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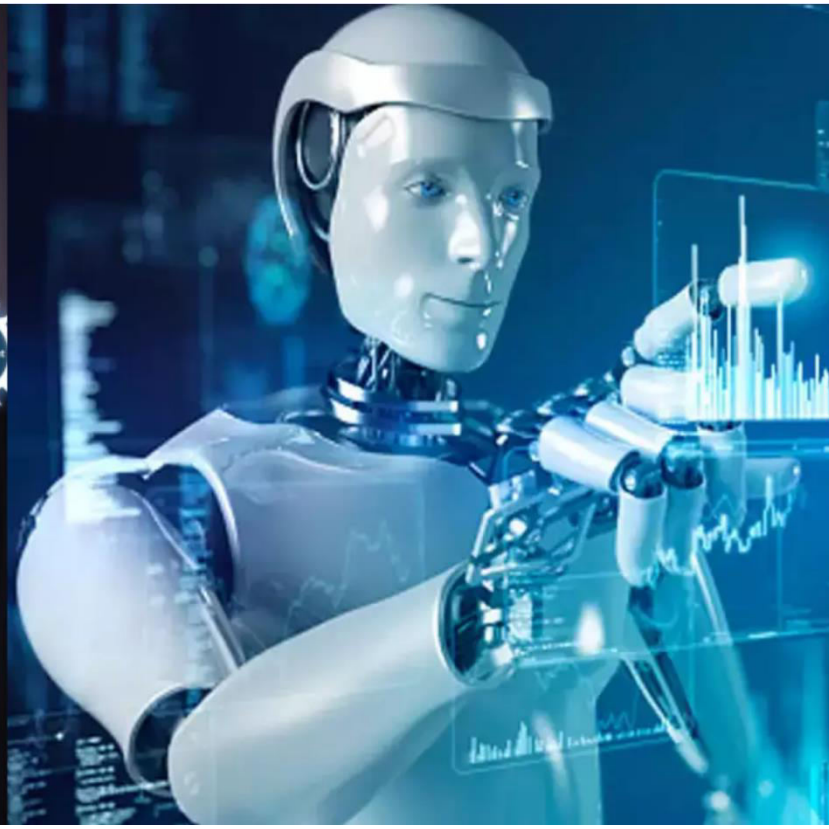

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CFD Analysis and Performance Enhancement of a Steam Ejector-Integrated LiBr/H_2O Vapor Absorption System

K. V. Lavanya[1], Nammi Vinay[2]

Assistant Professor, Department of Mechanical Engineering, Sanketika Vidya Parishad Engineering College, Visakhapatnam, Andhra Pradesh, India[1]

P.G. Student, Department of Mechanical Engineering, Sanketika Vidya Parishad Engineering College, Visakhapatnam, Andhra Pradesh, India[2]

ABSTRACT: This study aims to enhance the efficiency of a LiBr/H_2O vapor absorption refrigeration system by integrating a steam ejector cycle. CFD analysis using ANSYS FLUENT, with geometry modeled in SolidWorks, is conducted under steady-state conditions based on ASHRAE and ESDU standards. The ejector, with a 4.13 mm throat nozzle and 10 mm mixing chamber diameter, utilizes kinetic energy to improve system performance. Results indicate that the ejector's entrainment ratio increases with higher generator temperature and lower evaporator pressure, while condenser pressure shows minimal effect. The integrated system achieves up to a 45% improvement in COP over the conventional configuration.

KEYWORDS: Computational Fluid Dynamics (CFD), LiBr/H_2O refrigeration, ANSYS FLUENT, SolidWorks modeling, entrainment ratio, Coefficient of Performance (COP), generator temperature, condenser pressure, evaporator pressure, energy efficiency, ejector design, single-effect absorption system, **and** thermodynamic analysis.

I. INTRODUCTION

The vapor absorption refrigeration system (VARS) serves as an energy-efficient alternative to conventional vapor compression systems by utilizing thermal energy instead of electrical energy. Integrating a steam ejector cycle into the VARS can further enhance its performance by recovering and reusing kinetic energy from high-pressure steam. This study focuses on improving the efficiency of a LiBr/H_2O single-effect vapor absorption system through steam ejector integration. The ejector is designed based on ASHRAE and ESDU standards and analyzed using Computational Fluid Dynamics (CFD) in ANSYS FLUENT, with the geometry modeled in SolidWorks. The research investigates the effects of parameters such as generator temperature, evaporator pressure, and condenser pressure on the system's entrainment ratio and Coefficient of Performance (COP). The results demonstrate that the integration of the ejector significantly improves energy utilization and overall performance, achieving up to a 45% increase in COP compared to the conventional absorption system.

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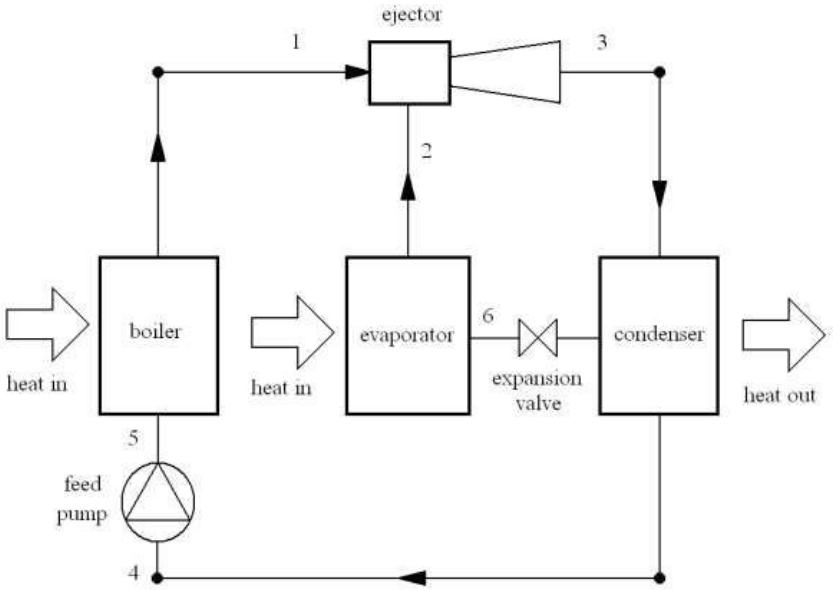

Fig 1.1: Schematic diagram of a steam ejector refrigeration cycle.

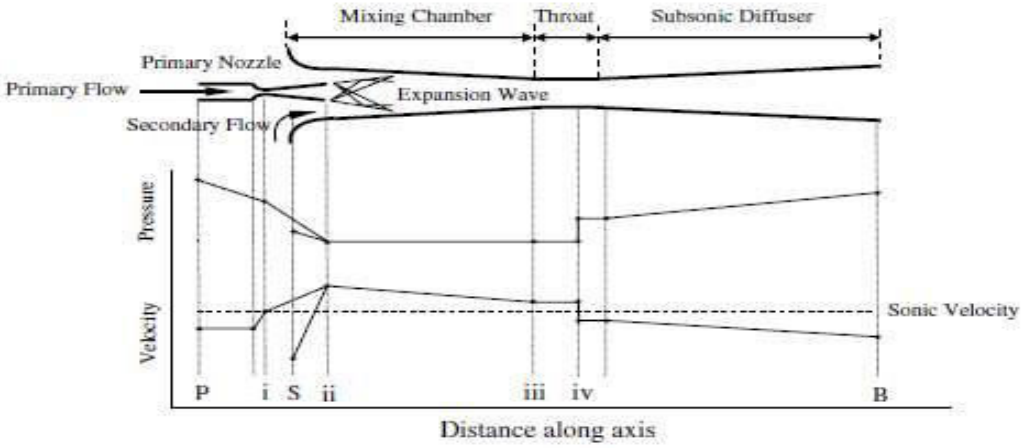

Fig 1.2: Typical steam ejector and flow characteristics in the ejector.

II. LITERATURE SURVEY

Early studies by Keenan and Neumann (1950) established the constant-pressure and constant-area mixing models, forming the foundation for ejector design and analysis. Subsequent research advanced these models using CFD and experimental methods to improve ejector performance. Studies by Li, Utomo, and El-Dessouky explored the effects of geometry, operating conditions, and converging angles on entrainment ratio and efficiency. Later works by Varga, Aphornratana, and others demonstrated that variable geometry ejectors significantly enhance Coefficient of Performance (COP) and adaptability. Modern CFD-based investigations continue to refine ejector configurations for refrigeration, desalination, and energy-efficient thermal systems.

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III. METHODOLOGY

In a vapor absorption refrigeration system, four main components—generator, condenser, evaporator, and absorber—work together between low- and high-pressure zones. The ejector, placed between the generator and condenser, enhances system efficiency by recovering and utilizing pressure energy. In this setup, heat applied to the LiBr/H_2O solution in the generator produces high-pressure vapor, which passes through the ejector and mixes with low-pressure vapor from the evaporator. This mixture flows through the diffuser and into the condenser. Meanwhile, the absorber circulates the LiBr solution from low to high pressure, separating water vapor in the generator before returning the concentrated solution to the absorber. The ejector's nozzle converts subsonic flow into supersonic, creating suction that entrains the secondary vapor. This process efficiently combines both vapors, improving cooling performance. The system's effectiveness is evaluated using two parameters—Coefficient of Performance (COP) and Entrainment Ratio (ER)—which indicate the overall efficiency and energy utilization.

$$COP = \frac{Qe}{Qg + Wp}$$

$$ER = \frac{ms}{mp}$$

EJECTOR WORKING PRINCIPLE

An ejector consists of four main parts: a motive nozzle, suction chamber, mixing section, and diffuser. It operates by converting the motive fluid's internal energy into kinetic energy through a converging-diverging nozzle, which accelerates the flow to supersonic speed. The high-velocity jet from the nozzle entrains the secondary fluid in the suction chamber, transferring momentum and creating mixing. To reduce shear losses, a secondary nozzle may pre-accelerate the suction flow. Depending on pressure and temperature, both flows may become choked, forming a virtual throat where the secondary flow reaches sonic conditions. Mixing occurs either under constant area or constant pressure, often accompanied by shock waves that increase pressure. The diffuser then converts kinetic energy into pressure energy for recovery. Overall, the ejector functions as a fluid pump, driven by motive flow, and its performance is defined by the suction pressure ratio and mass entrainment ratio, key indicators of efficiency.

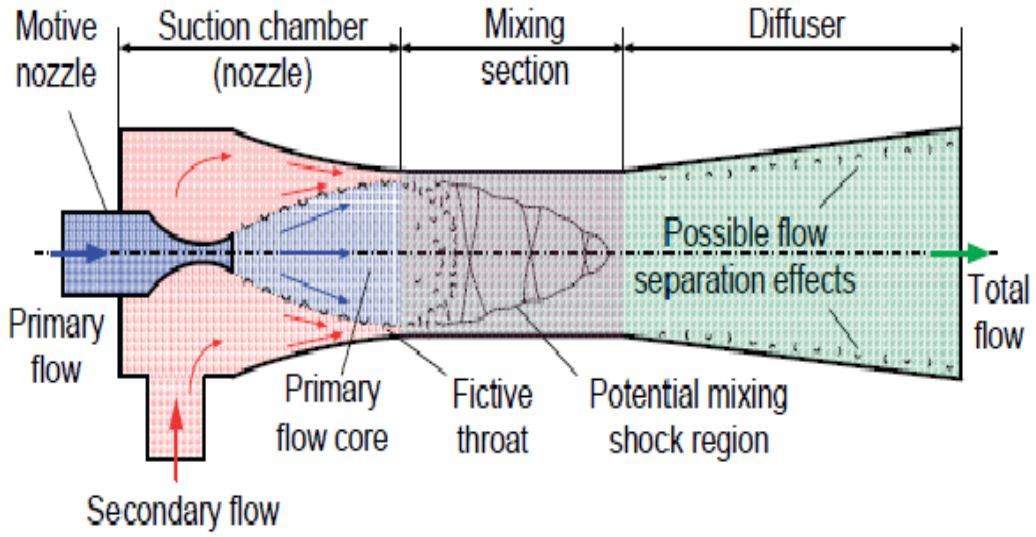

FIG 1.3: STAGES OF EJECTOR

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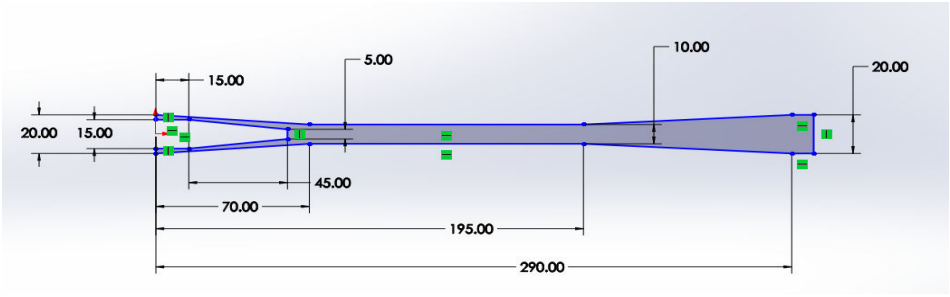

Fig 1.4: Sketch view of ejector

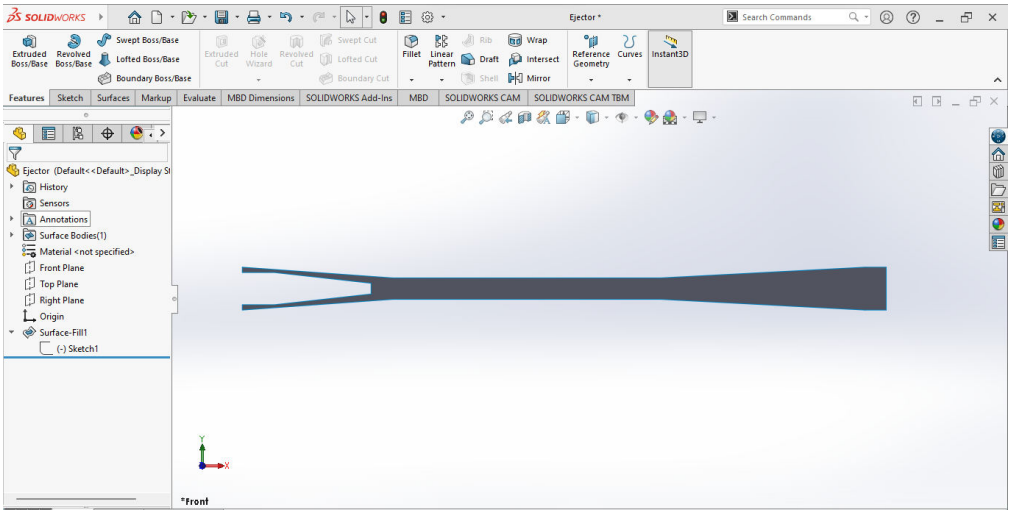

Fig 1.5: Geometry model of ejector system

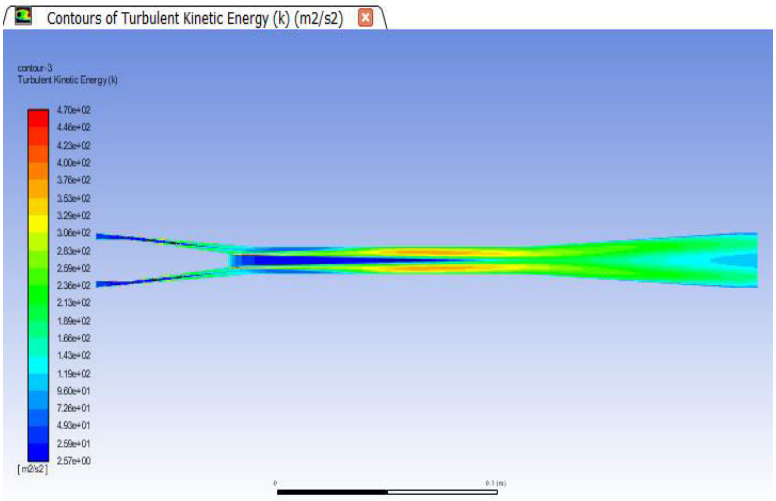

Fig 1.6: Turbulent kinetic energy distribution and readings for Evaporator Pressure (Secondary) while Generator Pressure (Primary) is Constant

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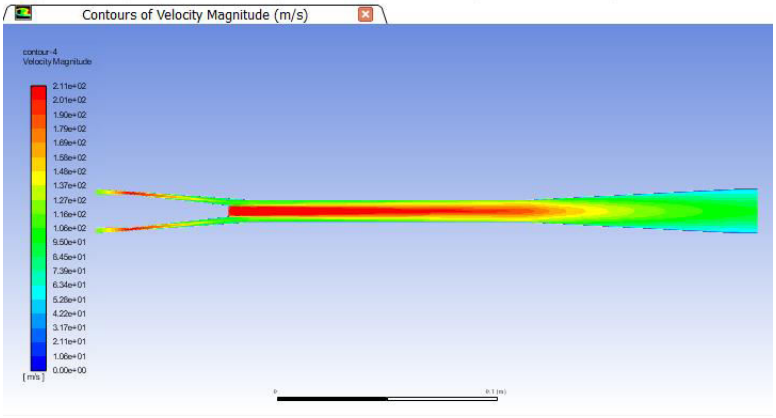

Fig 1.7: Velocity distribution and readings for Evaporator Pressure (Secondary) while Generator Pressure (Primary) is Constant

IV. RESULTS

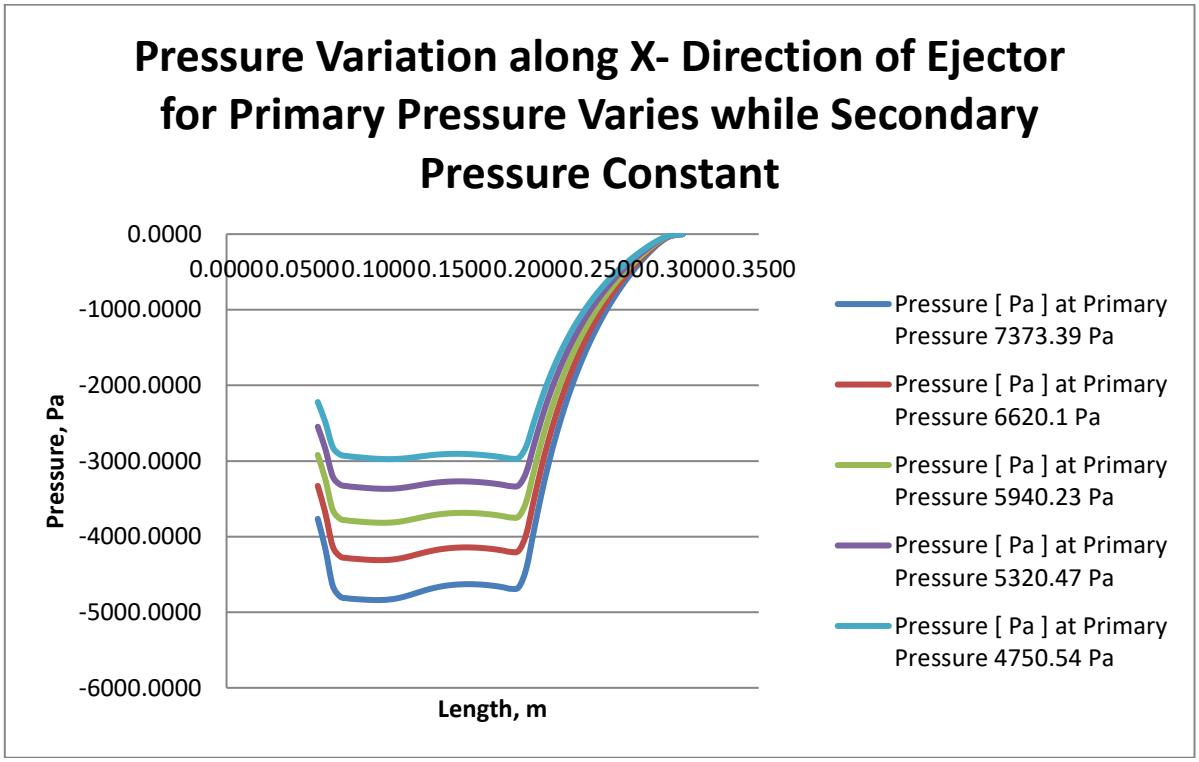

Fig 1.8: Pressure Variation along X- Direction of Ejector for Primary Pressure Varies while Secondary Pressure Constant

The motive fluid accelerates, its pressure drops significantly. This pressure drop is crucial for entrainment as it creates a suction force to pull in the suction fluid. Due to mixing and friction, the pressure of both fluids decreases slightly in the mixing chamber. However, the motive fluid experiences a more significant pressure drop than the suction fluid. In the diffuser, the pressure of both fluids increases as kinetic energy is converted back into pressure energy. The pressure rise for the suction fluid is the key output of the ejector, making it valuable for various applications.

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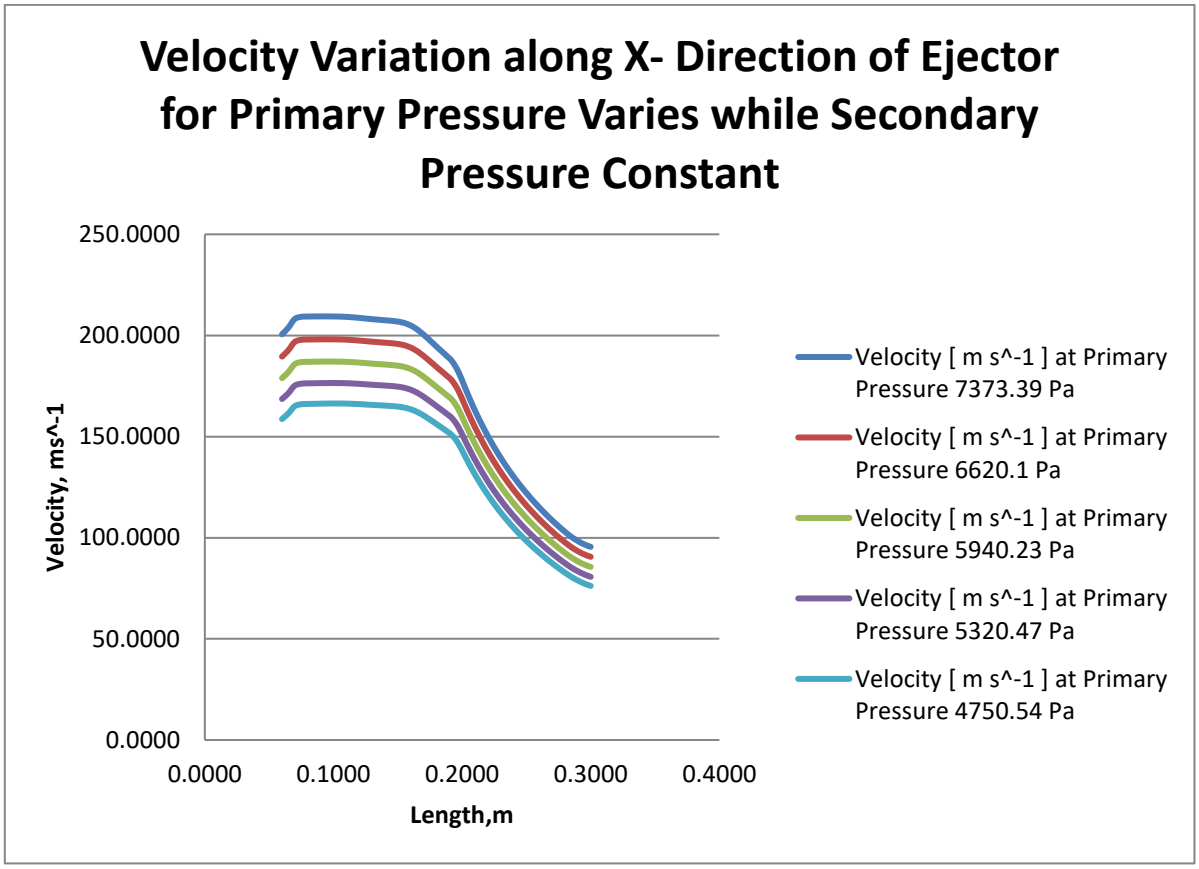

Fig 1.9: Velocity Variation along X- Direction of Ejector for Primary Pressure Varies while Secondary Pressure Constant

The high-pressure primary fluid enters through a nozzle, which constricts the flow and converts pressure energy into kinetic energy, resulting in the initial velocity increase. The primary fluid entrains the secondary fluid, creating a region of turbulent mixing. This mixing process causes some energy loss, leading to a slight decrease in velocity. The combined fluid stream then enters a diffuser, which gradually widens the flow path. This expansion converts kinetic energy back into pressure energy, causing the velocity to decrease further while the pressure rises.

V. CONCLUSION

Primary pressure strongly influences ejector performance by controlling pressure variation, suction force, and diffuser pressure recovery. Higher primary pressure increases nozzle velocity, enhancing secondary fluid entrainment and energy transfer. The outlet temperature depends on primary temperature, mixing efficiency, and geometry—decreasing during expansion and rising during compression. Primary mass flow rate rises with pressure but eventually limits due to friction and choking effects. These interrelated parameters—pressure, velocity, temperature, and mass flow rate—govern ejector efficiency. Optimizing them, along with geometric design and fluid properties, ensures effective suction, improved energy utilization, and stable operation across various industrial and refrigeration applications.

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