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"A Research Review on the CFD Application in Design, Analysis and Optimization of Vacuum System (Ejector)"

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ABSTRACT

Because of their simplicity and excellent dependability, jet ejectors are often utilized in the chemical process industries. They are frequently used to create vacuums, ranging in size from minuscule to huge. Constant pressure jet ejectors that are appropriately constructed for a condition are particularly forgiving of mistakes in anticipated amounts and of operational upsets due to their simplicity. This project aims to improve the geometry of a steam jet ejector used in a chemical plant's refrigeration system. In order to enhance overall performance, a thorough investigation has been made into the effects of geometrical characteristics on the effectiveness of the ejector as well as crucial flow parameters. Researchers generally agree that using computational dynamics will help the jet ejector work better. CFD provides in-depth knowledge of the flow parameters, enabling precise ejector geometry optimization. Using computer simulations early in the design phase will considerably decrease the need for prototype trials since the ejector requires single point design for particular applications. In order to improve efficiency by lowering pressure drop throughout the ejector geometry, the findings of the CFD study will be utilized to optimize the ejector's design.

Keywords: CFD, Ejector, Design, Analysis.

1. INTRODUCTION

Ejectors have a number of benefits, including the fact that they need less maintenance because there are no moving parts to wear out or fail. Due to their straightforward design, they have cheaper initial investment costs than mechanical devices. They have a fairly simple design. They need little monitoring and are simple to install.

Steam Jet ejectors, on the other hand, have the following primary drawbacks: They are made to function at a certain optimal point. Efficiency can be significantly decreased by deviating from this ideal spot. At high compression ratios, they have a poor thermal efficiency.

1.1 WORKING PRINCIPLE

The standard jet ejector design includes four main parts, as seen in Figure 1:

a. Nozzle
b. A vacuum chamber
c. Throat
d. Dimmer

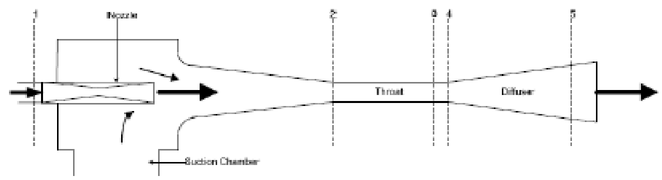

Fig.1. DESIGN OF JET EJECTOR

The following is a description of how jet ejectors work:

(1) Point 1 is where the subsonic motive stream enters the nozzle. As it moves toward the nozzle's converging portion, its velocity rises and its pressure falls. The stream accelerates to sonic velocity near the throat of the nozzle. The nozzle's diverging portion is when the velocity reaches supersonic levels.
(2) The pushed fluid that was entrained enters the ejector and travels to Point 2. Its pressure drops while its velocity rises.
(3) In the suction chamber, the motive stream and the entrained propelled stream start to mix; the mixing is finished in the throat.
(4) A shock wave develops inside the throat when the mixture velocity drops to a subsonic level. Condensation may occur at Point 3 as a result of the back-pressure resistance.
(5) The mixture enters the diffuser's diverging portion, where its kinetic energy is converted into pressure energy. The fluid's pressure is a little bit greater at Point 5 than it is at Point 3 at this point.

1.2CFD ANALYSIS OF EJECTOR

Computational fluid dynamics (CFD) is the computer-based modeling of systems including fluid movement, heat transport, and related phenomena such as chemical reactions. The technology is extremely effective and has a wide variety of industrial and non-industrial applications.CFD approximates the equations that control fluid motion numerically. The following procedures must be taken before using CFD to analyze a fluid problem:
The mathematical equations describing the fluid flow are first written down. Typically, they are a series of partial differential equations. These equations are then discredited to get a numerical equivalent. After that, the domain is separated into little grids or components. Finally, the beginning and boundary conditions of the particular issue are employed to solve these equations. The method of solution might be direct or iterative. Furthermore, some control parameters are employed to govern the method's convergence, stability, and accuracy.

EXAMPLES INCLUDE:
• Turbo machinery: flows inside rotating tubes, diffusers, etc.
• Electrical and electronic engineering: cooling of equipment including microcircuits
• Aerodynamics of planes and vehicles: lift and drag
• Hydrodynamics of ships
• External and internal environments of buildings: wind loading and heating/ventilation;
• Chemical process engineering: mixing and separation, polymer moulding;

CFD analysis can be categorized into four main steps-

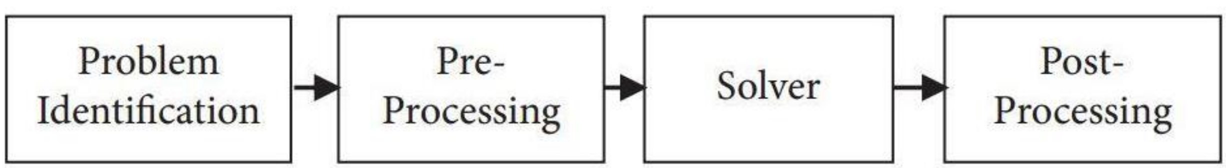

Fig.2 CFD MODELING REVIEW

2. LITERATURE REVIEW

REVIEW OF PAST STUDIES:

Natthawut Ruangtrakoon et al. (2013) [1] investigated the impact of the main nozzle geometries on the functionality of an ejector utilized in the steam jet refrigeration cycle using CFD approach. Only one fixed shape mixing chamber and eight distinct main nozzles were examined numerically in each instance using the CFD programme. The main nozzle was performing at its best when it had a throat diameter of 2.3 mm, an exit Mach number of 4, and a boiler temperature of 120 °C at an evaporator temperature of 7.5 °C. This investigation has led to the conclusion that the CFD approach may be a useful tool for predicting a steam ejector's performance. The mixing process, which cannot be described empirically, may also be explained using it. The findings demonstrate that the main nozzle geometry and operating circumstances have a significant impact on the ejector performance &, therefore, the system COP.

Table – 1: Dimensions of Primary Nozzle

Nozzle code	d (mm)	$(D:d)^2$	Calculated exit Mach number	Ejector's area ratio
d1.4M4	1.4	20:1	4.0	184:1
d1.7M4	1.7			124:1
d2.0M4	2.0			90:1
d2.3M4	2.3			68:1
d2.4M4	2.4			62:1
d2.6M4	2.6			53:1
d1.4M3	1.4	7:1	3.0	184:1
d1.4M5.5	1.4	88:1	5.5	

Szabolcs Varga et al. (2009) [2] investigated the impact of geometrical parameters on steam jet ejector performance using three geometrical factors: nozzle area ratio and area of constant section (r_A), nozzle exit position (NXP), and constant area section length (Lm). Depending on the operating circumstances, the findings suggested the existence of an ideal area ratio. The critical back pressure and entrainment ratio were both modified by the nozzle exit location. The optimal placement for the nozzle exit was discovered to be 6 cm from the intake plane of the converging section, resulting in a 5% and 12% improvement in the entrainment ratio and critical back pressure, respectively. The critical back pressure was raised by increasing Lm to 155mm. A further increase had no effect on the performance metrics, therefore it may be deemed ideal for the current ejector.

Hongqiang Wu et al. (2014) [3] utilized computational fluid dynamics (CFD) to evaluate the impact of mixing chamber geometries on the performance of steam ejectors used in multi-effect distillation systems. The internal flow parameters of the steam ejector, as well as the impacts of mixing chamber length and convergence angle, were determined. It is concluded that there is an ideal range of mixing chamber length at which the ejector achieves its maximum entrainment ratio, and that the mixing chamber has an optimum convergence angle at which the steam ejector performance is the best.

E. Rusly et al. (2005) [4] investigated numerous ejector designs using finite volume CFD techniques to resolve ejector flow dynamics. The CFD results were confirmed using experimental data. The highest entrainment ratio is obtained in the ejector shortly before a shock occurs; therefore the nozzle location is an essential ejector design element. According to the findings, increasing the constant area diameter can only enhance ejector performance when it is working in critical mode with a shock in the diffuser. The constant area diameter can be constantly adjusted to achieve maximum output until the shock goes but the secondary flow choking persists.

T. Sriveerakul et al. (2007) [5] looked at the use of CFD to forecast the performance of a steam ejector used in refrigeration applications in Part-1 of their study. Its performance was examined for the impacts of operating circumstances and geometries. It was discovered that the CFD's predictions and the actual values acquired from the experimental steam jet refrigerator agreed rather well. A deeper understanding of the flow and mixing processes inside the ejector was also provided by the CFD, which was not just a sufficient tool for forecasting ejector performance. Average errors of the critical back pressure and anticipated entrainment ratio were both determined to be less than -7%. Keep in mind that a negative sign means the results of the CFD calculations were overestimated.

T. Sriveerakul et al. (2007) [6] examined the flow processes occurring inside the steam ejector under various operating circumstances and geometries in Part-2 of their investigation. The modeled ejectors' flow structure could be graphically constructed using the CFD software's applications, and the flow passage's phenomena were investigated. It is clear that changing three parameters the primary nozzle size, secondary fluid saturation pressure, and entrainment ratio will change both the critical back pressure and the critical entrainment ratio at the same time. The primary fluid saturation pressure and critical back pressure cannot be raised simultaneously while adjusting, though. The only change that may concurrently raise both values is a higher secondary fluid saturation pressure.

Jianyong Chen et al. (2014) [7] have provided a model for an ejector to calculate its ideal performance and design area ratio in a refrigeration system. The entrainment ratio rises as the generator and evaporator temperatures rise, but instead of a sudden drop, the entrainment ratio gradually falls as the condenser temperature rises. Area ratio is more influenced by nozzle and mixing efficiencies than diffuser efficiencies. To maximize performance and broaden the working conditions, variable geometry ejectors are crucial.

Natthawut Ruangtrakoon et al. (2011) [8] built an experimental refrigerator with a 1 kW cooling capacity and tested it. The system was put to the test using various primary nozzles and operational temperatures. From 110 to 150 C was the boiler saturation temperature range. The evaporator's temperature stayed at 7.5 C all the time. We employed eight main nozzles with various geometry. Six nozzles with exit Mach numbers of 4.0 and throat widths ranging from 1.4 to 2.6 mm. Equal in throat diameter at 1.4 mm, the remaining two nozzles have different exit Mach numbers of 3.0 and 5.5. The critical mass flow rate via one specific primary nozzle, which is run at a constant evaporator saturation temperature, rises as the boiler pressure rises. However, the nozzle exit Mach number has not altered. Different quantities of critical mass flow rate are generated by these nozzles when a number of them are utilised, each with a different throat diameter, while the boiler and evaporator saturation temperatures remain fixed. The results of this study allow us to draw the conclusion that the primary nozzle's geometrical characteristics strongly influence how well the ejector works and how efficiently the system operates.

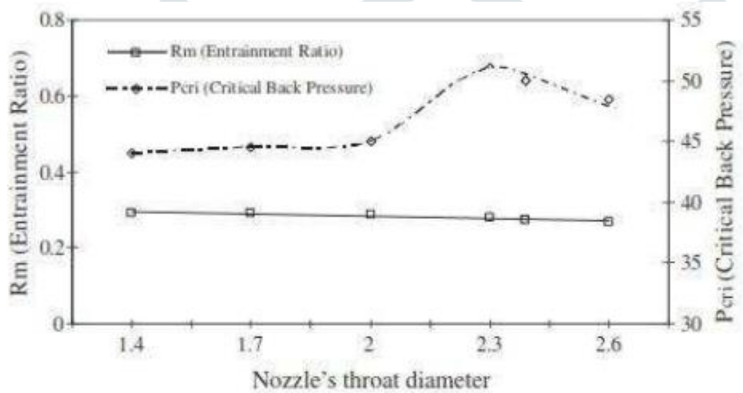

Fig3 **variation in the entrainment ratio as well as the critical back pressure when using different nozzles**

Figure 3. Shows the variation in the entrainment ratio as well as the critical back pressure when using different nozzles, but fixes the critical mass flow rate and also the exit Mach number.

R. Yapici et al. (2008)[9] investigated the best ejector refrigeration system performance dependent on ejector area ratio. The effectiveness of the cylindrical mixing chamber ejectors used in the ejector refrigeration system is investigated under operation conditions with choking in the mixing chamber.The investigation is conducted using an ejector area ratio between 6.5 and 11.5 at a compression ratio of 2.47. As the ideal generator temperature rises from 83 to 103 C, the experimental coefficient of performance of the system in the research varies from 0.29 to 0.41.When the nozzle and diffuser efficiencies are considered as 0.90, similar findings were also discovered in the parametric analysis. There is a best generator temperature at which the ejector refrigeration system produces the most COP for a given ejector area ratio. When the generator temperature is reduced below the ideal temperature that corresponds to its area ratio, the system's COP decreases very abruptly. In the examined range, the optimumarea ratio roughly rises linearly with the generator temperature.

K. S. Agrawal (2013)[10] completed an experimental observation on a multi-nozzle liquid jet ejector for a laboratory-scale chlorine (Cl_2)-aqueous caustic soda system (NaOH). The design of the mass transfer equipment is influenced by the forecast of the gas removal effectiveness in the liquid jet ejector. The concentration of absorbing liquid and solute in the gas as well as the flow rates of gases and liquids have a significant impact on the effectiveness of jet ejectors. Different sets of nozzle plates were used in the experiment. In this study, a liquid jet ejector was used to assess the rates of chlorine absorption from various gas concentrations into aqueous sodium hydroxide solutions of varied concentrations. The penetration hypothesis for gas absorption was used to analyze the experimental data. Theoretical absorption rate calculation model is created. The projected rate of absorption from the generated model is compared with the outcomes of the experiments. They were in complete accord. The development of a mathematical model to calculate the enhancement factor for a jet ejector using the Higbie penetration theory has also been attempted in this study.

K. S. Agrawal [11] developed a mathematical model to estimate the mass transfer coefficient and interfacial area of a multi-nozzle jet ejector, which was then compared to actual data. The measured values of the interfacial area in the jet ejector are in the 3000 to 13000 m2/m3 range. The gas side mass transfer coefficient (kG) and interfacial area (a) must be estimated in order to anticipate mass transfer characteristics. Using a chlorine-aqueous sodium hydroxide solution, a mathematical model is created to estimate the value of (kG) (a).

Szabolcs Varga, Armando C. Oliveira, and Bogdan Diaconu[12](2009) Studied With the help of an axe-symmetric CFD model, the ejector efficiencies for the primary nozzle, suction, mixing, and diffuser were found for the first time. The working fluid was thought to be water, and the operating conditions were chosen to be good for an air conditioner that uses solar thermal energy. The performance of the ejector was figured out for different ratios of nozzle throat to constant section area. The results showed that, depending on the operating conditions, there is an optimal ratio. For different operating conditions, the efficiency of the ejector was calculated. It was found that the efficiency of the nozzle can be thought of as constant, but the efficiency of the suction, mixing, and diffuser parts of the ejector depends on how it is being used**.**

3. CONCLUSIONS

Jet ejectors are used a lot in the chemical industry because they are very reliable and don't cost much to buy or keep up. But compared to mechanical compressors, jet ejectors aren't very good at what they do. So it's necessary to improve the efficiency of ejectors to resolve the low efficiency problem. Lot of research conducted experimentally to investigate the performance of the ejector. But few of them by apply CFD analysis in ejector performance. That's why I choose CFD application in design, analysis and optimization of ejector. A CFD analysis shortens the time it takes to make a prototype, cuts costs, and makes it more reliable.

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