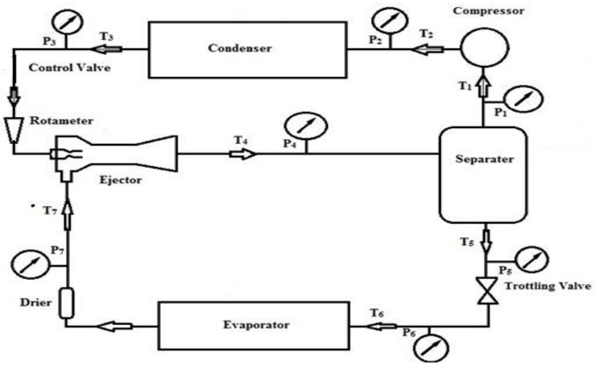

Fig. 2 Ejector Expansion Refrigeration system

The combined fluid flows to the separator. And then separates liquid and vapour. Vapour flows through compressor and then through condenser. Then liquid flows through the expansion device and enters the evaporator, where it is evaporated to vapour. The vapour is finally entrained into the ejector again, thus finishing the ejector refrigeration cycle.

II. LITERATURE REVIEW

G. Grazzini, A. Milazzo, D. Paganini [1]presented a design procedure for ejector compression refrigeration system, based on a one-dimensional simulation. Heat exchangers were included in the calculation, accounting for temperature differences between thefluids and for pressure losses. The ideal gas assumption, which is quite common in the literature concerning ejector systems, was avoided in this paper. Furthermore, the supersonic diffuser was designed with a continuous profile,without cylindrical piece, controlling the variation of momentum along the flow path and accountingfor friction. At design conditions, this should reduce the irreversibility due to the normal shock.A comparison between different operating fluids is presented and R245fa was selected. The results of thedesign procedure and the expected performance, in terms of first and second law efficiency, werepresented.

B.J. Huang*, J.M. Chang, C.P. Wang, V.A. Petrenko [2]presented a 1-D analysis for the prediction of ejector performance at critical-mode operation. In constant-area section of the ejector, constant pressure mixing was assumed. The entrained flow at choking condition was analyzed. They also carried out an experiments using 11 ejectors and R141b as the working fluid to verify the analytical results with experimental results. The test results were used to determine the coefficients such asη_p,η_s, ϕ_p and ϕ_m defined in the 1-D model by matching the test data with the analytical results. The1-D analysis using the empirical coefficients can accurately predict the performance of the ejectors was proved.

Abdelouahid Dahmani[a], Zine Aidoun[b], Nicolas Galanis[a,*][3] presenteda design methodology for simple ejector refrigeration systems applied for a particular combination of four parameters like generator, ejector, condenser and the evaporatorof fixed cooling capacity operating with fixed temperatures. The existence of optimum values for the refrigerant pressure in the generator (P_G) and the temperature difference in the heat exchangers (Δ_T) which minimize the total thermal conductance of the system were established.These optimum values of P_G and Δ_T were particularly interesting since they yield high values for the coefficient of performance and the exergetic efficiency of the system. They had been determined for four refrigerants (R134a, R152a, R290, and R600a). For first approximation an objective function is proportional to the product of the capital and operational costs was defined and used to compare the performance of the system with above refrigerants.

K. Cizungu[a,*], M. Groll[a], Z.G. Ling[a] [4] formulateda one dimensional compressible flow model, which was based on the control volume approach, and in a jet cooling system it optimize two-phase ejectors in steady-state operation with particular reference to their deployment. The working fluid can be both single-component (NH_3) and two component (NH_3–H_2O). The developed model takes into account the duct effectiveness, wall friction, momentum loss, ejector geometry, shock waves as well as the acceleration of the induced flow in the conical part of the mixing section. The usual assumption of mixing at constant pressure over the mixing chamber cross section was not that of a constant mixing chamber cross section were made. A comparison with available experimental data as well as other computation methods from the literature was presented. The performance was influenced by the ejector geometry.

DA-WEN SUN etal. [5] reviewedthat refrigeration and air-conditioning units powered by low-grade thermal energy have economic advantages. However, the current market is dominated by electrically worked mechanical vapour-compression systems. Ejector-refrigeration cycles offer a low-cost and reliable option for saving low-grade thermal energy. Recent studies were shown that for achieving optimal performance variable geometry ejectors play an important role. Unfortunately, in the public domain the detailed design information is not available. Here, we analyses the effect of ejector geometries on performance. Technical data including flow rates, entrainment ratio and ejector geometry were provided for a 5kW steam-jet refrigerator. These data may serve as guides in designing ejector-cycle refrigerators with other cooling capacities.

Praitoon Chaiwongsa, Somchai Wongwises* [6]investigatedthe performance of the refrigeration cycle using a two-phase ejector as an expansion device experimentally. Refrigerant R-134a was used as working fluid. Motive nozzles having three different outlet diameters were tested. New experimental data on external parameters that have never been seen before were presented. Effect of heat sink and heat source temperatures on the coefficient of performance and various relevant parameters were presented i.e. primary mass flow rate of the refrigerant, secondary mass flow rate of the refrigerant, recirculation ratio,compressor ratio, average evaporator pressure, discharge temperature and cooling capacity. The effects of size of the motive nozzle outlet on the system performance were also discussed.

H. Kursad Ersoy, Nagihan Bilir Sag [7]investigatedthe use of an ejector as an expansion device instead of an expansion valve for expansion work recovery in a vapor-compression cycle was experimentally. Under the same external conditions,the coefficient of performance (COP) values for both conventional and ejector systems were experimentally investigated. It was observed that, in the conventional system the pressure drop picks up to 133 kPa although the drop in the refrigerant pressure in the evaporator of the ejector system was almost negligible. Depending on the operating conditions,in the ejector it was found that the work recovery was between 14% and 17%. It was also found that the refrigeration system with an ejector as the expander exhibited a COP that was 6.2%–14.5% higher than that of the conventional system. The approximated error were found within 10% when experimental results were compared with theoretical results.

Praitoon Chaiwongsa, Somchai Wongwises* [8]presented the experimental study of the performance of the two-phase ejector expansion refrigeration cycle. In this study, three two-phase ejectors were used as an expansion device in the refrigeration cycle. Also presented the effects of throat diameter of the motive nozzle, on the coefficient of performance, primary mass flow rate of the refrigerant, secondary mass flow rate of the refrigerant, recirculation ratio, average evaporator pressure, compressor pressure ratio, discharge temperature and cooling capacity, which have never before appeared in open literature. The effects of the heat sink and heat source temperatures on the system performance are also discussed.

Somjin Disawas, Somchai Wongwises* [9]presentedthe new experimental data on the performance of a never before seen two-phase ejector refrigeration cycle. In this refrigeration cycle, a two-phase ejector was used as an expansion device. The results were compared with those of the conventional refrigeration cycle (CRC). The effects of heat sink and heat source temperatures on the system performance were discussed. Over the whole range of experimental conditions the results show that the coefficient of performance of the TPERC is higher than that of the CRC. This is due to a higher refrigerant-side heat transfer coefficient in the evaporator, resulting from the higher refrigerant mass flow rate passing through the evaporator. However, the heat sink temperature increasesthe increase in COP becomes relatively smaller.

M. Hassanain, E. Elgendy, M. Fatouh [10] presenteduse of a two-phase flow ejector as an expansion device in vapor compression refrigeration systems is one of the efficient ways to enhance its performance. This work aims to design a constant-area two phase flow ejector and to evaluate performance characteristics of the ejector expansion refrigeration system working with R134a. A simulation program was developed and effects of operating conditions and ejector internal efficiencies on the system performance were investigated using EES software. Comparison between published experimental data and present data revealed that the developed model can predict the system COP with a maximum error of 2.3%. As evaporation temperature changed from -10°C to 10°C, the system COP increased by 87.5%. Finally, the correlations regarding ejector main diameters as a function of operating conditions, system cooling capacity and ejector internal efficiencies were reported.

Khaled Ameur, Zine Aidoun, Mohamed Ouzzane [11]presented a modeling procedure of liquid-vapour ejectors for refrigeration, heat pumps and several other potential industrial applications. The modeling relies on a thermodynamic approach where properties of real refrigerantsandconservation equationswere used.Refrigerant liquid and vapour phases were assumed to be in homogeneous equilibrium.Fluid flow in the ejector is two-phase and compressible. The design of primary and secondary nozzles was performed by maximizing the mass flow rate at their respective throats, thus the approximate determination of the velocity of sound and the Mach number in a two-phase flow environment. In the mixing chamber, wall friction is taken in the momentum balance equation. The result of computations by the present model matches fairly with experimental data from a dedicated test bench as well as with those found in the available literature. Computations were performed using this model for an ejector in typical conditions of a refrigeration application.

Nagihan Bilir and H. Kursad Ersoy[*] [12]investigatedthe performance of a vapour compression system that uses an ejector as an expansion device. In the analysis, a two-phase constant area ejector flow model was used. R134a was selected as the refrigerant. According to the obtained results, there are different optimum values of pressure drop in the suction chamber, ejector area ratio, ejector outlet pressure and cooling coefficient of performance (COP)for any operating temperature. The improvement ratio in COP rises whereas ejector area ratio drops, when the difference between condenser and evaporator temperatures increases. The minimum COP improvement ratio in the investigated work was 10.1%, while its maximum was 22.34%. Even in the case of an off-design operation, the COP of a system with ejector is higher than that of the basic system.

Jianyong Chen, Hans Havtun*, Björn Palm [13]presentedan ejector model to determine the optimum performance as well as obtaining the design of an area ratio of an ejector in a refrigeration system. Auxiliary dynamic equations andworking fluid properties were used to model the processes in the ejector. In the mixing chamber, the normal compression shock was considered. To validate the model experimental data from literature were used, and the agreement with the model at different optimum operating conditions was very good. The deviation between the experimental data and the model at non-optimum conditions was slightly larger.A study shows that the working conditions for refrigerants R123 and R141b indicates that the condenser temperature has more influence on area ratio and the entrainment ratio in the ejector than the generator and evaporator temperatures on the area ratio. As operating conditions are changed area ratios need to keep up the pace with the variation of entrainment ratio. To ensure that the ejector refrigeration system operates at its optimum conditions a variable-geometry ejector seems a very promising alternative. Ejector efficiencies play a very important role in this model, and the influence of the efficiencies on the ejector performance was investigated.

Szabolcs Varga[a], Armando C. Oliveira[a,]*, Bogdan Diaconu[a.b] [14]determined ejector efficiencies for the primary nozzle, suction, mixing and diffuser for the first time by using an axi-symmetric CFD model. Water was considered as working fluid and the operating conditions were selected in a range that would be suitable for an air-conditioner powered by solar thermal energy. Ejector performance was estimated for constant section area ratios and different nozzle throat. Depending on operating conditions,the results indicated the existence of an optimal ratio. Ejector efficiencies were calculated for different operating conditions. It was found that while nozzle efficiency can be considered as constant, the efficiencies related to the suction, mixing and diffuser sections of the ejector were depend on operating conditions.

Jahar Sarkar[*] et al. [15]presented thermodynamic analyses and comparison of ammonia, propane and isobutane based vapour compression refrigeration cycles using constant area mixing ejector as an expansion device. Optimization of ejector geometric parameter based on the performance improvement and maximum cooling COP for different operating conditions was studied. Results show that the optimum geometric parameter increases with decrease in condenser temperature and increase in evaporator temperature, whereas the COP improvement over basic expansion cycle increases with decrease in evaporator temperature and the increase in condenser temperature. Expressions for optimum ejector geometric parameters were developed, which offer useful guidelines for operation and optimal design. Study shows that the COP improvement as well as optimum parameters using ejector as expansion device are strongly dependent on the operating conditions as well as therefrigerant properties. The optimum geometric parameter was minimum for isobutane, whereasmaximum for ammonia. Using ejector as an expansion device, isobutane yields maximum COP improvement of 21.6%, propane (17.9%) and ammonia (11.9%).

K.O. Shestopalov[a, b,*], B.J. Huang[a], V.O. Petrenko[a, b], O.S. Volovyk[a] [16]presentedthe ejector refrigeration machine (ERM) offers several advantages over other heat-driven refrigeration machine, including simplicity in design and operation, high reliability and low installation cost. It enable its wide application in the refrigeration. In this paper the ejector refrigeration cycle performance and theoretical analysis of ejector design was presented. ERM performance characteristics is stronglydepend on the operating conditions, the efficiency of the ejector used, and the thermodynamic properties of the refrigerant used. A 1-D model for the prediction of the entrainment ratio, and an optimal design for ejectors with cylindrical and conical-cylindrical mixing chambers are presented. It is necessary first of all to improve the performance of the ejector, in order to increase ERM performance values.

Krzysztof Banasiak[b,*], Michał Palacz[a], Armin Hafner[b], Zbigniew Bulinski[a], Jacek Smołka[a], Andrzej J. Nowak[a], Adam Fic[a][17] presented a CFD-based numerical analysis of the flow irreversibility in R744 ejectors. A validated CFD was used to investigate three cases that were differentiated by the massflow rate per unit area (mass flux) that passed through the mixer, which represented threedissimilar flow patterns. To evaluate the ejector performance a new factor wasproposed based on the reference entropy increase in aclassic expansion valve. The mixer mass flux was found to significantly affect the ejectorperformance. To assess thecontribution of the local irreversibilities to the overall entropy increasean original approach was introduced. In addition, the influence of the mixer diameter and length on theejector performance was numerically analyzed, which showed that the effects of bothgeometric parameters are very important. In the conditions considered, bothenlargement of the mixer cross section area by 33.3% as well as shortening the mixerlength by 17.4%resulted in the increase of the overall entropy growth rate by5.4% and8.9%, respectively.

Neal Lawrence, Stefan Elbel*[18] presentedthe comparison between the standard two-phase ejector refrigeration cycle withless commonly considered two-phase ejector refrigeration cycles and also compared a liquid-vapor separator to two alternate, as well as to a conventional cycle with an expansion valve. An analytical comparison of the different ejector cycles was presented. Also theoretical COP was presented and used to show that they have the same theoretical COP. Numerical models were used to further compare the cycles in terms of availability destruction andtheoretical COP. The results show that the standard two-phase ejector cycle has higher Second Law efficiency andlower availability destruction than the alternate ejector cycles despite having the same theoretical COP. Some advantages and disadvantages of the different ejector cycles that are not accounted for in the theoretical COP were discussed in this paper.

J.M. Abdulateef*, K. Sopian, M.A. Alghoul*, M.Y. Sulaiman [19] reviewed the literature on solar-driven ejector refrigeration systems and to give useful guidelines regarding operating principles and background of ejector. The development of solar-driven ejector refrigeration systemshistory and recent progress were reported. It shows that solar-driven ejector refrigeration technologies are not only can serve the needs for cooling requirements, but also can meet demand for energy conservation and environment protection. For these reasons, to solve the crucial points of the research activities in this sector are still increasing that make these systems not yet ready to compete with the well-known vapour compression system. However, a lot of research work still needs to be done for the replacement of conventional refrigeration machines andfor large-scale applications in industry.

Jahar Sarkar et al. [20]revieweda literature on two-phase ejectors and their applications in vapour compression refrigeration and heat pump systems. Also summarised geometry, modelling and operation of ejector, and effects of various geometric and operatingparameters. Also categorised the refrigerant varieties on the ejector performances as well as performance characteristics of both subcritical and trans-critical vapour compression systems with various cycle configurations. Moreover, system control andoptimal operation to get maximum performance by using ejector as an expansion device were also discussed. However, a lot of research work still needs to be done for large-scale applications in industry and for the replacement/modification of heat pump machines andconventional refrigeration. Also discussed the performance improvement along with several advantages in installation, operation and control with ejector stimulates the commercialization of ejector enhanced refrigeration and heat pump systems.

TABLE I

Two phase flow ejector length and angles (Refer fig.3)

Reference	**Refrigerant**	$\frac{L_{m1}}{D_{m1}}$	$\propto_{m1}$	$\frac{L_{m2}}{D_{mn,e}}$	$\propto_{m2}$	$\frac{L_{sn}}{D_{sn}}$	$\propto_{sn}$	$\frac{L_{ms}}{D_{ms}}$	$\frac{L_d}{D_d}$	$\propto_d$
Banasiak et al. (2014)	R744	1.59	15	-	1	-	21	10	4.3	2.5
Lee et al. (2014)	R744	1.53	15	4.8	2	-	-	12	5.2	3
Liu et al. (2012)	R744	-	-	-	-	-	-	6.5	2.7	7
Nakagawa et al. (2012)	R744	-	-	14.4	0.5	-	-	6	3.8	5.2
Disawas and Wongwises (2004)	R134a	1	23	8	2.3	1	18.4	11	4	3.8
Chainwongsa and Wongwises (2008)	R134a	1	23	8	2.3	1	18.4	11	4	3.8
Chainwongsa and Wongwises (2007)	R134a	1	23	11.11	1.3	1	18.4	11	4	3.8

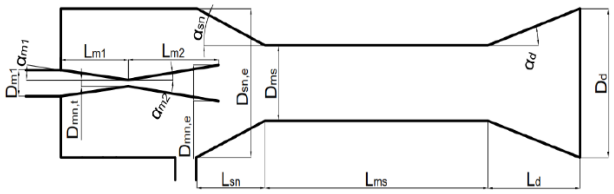

Fig.3 Ejector parameters

IV CONCLUSION

1. This paper presents the principles for the recent enhancements and development and ejector design in ejector refrigeration technologies.
2. Research on ejector refrigeration systems over the last two decades involve system modelling, design, and system optimization.
3. The optimal geometry parameters of ejectors depend on the operating conditions andworking fluids.
4. Other parameters such as the length of the constant area mixing section and the converging angle of the constant pressure mixing section are less studied because of their small influence on ejector performance.
5. The research and development are focuses on feasibility enhancement and performance by combining the ejector refrigeration system with other systems.

The following conclusions are obtained on the basis of the reviewed studies:

1. Ejector refrigeration systems are have low investment costs and mechanically simple. However, such refrigeration systems have relatively low COP than other conventional refrigeration technologies.
2. At any given evaporator, condenser, and generator temperatures, only one unique geometry will result in the highest COP and entrainment ratio of the ejector.
3. Dry fluid refrigerants, such as butane, isobutane,R113, R114, and R141b, require less excessive energy for superheating than wet fluids and yield better performance and isentropic fluids at the same operating temperatures.
4. The area ratio between primary nozzles is an important non-dimensional factor that affects ejector performance. The optimum area ratio depends on the refrigerant type andoperating conditions.
5.With increasing generator temperaturethe optimum value of the primary nozzle diameter decreases.
6.The optimum primary nozzle position or converging angle cannot be predefined to meet all operating conditions. Whereas from the design point the operating conditions are different. To maximize ejector performance nozzle exit position should be adjusted.
7.Constant area section length has no effect on entrainment ratio.
8.Variable area geometry ejectors based on CRMC methods are operate at high critical condenser pressures.

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