Performance Optimization of Steam Jet Ejector using CFD

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Abstract

Jet ejectors are popular in the chemical process industries because of their simplicity and high reliability. They are widely used to generate vacuums with capacity ranges from very small to enormous. Due to their simplicity, constant-pressure jet ejectors that are properly designed for a given situation are very forgiving of errors in estimated quantities and of operational upsets. Additionally, they are easily changed to give the exact results required. The purpose of this project is to optimize the geometry of steam jet ejector used for refrigeration application in chemical plant. Exhaustive survey has been conducted on the influence of geometrical parameters on the efficiency of the ejector as well as critical flow parameters to improve the overall performance. The use of computational dynamics has been widely adopted by researchers to improve the performance of jet ejector. CFD provides detail insights on the flow characteristics, which allows accurately optimizing the ejector geometry. Since the ejector requires single point design for specific applications, using computer simulations early in the design process will significantly reduce the requirement of prototyping trials. Utilizing the benefits the CFD offers, the dimensions of the ejector system has been measured, which will be further utilized to develop a computational domain and perform numerical iterations to obtain fluid flow characteristics. The results obtained through CFD analysis will be used to optimize the geometry of the ejector, to achieve better efficiency by reducing pressure drop across the ejector geometry.

Keywords: Mixing chamber, fluid domain heat transfer, pressure plot, velocity plot, CFD simulation

I. SELECTION OF EJECTOR MODEL

The ejector model has been selected from a steam jet refrigeration system developed for a chemical processing plant. The operating conditions and geometrical dimensions are described in the table and figure below respectively:

Table 1:
Design Data

Sr. No.	*Particulars*	*Unit*	*Value*
1	*Primary Fluid Suction Pressure*	*TORR*	*25.0*
2	*Primary Fluid Suction Temperature*	*^0C*	*41.43*
3	*Suction Load (Air)*	*Kg/hr*	*25.49*
4	*Suction Load (Water Vapor)*	*Kg/hr*	*56.05*
5	*Motive Steam Pressure*	*Kg/cm^2*	*6.0*
6	*Cooling Water Temperature*	*^0C*	*32*
7	*Primary Discharge Pressure*	*TORR*	*175*

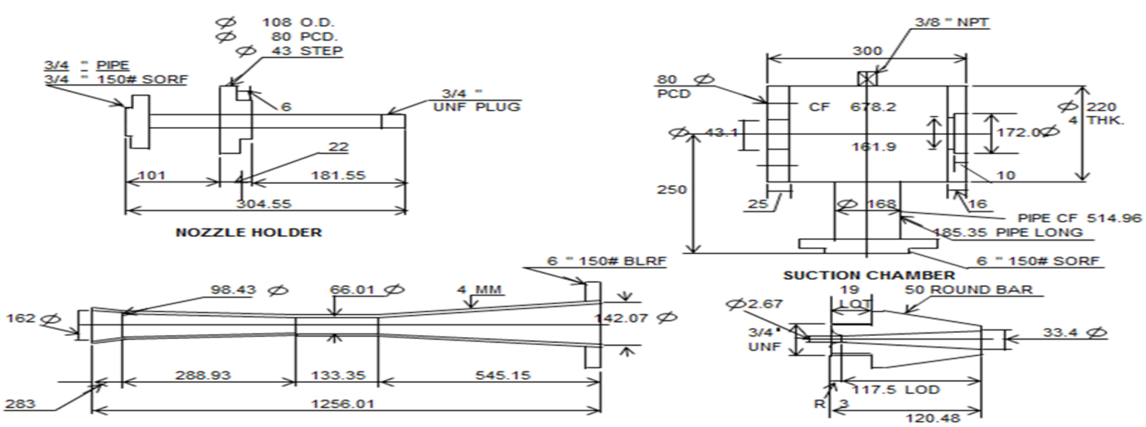


Fig. 1: Dimensional parameters

A. Experimental Data

In order to evaluate the performance of the proposed ejector system for a steam jet refrigeration plant, performance tests were done by varying the suction load and suction pressure and keeping the motive and discharge pressure constant. Following results were obtained through the experiments.

Table 2:
Experimental results

Motive Pressure (Pa) (Nozzle Inlet)	*Suction Load (Flow rate) (Kg/hr)*	*Suction pressure (Pa) (Secondary Inlet)*	*Discharge pressure (Pa) (Outlet)*
774725.35	*0*	*1333.2237*	*23331.41475*
774725.35	*32*	*2666.4474*	*23331.41475*
774725.35	*64*	*2666.4474*	*23331.41475*
774725.35	*96 (design point)*	*2666.4474*	*23331.41475*
774725.35	*128*	*4799.60532*	*23331.41475*

B. Steam Conditions

- Dryness fraction: 0.96 saturated steam
- Motive steam temp. 3700C
- Suction load temp. : 41.430C
- Discharge temp.: 2870C

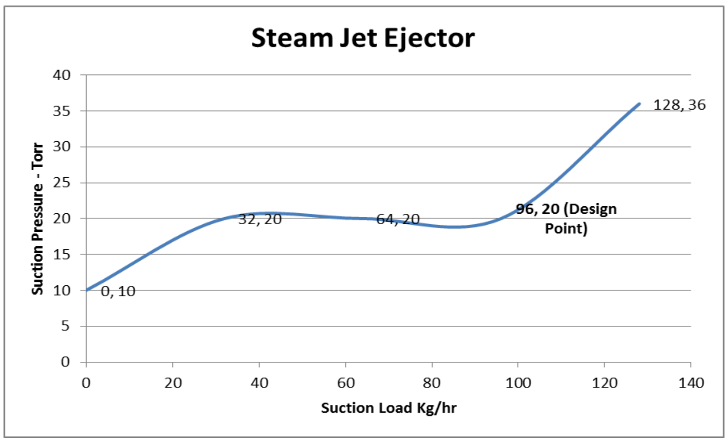


Fig. 2: Suction pressure Vs Suction Load

C. Geometry

In order to perform CFD pressure drop analysis for the selected ejector, the fluid domain was developed using ANSYS Design Modeler. As shown in the figure, the domain neglects solid geometrical regions and considers only the region containing fluid.

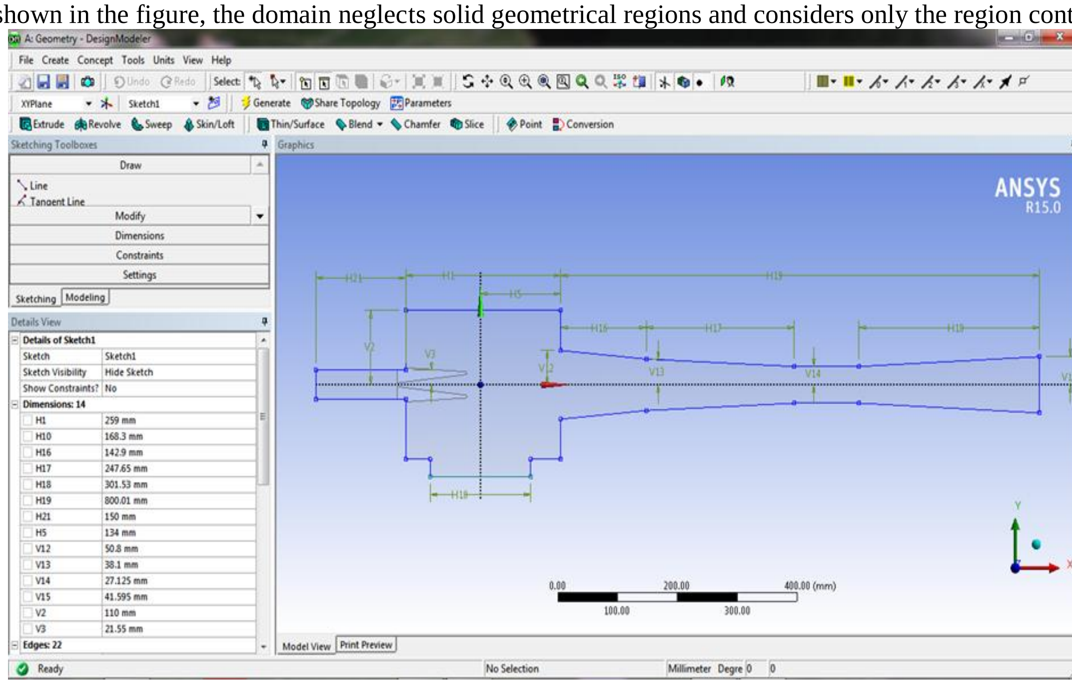


Fig. 3: Ejector Fluid Domain

D. Meshing

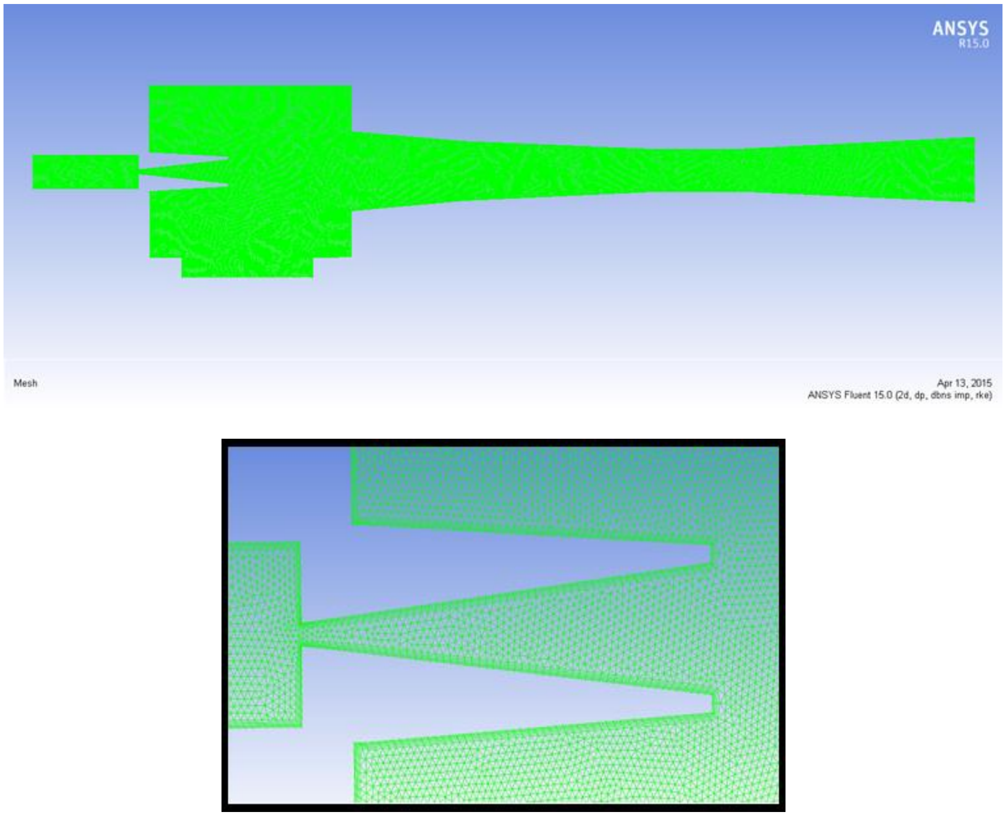


Fig. 4: Meshing

E. Boundary Conditions

Boundary conditions were applied according to the experimental data to validate the results using CFD.

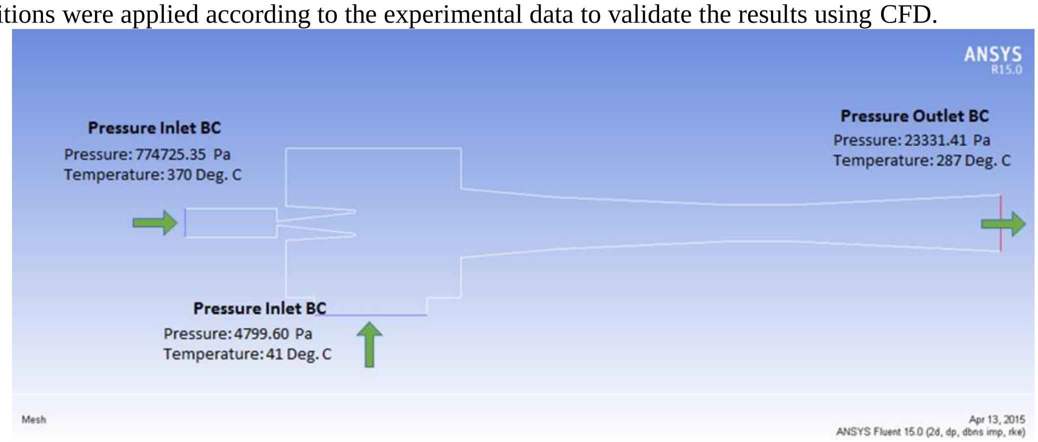


Fig. 5: Boundary conditions

II. MATHEMATICAL MODEL

For compressible flow simulation of the fluid and turbulence modeling, following quations are used:

1) Conservation of mass:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla \cdot (\rho \vec{v} Y_i) = -\nabla \cdot \vec{J}_i + R_i + S_i$$

2) Conservation of momentum:

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\overline{\overline{\tau}}) + \rho \vec{g} + \vec{F}$$

SST k-omega turbulence model with standard wall function is used for turbulence modeling.

A. CFD Results

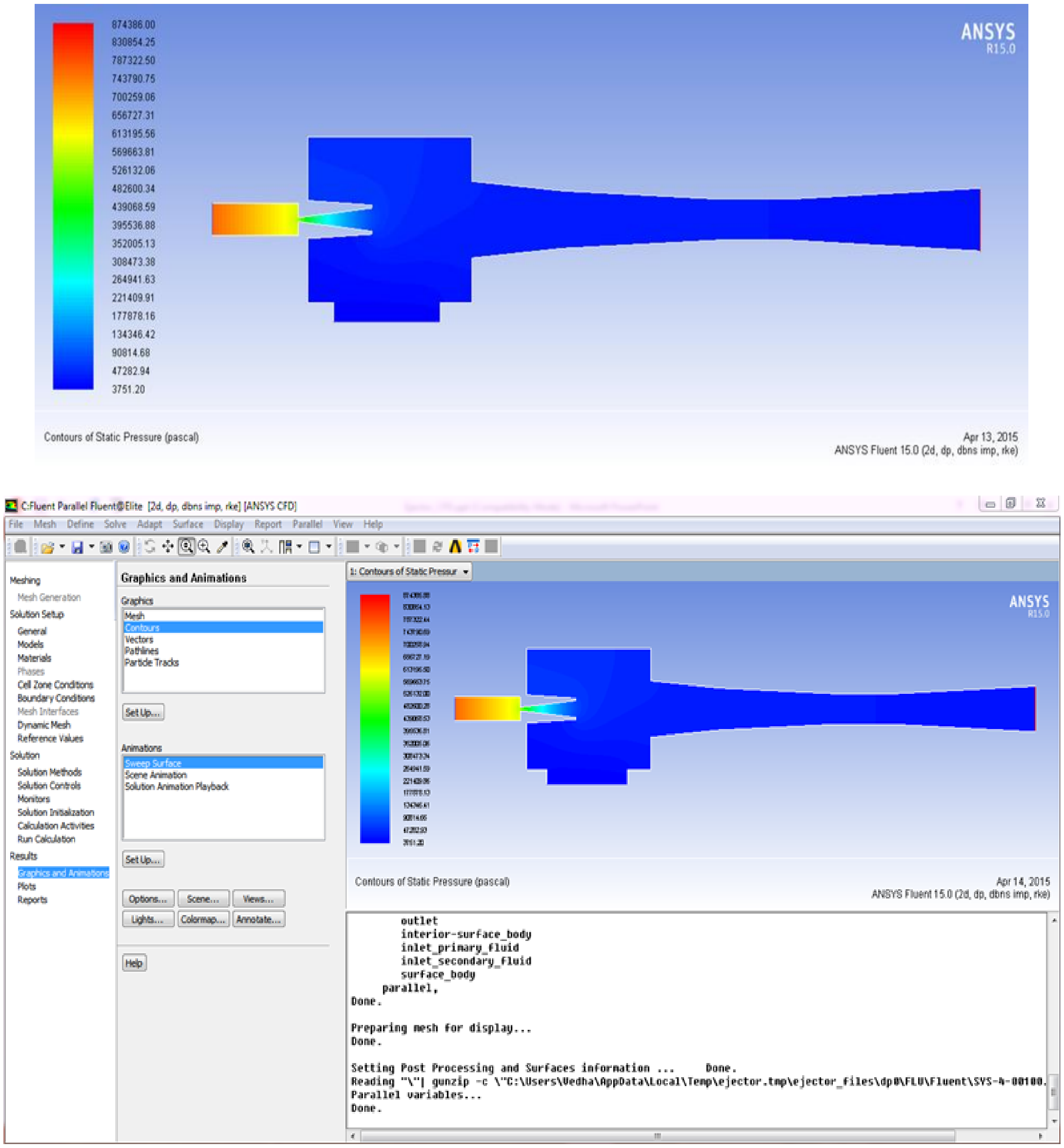
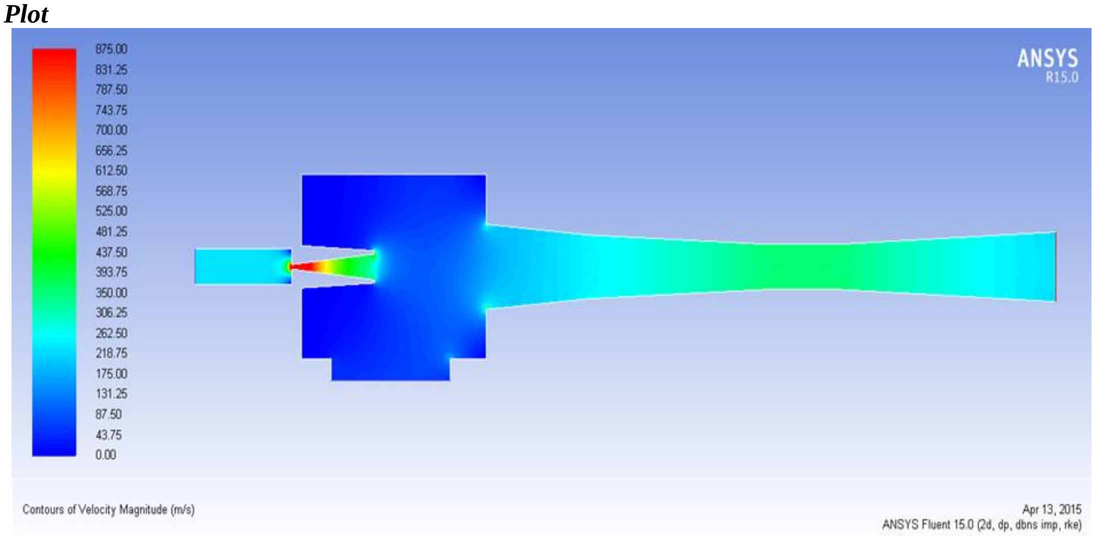


Fig. 6: Pressure variations in ejector geometry

B. Velocity Plot



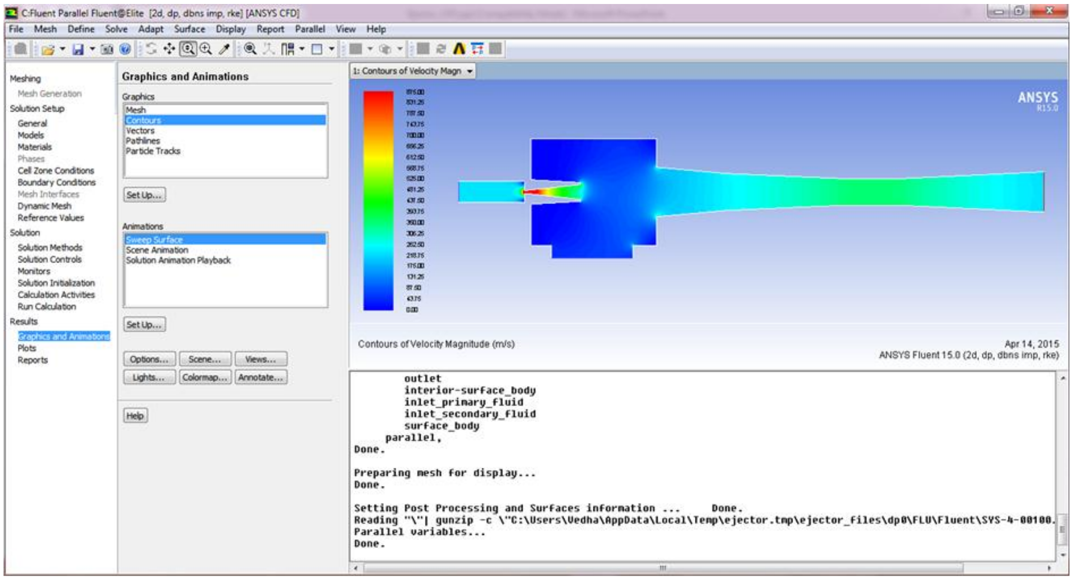
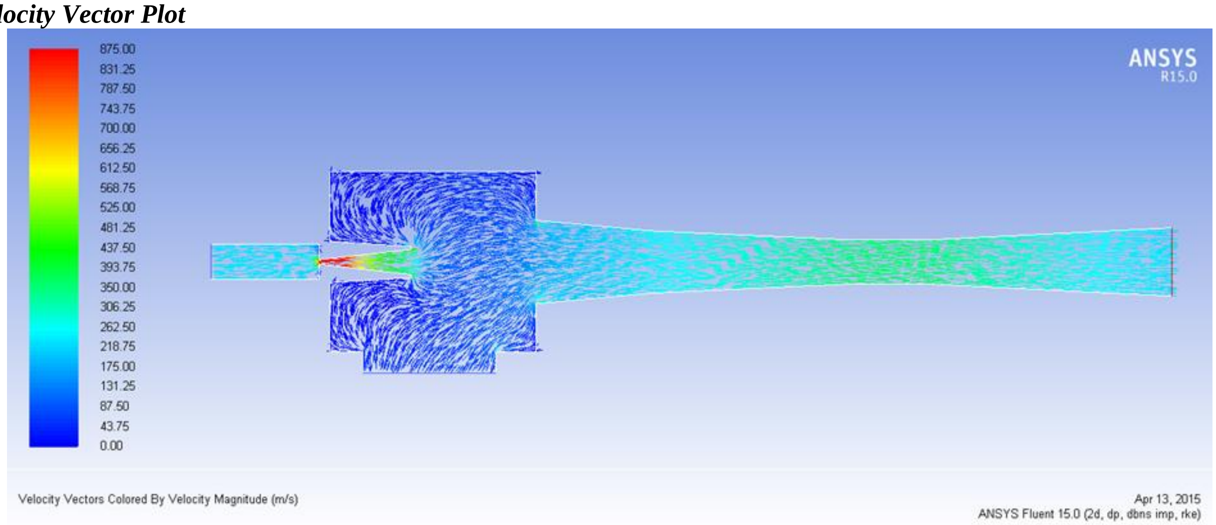


Fig. 7: Velocity distribution

C. Velocity Vector Plot



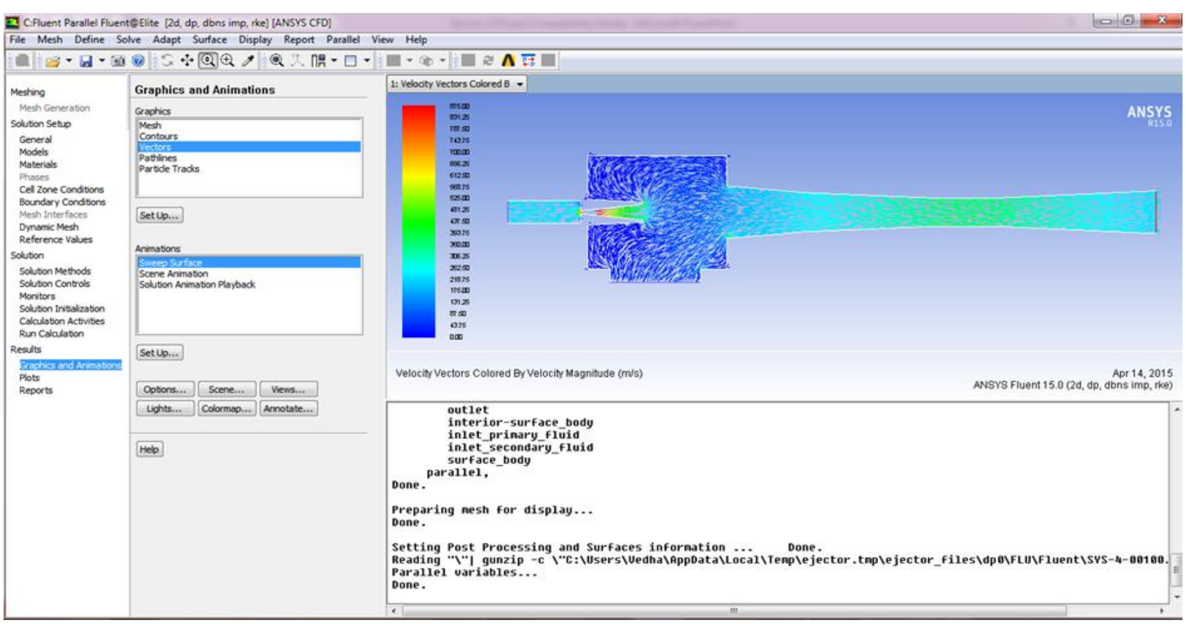


Fig. 8: Velocity vector plot

D. Experimental Vs CFD

The results obtained through CFD analysis closely match with that of the experimental values obtained at suction load of 128Kg/hr. Thus, it is possible to consider CFD results as valid and further optimization can be done using the CFD approach to improve ejector performance.

III. EJECTOR OPTIMIZATION

The optimization of the ejector is performed to reduce its dimensions and subsequently reduce material usage without affecting suction load and outlet pressure. The length of the suction chamber reduced by 10 mm and CFD analysis is performed to identify the outlet and suction conditions with the optimized ejector geometry. The motive inlet pressure is assumed as 650000 Pa with a temperature of 350 deg. C. The details of the analysis are as shown below:

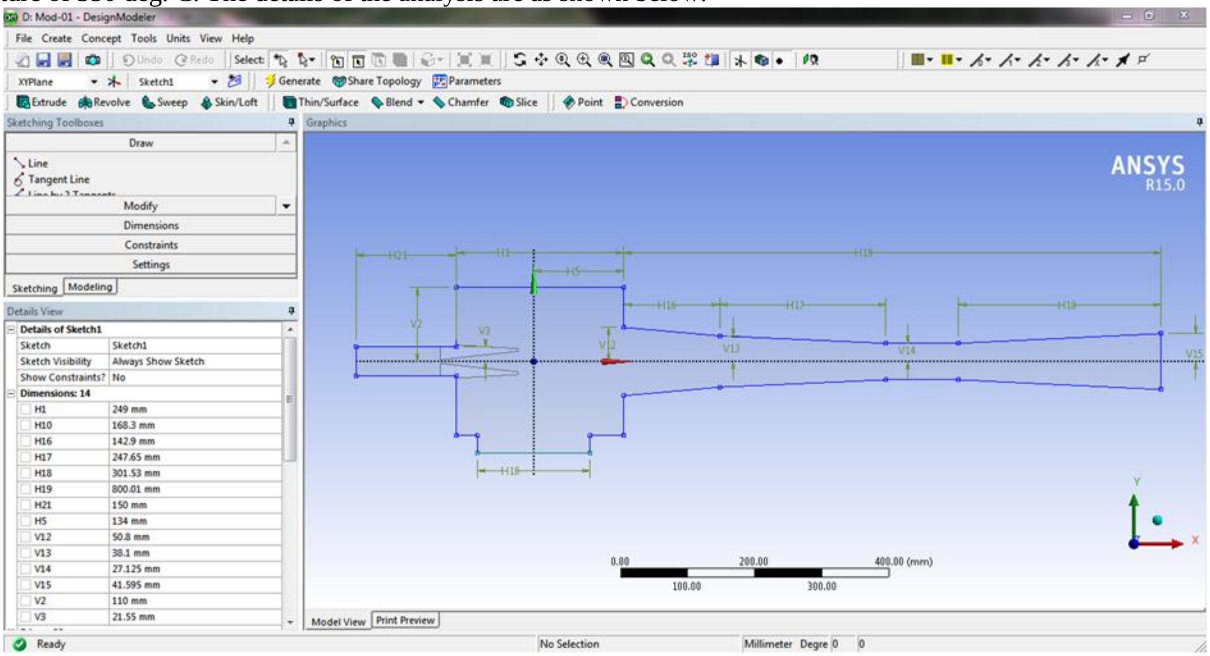
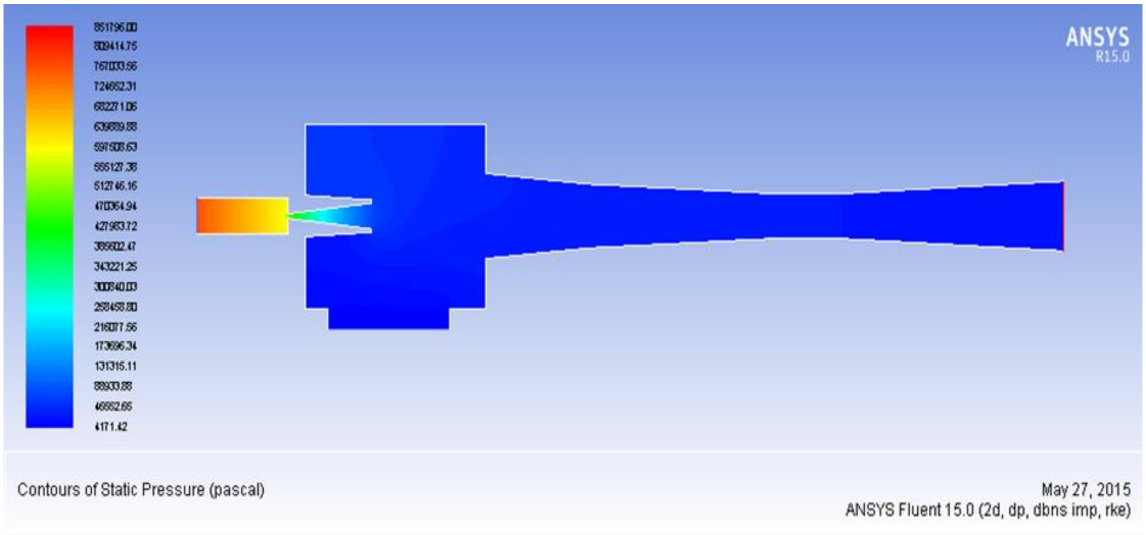


Fig. 4.7: Optimized ejector geometry



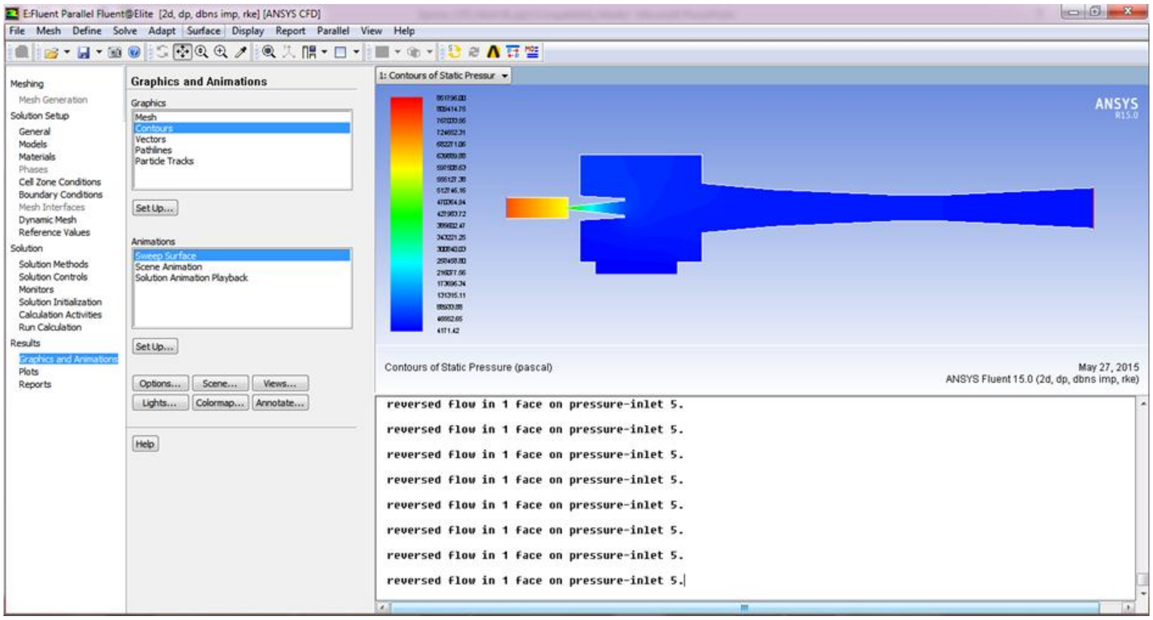


Fig. 4.8: Pressure plot

IV. CONCLUSION

- The ejector performance is first measured using experimental tests and is validated against CFD results.
- Based on the CFD results, it is observed that there is a room to perform design optimization of the ejector without affecting outlet conditions.
- The suction chamber design is optimized by reducing the length of one of its side by 10 mm and the motive inlet steam pressure is reduced to 650000 Pa as compared to 774725 Pa and temperature as 350^0C from 370^0C

The results obtained through the analysis show that despite reducing the steam inlet pressure, the outlet pressure condition remains the same, as such the efficiency of the refrigeration plant is improved since less energy is required to generate motive steam pressure and temperature.

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