

A Comprehensive Study of an Ejector System and Its Applications: A Review



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Abstract The review aims to give a writing overview of the examination endeavors achieved in the case of an ejector geometry framework. An ejector is a device used to increase the delivery rate of a fluid. They are used in the refrigeration cycle and the rocket engines as well. It is difficult to understand the flow characteristics of the fluids and the thermodynamic properties of the streams. They can be understood using some computational techniques and tests. The mathematical models for the flow of the fluids inside the ejector are least observed since it is difficult to investigate a fast-moving stream of the fluids inside the ejector. Ejectors have many applications, where heat transfer takes place at a higher rate and helps create the vacuum. This review paper examines the construction and working, applications, and new advances related to the ejectors. Furthermore, it is observed that there is a special need to investigate various aspects of the ejector.

Keywords Ejector · Working fluids · Geometry optimization · Mathematical modeling · Applications

1 Introduction

A supersonic ejector is used for a broad range of applications in the industries as a compressor. These include desalination, refrigeration, steam turbine, paper making machine, wood drying equipment, etc. The analysis of the flow of the fuels through the section of the ejector is quite complicated when we consider the high-speed flow the motive fuel and its mixing with the secondary fuel or the ambient fluid when we consider the effects of compressibility at higher Mach numbers. Hence, the ejector is basically a flow device that does not have any moving part [1]. The ejectors were first used in the vacuum braking systems of the railway trains, which date back to the eighteenth century. The ejector was driven by the waste steam from the steam engine, which was used to maintain vacuum partially in the braking cylinders fitted

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161

to the cartridges. The ejector has always had the potential to be used in various areas of application because of its ability to use the extra gas as a driving fluid and its simple design. Therefore, the ejectors are extensively found and their uses are seen in various applications in the industries. But, due to not being fully understood and the fact that a slight change in the geometry of the ejector and the working parameters will result in the difference in the performance characteristics, new designs of the ejectors are used which are based on the existing design [2]. The ejectors are used in the industries in numerous ways, i.e., to create a vacuum at different levels by using them in stages, and they can be used as transfer pumps as well as mixing pumps. The important reason that the ejectors are preferred over regular pumps is that they have a very simple and sturdy design. In addition to that they hold the capacity to handle extensive volumes of gases in a relatively limited amount of size of equipment. The ejectors also require less maintenance as the operation is simple. The ejector works upon the principle of compressing and transporting a pressurized fluid from the suction point to the exhaust point. The pressure of an actuating fluid or the primary fluid is brought to the level of that of the secondary fluid. During this expansion, the velocity of the primary fluid is increased by accelerating it by the influence of the nozzle shape as the velocity with which it enters is a negligibly small orifice. Due to the increased velocity of the primary fluid, a region of low pressure is induced in the suction chamber, which helps mix the fuels. As the mixing takes place, the primary fuel decelerates, and the velocity of the secondary fuel increases. This mixture is introduced into the diffuser and is decelerated rapidly because of the neck of the ejector. Here, it is compressed to the exit pressure [3]. The function of subparts of the ejector (refer to Fig. 1) is described below.

- Primary fluid chest: This is a connecting chamber that is used to introduce the pre-eminent high-pressure fluid into the nozzle section of the ejector.
- Suction chamber: It is also called the secondary inlet through which the secondary fluid is taken in because of the pressure difference created by the expansion of the primary fluid. In the cases, where a compact design and cost-cutting are

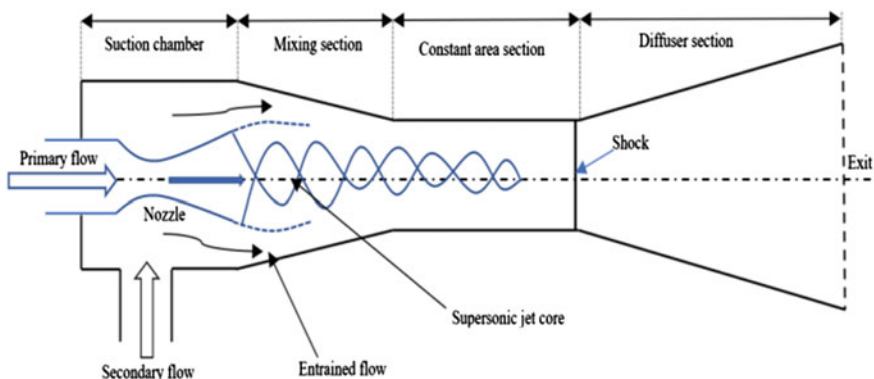


Fig. 1 Ejector system [13]

required, the suction chamber is eliminated. For this purpose, a nozzle and a diffuser connection are incorporated in the vessel or the ejector body that needs to be evacuated. It is so designed that the inlet velocity of the fluid should be lowered, and hence, it will ensure the minimum level of swirl in the other parts.

- **Nozzle:** This main component of the ejector assembly converts the high-pressure primary fluid into a high-velocity stream directed toward the diffuser. Because of the nozzle, the exit velocity and the total flow inside the ejector are controlled. Other dimensions are governed by the guidelines provided by the ESDU, which suggest the appropriate radii for the convergent and divergent sections. Also, the nozzle tip is sharply designed to help the mixing of the two streams.
- **Diffuser inlet:** The inlet section of the diffuser is designed in such a way that it should be able to withstand the high-velocity fluids being converted into high pressure. In this section, the mixing of the motive fluids takes place and is compressed. The best results depend upon the length of the chamber, which enables the mixing of the two streams.
- **Throat:** It is a converging section with a reduced diameter between the diffuser inlet and outlet where the velocity of the fluids is brought down to subsonic. It is at this section where the compression takes place.
- **Diffuser outlet:** The diffuser outlet is the ejector's diverging section, which completes the conversion process of velocity into pressure. Since the velocity of the mixture of fluids is subsonic, the diffuser outlet further reduces the velocity of the fluid to a reasonable level to convert the velocity into the pressure energy completely [4].

2 Compressible Fluid Dynamics (CFD) Analysis

In an ejector refrigeration framework, the ejector works as a blower yet without utilizing any movable parts. The authors prepared a CFD model using an ERS test rig using R134a [5]. The ideal mathematical boundaries and uneven surface of the nozzle were acquired using CFD examinations. The study results showed that the throat and the nozzle should be located closer to each other when designing the ejector since the entrainment portion of the ejector is dependent upon the length of these two parts. Steam ejectors were examined mathematically using various nozzle geometries and CFD strategies. The exhibition of the steam ejectors with five unique nozzle shapes, specifically, square, conelike, curved, rectangular, and cross-formed nozzles, has been thought about under similar conditions [6]. The ratio increment can be accomplished by effective blending because of the connections between the streamwise and the spanwise vortex. Streamwise vortex results in disfiguring and breaking the spanwise vortex because of its strength. Crashes of these vortices in the blending channel at an early stage would increase the mechanical energy and lessen the pressure in the region for the auxiliary stream to go through, which results in a notable reduction of the entertainment ratio and backpressure. This situation must be avoided while designing the nozzles [7]. The two significant boundaries used to

portray the ejector execution are ratio and backpressure. The CFD has proven to be an effective tool for stream field investigation and ejector execution expectations for a long time. Various CFD examinations have been completed to contemplate the impact of ejector calculation on its execution, for example, nozzle exit position, the region proportion of nozzle throat to steady region segment, and the length of consistent region segment [8]. Guillaume et al. [9] worked on the productivity of a fly siphon by utilizing a curved nozzle, yet the nozzle is a combining one, and the wind streams inside the fly siphon at low speed without concerning the compressibility. Chang and Chen [10] tentatively explored a steam-stream refrigeration system utilizing petal and cone-shaped nozzles. Their exploratory outcomes show the COP of the framework with a petal nozzle is superior to that with a funnel-shaped nozzle when worked at bigger region proportions. Narabayashi et al. [11] did exploratory and CFD investigations of stream in single and multi-opening nozzle fly siphons. The productivity of the five-nozzle fly siphon was low because of a low mass-stream proportion fly siphon due to a channel stream obstruction between the nozzle fingers and throat. Recently, a two-stage supersonic ejector system was proposed and analyzed numerically. It was suggested that the two-stage ejector system is more efficient and has better suction power than single-stage ejectors [12, 13].

3 Nozzle Geometry

It can be observed through the computer simulation that the computational fluid dynamics techniques help in the prediction of the performance of the ejector without the use of an actual model and explain some of the facts that limit the performance or working of an ejector. Hence, we can use CFD to analyze the supersonic ejector and the flow process that occur within it. Computational techniques can be advantageous over analytical and experimental techniques since we can obtain results for the flow process of the fluid flowing streams inside the ejector, which is the main study objective while testing an ejector. Since the flow of the primary fluid should be supersonic for the stable operation of the ejector, the flow of the fuel inside the ejector is confined, and the mixing process is complex due to the initial supersonic fluid and subsonic later fluid. The CFD analysis will visualize the flow and provide the mass flow results without affecting the flow process.

The developments in computer technology and hardware and the advancements in software have changed the course of the design of the automobile, airplanes, and ships. Using the commercialized software packages, the design and analysis of the processes have not only saved time and cost but have also allowed the study of systems for controlled experiments, which are difficult to perform. A comparative analysis of CRMC and the conventional nozzle was investigated analytically and numerically. It was found that the flow behavior of fluid inside the CRMC nozzle geometry is in better condition as compared with conventional nozzle [14]. Khan et al. [15] performed a numeric study to optimize micro jets' potency by controlling the initial pressure in a suddenly expanded 2D planar channel. The author carried out the analysis in this

research to design a supersonic C-D nozzle, considering the compressible flow of the perfect gas. The authors here observed the pressure and velocity inside the duct by analyzing different counters and plots. The nozzle is designed so that the total flow is kept constant and due to which the speed of the fluid flowing through it will increase when the section is narrowed. The primary or the motive fluid is isentropic, and during the subsonic flow, the gas is compressible. As the cross-section area decreases at the throat, the state of choked flow is reached, and a sonic velocity of the gas is achieved. As the gas moves further into the increased cross-section, the fluid will start to expand, and the flow will become supersonic. Varga et al. [16] discussed this principle, illustrating that the nozzle controls the characteristics of the fluid flowing through it. The authors analyzed a De-Laval nozzle and explained its concepts and the working of this nozzle. The theoretical analysis was done at different nozzle sections, and the changes in the characteristic flow framework were studied using CFD. A simulation for the shockwave was also prepared using the CFD, and a significant increase in the velocity as well as the temperature and pressure reduction was observed. Dongping Zeng et al. [17] studied a novel drug delivery method known as a needle-free injection (NFI), which involves using a high-speed stream of fluid to deliver a drug into the skin. NFIs are an old strategy that has great potential to become an important drug delivery method. Although they have shown obvious advantages over standard needle injection, they have not gained widespread acceptance due to their unpleasantness. As the diameter of the nozzle gets bigger, the injected depth gets larger, which could cause more bleeding. This causes the wound to widen, which could cause more serious injuries.

The theoretical model has first been proposed to understand the influence of numerous factors on the controllability of spring-powered jet injection. The model proposed various controllability factors for the injection. A study conducted by Chen and Zhou [18] revealed that the maximum pressure that a jet can exert upon the skin is known as stagnation pressure. A similar method was used by Taberner et al. [19] for controlling a prototype jet injector. A custom-made, high stroke linear electromagnetic-force motor was used to control the flow of a drug through a jet injection device. Through this procedure, the researchers were able to improve the efficiency of the drug's injection. The goal was to improve the model by identifying the factors that affect the penetration capability of an injection, but this was not yet possible due to the lack of friction and hydraulic loss in the system. The concept of particle growth and nucleation during the partial expansion of dilute supercritical solutions is presented.

4 Mixing Geometry

This paper portrays an exploratory investigation of a steam-ejector cooler utilizing an ejector with an essential nozzle that could be moved pivotally inside the blending chamber area [20]. The results for the coefficient of execution and cooling limit created by changing the operating conditions of the nozzle were considered. The test

apparatus and technique are depicted, and results are introduced, which unmistakably show the advantage of utilizing a particularly essential nozzle. Smith-Kent et al. [21] stated that the ordinary strong rocket engines have an appropriate fuel grain size and the diameter of the throat of the nozzle for the push. Pintle nozzles have been proposed as a method for giving variable and programmable push inside specific cut-off points. Subsequently, a pintle nozzle can provide a strong rocket engine. This paper audits the one-dimensional investigation to incorporate the conditions expected to be the best for an ejector working in a refrigeration cycle [22]. The considered arrangement gives a more prominent pressure proportion while utilizing a similar measure of essential mass flow. The outcomes obtained show that utilizing the third stage, the ideal gas model used could lose actual significance [23]. The current paper fostered a thermodynamic displaying strategy for ejectors utilized in discharge refrigeration framework [24]. For a fixed-geometry ejector, the cooling limit was observed to be restricted by the condenser pressure. The cooling limit could be improved with a higher set evaporator temperature. Furthermore, with lower condenser pressures, a bigger cooling limit could be accomplished with even lower evaporator pressures [25]. It is hypothesized that the secondary fumes arrive at sonic speed and are successfully choked at some cross-part of the ejector. Standard estimations of spout stream empower the limit of the ejector to be found, and thusly a forecast of steam nozzle cooler execution occurs [26]. In this review, an ejector model was created for the assessment of fume ejector execution. In this model, real gas conditions are thought of. The scope of its applications is not limited to dry fume ejectors as on account of the 1D technique. The proposed model thinks about the energy transfer between the two streams (essential and optional) during their connection in the mixing chamber, until the auxiliary stream is introduced [27]. The CFD investigation was performed for the supersonic stream in the consistent strain blending ejector. The CFD result was approved with test information. From this approval, it can be presumed that CFD reproduction has a decent similarity with test results [28]. This review utilized CFD methods to explore the stream construction and execution of an ejector utilized in a MED framework. The impacts of different forces on the ejector execution were examined. The CFD results were observed to be in good concurrence with the exploratory outcomes [29].

The ideal upsides of two significant ejector geometry boundaries in this work: essential spout exit position and meeting point of blending segment, were examined by CFD procedure. The CFD model was first and foremost adjusted with genuine exploratory information. Afterward, the model design was utilized to create as numerous as 95 distinct ejector calculations and 210 unique geometries. The impacts of the two calculation boundaries on the ejector execution were separately investigated [30]. The thermo-blower in MED-TVC plants ought to be intended for higher release strain. Blending proficiency of a common thermo-blower has a direct effect after entraining pace of low-pressure steam [31]. The observations were made on how the ideal region ratios and COP esteems changed with the differing temperature. The ideal region proportion increases with generator temperature diminish with condenser temperature and are significantly less influenced by the variety in evaporator temperature [32]. It was checked that the CFD is an effective way to

foresee the entrainment proportion and essential back pressure of the ejector. The arranged ejector exhibitions from the trial and the computations show the exactness of the model. The benefits of CFD over other regular strategies were proposed. The review showed that the built CFD model may not address the examination ejector impeccably. Subsequently, a few enhancements for the model arrangement and the computation space are required [33]. In this research, the definition predicts a variety of various stream boundaries viz., Mach number, static tension, of the CRMC ejector. The scientific results have good concurrence with re-enactment and trial results demonstrating the viability of the model. Further, the advantage of utilizing the present scientific model contrasted with the isentropic model has likewise been introduced [34].

5 Diffuser Geometry

In this work, the calculation advancement of the ejector in the SOFC framework was mathematically explored using CFD. Ideal upsides of the four significant calculation boundaries like nozzle divergent part length, nozzle exit position, mixing chamber length, and diffuser length were studied for a wide scope of activity conditions [35]. In this study, the CFD model was first and foremost approved with the real trial results. The authors used different parameters for the adjustable ejector in the multi-evaporator refrigeration system [36]. A small-capacity heat pump was studied with the best ejector geometry experimentally and numerically. Various ejector lengths and diameters for the mixer section and different angles for the diffuser were considered. After the proper investigation, it was observed that the length and the angles had a huge impact [37]. The effect of different length of diffuser section was also analyzed on the performance of the ejector and suggested that the optimum length of the diffuser section plays a significant role in the enhancement of ejector performance [38].

6 Mathematical Modeling of Ejector

Zhu et al. [39] studied another displaying strategy for ejectors with high entrainment proportion, lower pressing factor increase, and overheated working fluid in anodic distribution [40]. A commonplace SOFC framework incorporates an energy component stack and fringe parts. They include a heat exchanger, fuel processor, blender, and a reformer [41]. The framework is built with no moving parts and minimum support by utilizing high pressing factor fuel gas as an essential liquid to suck the anodic depletes [39]. The energy spent on the fuel compression is almost 7% of that of the total power [42]. An outrageous consideration ought to be taken in the ejector plan and operation for ideal framework execution. A precise fuel ejector model and

the assessment of on-plan and off-plan exhibitions are fundamental [25]. The practices of an ejector identified with entrainment limit, steam to carbon proportion, and outlet temperature are unequivocally impacted by the calculations and functional states of the ejector [43]. In any case, the greater part of the current models is created based on 1D procedures for cooling and refrigeration applications. These displaying techniques will cause enormous blunders to demonstrate fuel ejectors in SOFC frameworks because of the distinctions in calculations, working liquids properties, and working conditions. Eames et al. [44] depicted improvements in refrigeration cycle execution. The design of ejectors for pressure energy recuperation requires an itemized examination of the inward ejector, working attributes, and geometry. To this point, a trial and mathematical analysis of an ejector refrigeration framework are led to decide the impact of the main ejector measurements, primary working conditions on ejector working qualities, and cycle execution. Results show that an increment in the essential measurement prompts the twofold improvement of the general ejector productivity [45]. Natthawut Ruangtrakoon [46] conducted a mathematical study of the essential nozzle on the ejector execution in an R141b ejector refrigeration. Essential nozzle region proportion is fluctuated to notice its impact on the ejector execution. Six essential nozzles are examined tentatively, and four of them are planned with various throat distances. It was discovered that utilizing a greater nozzle throat worked with lower generator temperature. The goal was that the ejector will be functional at its best execution. Eilers et al. [47] introduced streamlined push vectoring results from logical and test examinations on a limited scope aerospike engine. The push vectoring framework utilizes four auxiliary infusion ports situated at around half of the nozzle length. The subsequent low-pressure base-region diminishes by large push levels. 2D strategy for qualities was utilized to measure the framework and permitted estimation of the ideal nozzle shapes. Mathematical model of supersonic ejector using 1D gas dynamic theory for real fluid by incorporating real gas equation of state (Redlich-Kwong equation) proposed [48] and analyzed numerically.

7 Ejector Applications

Eilers et al. [49] in this paper give a writing audit on ejectors, their parts, and their applications in refrigeration systems. Various examinations are gathered and discussed in a few subjects. They include the foundation and hypothesis of ejector and stream refrigeration cycle, execution attributes, refrigerant, and optimization of stream cooler. Besides, uses of an ejector in various sorts of refrigeration systems are portrayed. Some part of the energy delivered in the ignition is lost to the environmental factors as waste. This waste heat can be used in certain kinds of refrigeration systems [50, 51]. It is trusted that this paper will be valuable for any newbie in this field of refrigeration advances. The core of the ejector refrigeration framework was designed by Sir Charles Parsons around 1901 to eliminate air from a steam motor's condenser. In 1910, an ejector was utilized by Maurice Leblanc in the first steam jet

refrigeration system [52]. This system experienced a rush of prominence during the mid-1930s for air molding massive structures [53]. Steam jet refrigeration frameworks were later replaced by frameworks utilizing mechanical blowers. Since then, improvement and refinement of the stream refrigeration framework have been nearly at a stop as most endeavors have been focused on further developing fume pressure refrigeration frameworks [54–57].

8 Summary and Future Scope

A comprehensive review of the fundamental background of ejectors and the working conditions they operate on is presented. Many researchers aimed to present their findings on the factors that vary the operation of the ejector and its application. It was concluded that the working of the ejector depends upon the various boundary conditions that many authors varied to study the changes in the flow field. This was carried out to improve the working of the ejector. It was observed that the ejector has many applications, and one of them is in refrigeration or cooling systems. Since each vehicle nowadays comprises an air conditioning system, they can be used in stages to improve efficiency. As of now, we can presume that the complete understanding of the ejectors is not achieved. New presumptions on blending and streaming qualities were constantly settled and applied to the numerical model and virtual experience examination. Even though these reenacted results were professed to turn out to be more precise than others, not very many of them were tentatively checked and endorsed. But we can say that the mathematical investigations could help us understand the ejectors, and it very well may be presumed that there is yet a need to continue the research around here.

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