Design and experimental research of the cryogenic ejector to inject liquid nitrogen

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1 Introduction

Cryogenic liquid is applied in more and more fields like medical equipment and scientific researches. Cryogenic liquid can provide cooling capacities in different temperature ranges and by various methods. However, the extraction of cryogenic liquid from cryogenic Dewar is a complex question in some situations. The cryogenic immersed pump is widely adopted nowadays. Nevertheless, the mechanical motion components of immersed pump lead to an extremely high requirement of machining especially when working in cryogenic condition. With some inevitable problems, the operational stability and service life is very likely unsatisfactory. In addition, the heat leak from the pump in cryogenic liquid results in a huge cooling capacity loss. Hence, a new kind of pump is researched in this paper to avoid those problems resulting from immersed pump.

2 Principle

The primary flow in high pressure flows through the nozzle turning out to be low-pressure and high-speed. Then the secondary flow is entrained in suction chamber because of the low pressure zone causing by the primary flow. The suction flow and primary flow mix together in mixing chamber and mixed fluid decelerates in diffuser chamber.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j}$$

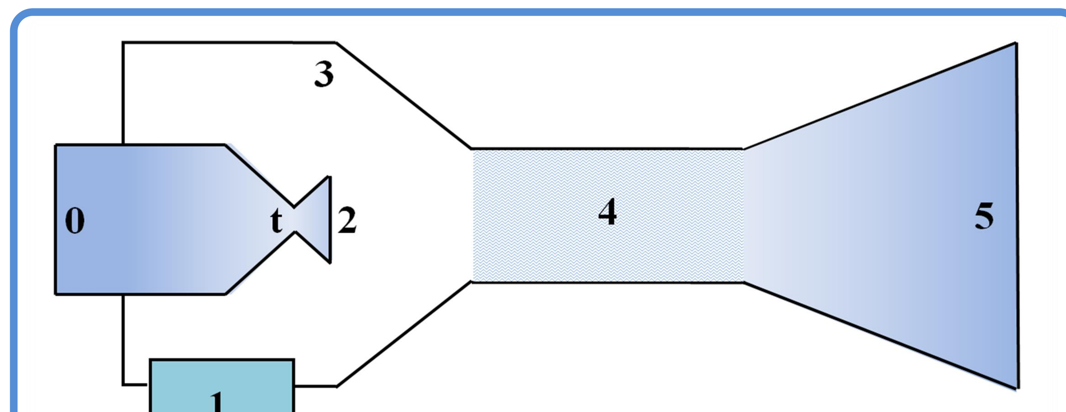
$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}(u_i(\rho E + P)) = \vec{\nabla}\left(a_{eff}\frac{\partial T}{\partial x_i}\right) + \vec{\nabla}(u_j(\tau_{ij}))$$

$$c = \left(-\upsilon^2\left(\frac{\partial p}{\partial \upsilon}\right)_s\right)^{1/2}$$

The continuity equation, momentum equation, energy equation and sound speed equation are shown above.

3 Method

Model



Model for cryogenic ejector

Assumption **Working Condition**

Stagnation State

$$h^* = h_0 + \frac{c_0^2}{2}$$

Equation of Property

OR

Specific Heat Capacity

Stagnation Physical Property

Nozzle Structure

$$v = \left(2C_p(T^* - T_t)\right)^{1/2}$$

Throat

$$c = \left(\gamma R_g T_t\right)^{1/2}$$

$$\frac{P_t}{P^*} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

Critical State

Verify the Validity

Real Velocity

Real Sound Velocity

$$r_t = \left(\frac{m_p}{\pi \rho_t v_t}\right)^{1/2}$$

$$\frac{P_2}{P_t} = \left(\frac{T_2}{T_t}\right)^{\frac{\gamma}{\gamma - 1}} \qquad r_2 = \left(\frac{m_p}{\pi \rho_2 v_2}\right)^{1/2}$$

Suction Chamber Structure

Momentum Conservation

$$r_4 = \left(\frac{m_p}{\pi \rho_2 v_4} + \frac{m_s}{\pi \rho_1 v_4}\right)^{1/2}$$

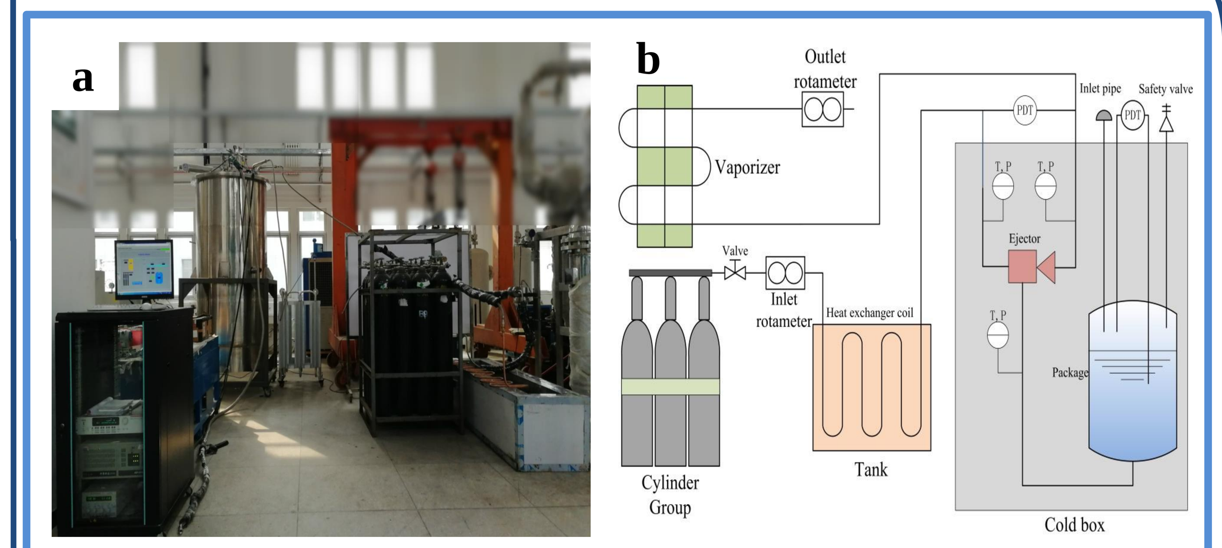
$$T_4 = \frac{m_p C_{p1} T_2 + m_s C_{p2} T_1}{m_p C_{p1} + m_s C_{p2}}$$

$$v_5 = \left(2C_{p3}(T_4 - T_5) + \frac{v_4^2}{2}\right)^{1/2}$$

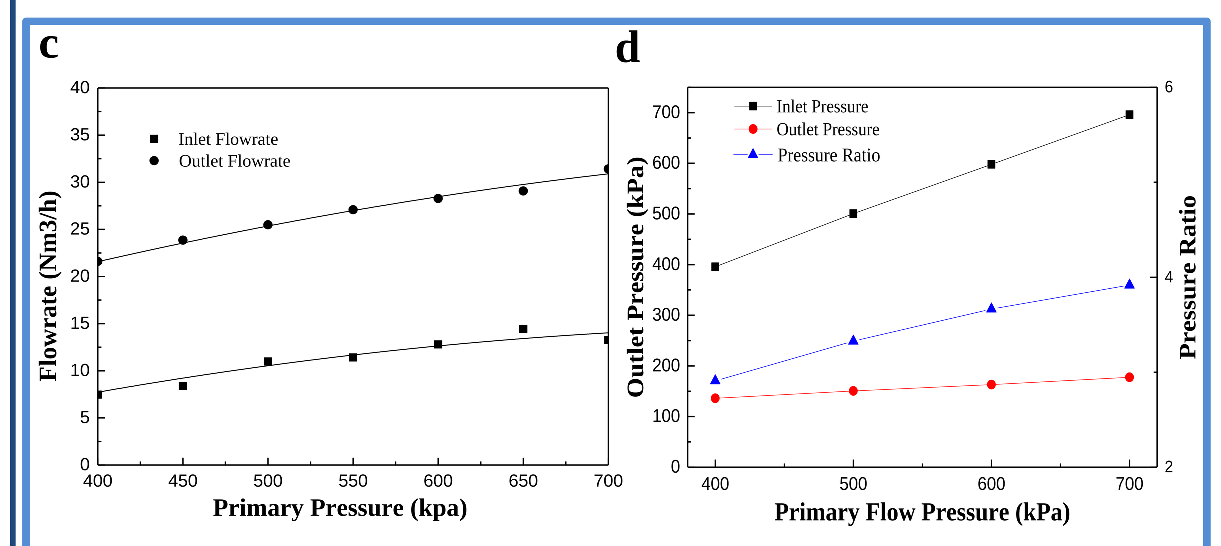
Energy Conservation

$$r_5 = \left(\frac{m_x}{\pi \rho_5 v_5}\right)^{1/2}$$

4 Experiment



a The experiment photo of ejector system
b Simplified schematic diagram for the system of cryogenic ejector
c Flow rate in the cases of different primary pressures
d Inlet pressure, outlet pressure and pressure ratio at different primary pressures



In the experiment, the primary pressure is regulated by the valve from 400 kPa to 700 kPa. The outlet flowrate is larger than the inlet flowrate, which indicates the liquid nitrogen from package is entrained by this cryogenic jet pump. Compared with the experimental data of package liquid level, the error of increased flowrate, less than 15%, is in a tolerant range considering cryogenic measurement. The feasibility of this design method is verified. The entrainment flowrate nearly increases with primary pressure rising. Primary fluid flows through nozzle for depressurization and acceleration, which will have a higher velocity if its pressure is higher in a certain range. More suction flow can be carried out by higher speed flow.

With the increase of primary pressure, the outlet pressure increase nearly linearly. The largest outlet pressure is 177 kPa when the primary pressure is 696 kPa. The pressure of secondary flow is regarded as atmospheric pressure because package opens to the surrounding. Pressure ratio, which is outlet pressure dividing inlet pressure, also rises as the primary pressure increases. The maximum pressure ratio is 3.9.

5 Conclusion

In this paper, a cryogenic jet pump in the range of liquid nitrogen temperature is designed. Based on the ideal gas assumption, a method is proposed for simplifying design process in the application of engineering. A liquid nitrogen experiment system is built to vilify the design method. By analyzing experimental data, liquid nitrogen is entrained by low temperature and high pressure inlet flow. This research can solve many problems for helium temperature ejector design. And it is promising that the ejector is used in taking liquid helium out of Dewar, adjusting the refrigeration capacities of liquid helium refrigerators and extracting high-pressure helium gas from cryogenic cavities.

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