International Journal of Thermal Technologies
ISSN 2277 - 4114

Available at http://inpressco.com/category/ijtt

Research Article

Enhancement of Entrainment Ratio in Jet Pump using Constant Rate of Momentum Change Diffuser

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Accepted 8 Jan 2013, Available online 1March 2013, **Vol.3, No.1(March 2013)**

Abstract

In this paper, study on the performance analysis of jet ejector has been carried out using a constant rate of momentum change diffuser. The various losses that occur in different regions of jet ejector have been quantified and an attempt has been made to increase the efficiency of jet ejector by reducing the losses based on minimization of entropy method. In the present work, new technique has been implemented to minimize the momentum difference between the motive and the propelled streams. This was carried out by changing the design of the throat and diffuser profile. The geometrical design parameters were obtained by solving the set of governing equations, a CFD package; FLUENT and it has been effectively used to evaluate the optimum entrainment ratio for a given set of operating conditions.

Keywords*: Jet pump, Entrainment ratio, Irreversibility, CRMC.*

1. Introduction

Jet pump are co-current flow systems, where simultaneous aspiration and dispersion of the entrained fluid takes place. This causes continuous formation of fresh interface and generation of large interfacial area because of the entrained fluid between the phases. The jet pump essentially consists of an assemble comprising of nozzle, converging section, mixing throat and diffuser. According to the Bernoulli's principle when the motive fluid is pumped through the nozzle of a jet pump at a high velocity, a low pressure region is created at just outside the nozzle. A second fluid gets entrained into the jet pump through this low pressure region. The dispersion of the entrained fluid in the throat of the jet pump with the motive fluid jet emerging from the nozzle leads to intimate mixing of the two phases. A diffuser section of the mixing throat helps in pressure recovery. The motive fluid jet performs two functions one, it develops the suction for the entrainment of the secondary fluid and the second; it provides energy for the dispersion of the one phase into the other. This process has been largely exploits in vacuum systems in which high speed fluid stream is used to generate vacuum. The jet ejector essentially consists of nozzle, converging section, mixing throat and diffuser. According to the Bernoulli's principle when fluid is pumped through the nozzle of a jet ejector at a high velocity, a low pressure region is created before the outside of the nozzle. A second fluid gets entrained into the jet compressor through this low pressure region. The dispersion of the entrained fluid in the throat of the ejector with the fluid jet emerging from the nozzle leads to intimate mixing of the two phases (A.Arbel et al,2003). A diffuser section of the mixing throat helps to recover the pressure. The fluid jet performs two functions: 1.It develops the suction for the entrainment of the secondary fluid. 2. It provides energy for the dispersion of the one phase into the other. This process has been largely exploits in vacuum systems in which high speed fluid stream is used to generate vacuum. In the ejector, three main irreversibility's are pure mixing kinetic energy losses, and normal shock wave. The pure mixing and kinetic energy losses occur simultaneously in the mixing section followed by the normal shock wave. Irreversibility due to mixing can be eliminated by appropriate choice of gas. In this aspect, Arbel et al. (2003)analyzed and characterized their reversibility's (pure mixing, kinetic energy, and normal shock wave) of the ejector internal processes to improve the overall efficiency. Eames (2002)introduced the concept of constant rate momentum change (CRMC) method to eliminate the loss due to shock wave for supersonic-jet pumps. Somsak watanawanavet (2005) optimized the design parameters (optimum length, throat diameter, nozzle position, and inlet curvature of the converging section) for high efficiency jet ejector. In the literature review, most of the researchers have concentrated to introduce the new methodology to improve the performance of the jet ejectors. In this regard,

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an attempt has been carried out to introduce the forced draught concept (blower) at the secondary inlet of the jet ejector to improve the performance by reducing the momentum difference between the two streams. This decrease the kinetic energy loss in the mixing area by forced draught system.

2. Description of the Model

A high-pressure fluid (motive fluid) with very low velocity at the primary inlet is accelerated to high velocity jet through a converging nozzle for the liquid jet pump or a converging-diverging supersonic nozzle for the gas ejector. The supply pressure at the inlet is partly converted to the jet momentum at the nozzle exit. Thus the high velocity, low static pressure primary jet induces a secondary flow (propelled fluid) from the inlet or suction port and accelerates it in the direction of the driving jet. The two streams then combine in the mixing section, and ideally the process is complete by the end of this section. A diffuser is usually installed at mixing chamber exit to lift the static pressure of mixed flow. In the present model, the geometry at the throat and the diffuser is modified to constant rate of momentum change method and a pump is used to increase the velocity of the primary stream at the inlet. This reduces the momentum difference during mixing and in turn reduces the kinetic energy losses. The schematic view of the present model is shown in Fig.1. Based on the present model, an efficiency comparison is made to compare the small and large momentum differences between the motive and propelled streams. The mass flow rate and velocity of the primary and secondary fluid are 1kg/s, 10 m/s and 1kg/s, 1 m/s respectively. The efficiency of the jet ejector is found to be 54.5%. If the velocity of the primary fluid is increased to 6 m/s, then the efficiency of the jet ejector is 87.1%. The efficiency is calculated based on Eq. (1).

$$\eta = \frac{E_{kmix}}{E_{km}+E_{kp}} \tag{1}$$

Where
η = efficiency
E_{kmix} = Kinetic energy of mixed stream J/s
E_{km} = Kinetic energy of motive stream J/s
E_{kp} = Kinetic energy of propelled stream J/s

The calculation shows that the efficiency increases substantially when the momentum difference between the motive and propelled streams decreases. This is achieved by increasing the velocity of the motive fluid using a pump, keeping the mass flow as constant.

3. Numerical Study

A 2D model of the jet ejector is created in Gambit. Axi-symmetric solver is chosen in the FLUENT, 3D effects can be reflected by 2D jet ejector model. The geometrical design parameters of the jet ejector were obtained by

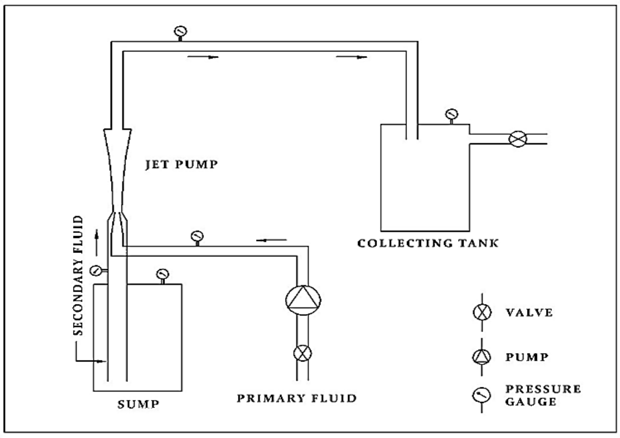


Figure 1(a): Description of the Model

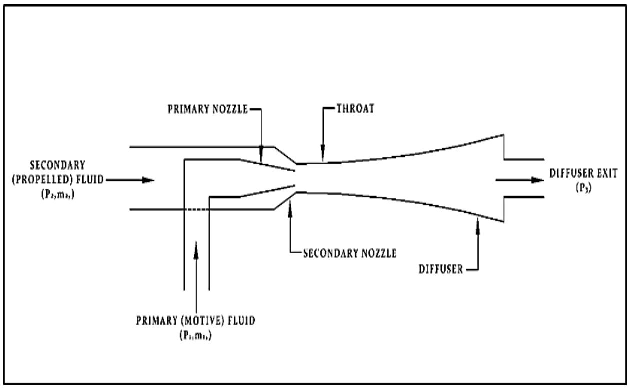


Figure 1(b) Enlarged View of Jet Ejector

solving the steady state Navier-Stokes equations as well as the equation of mass and energy transport for compressible flows, which is given in Eq. 2-4. Turbulent k-ε model was used to solve the equations using CFD package, FLUENT. Grid independent study was carried out. The optimum structured triangular grid size of 1.5 mm is used in the present model. The meshed geometry for conventional and CRMC based jet ejector are shown in Fig. 2. The following boundary conditions are used in the present model. The boundary conditions are (1) Mass flow inlet at nozzle inlet, (2) Pressure inlet at secondary flow inlet and (3) Pressure outlet at exit of the jet ejector. The converged solutions were obtained for the residual values of $10^{-6,}$ $10^{-3,}$ 10^{-6}, 10^{-3}, and 10^{-3} for continuity, momentum, energy, k and epsilon.

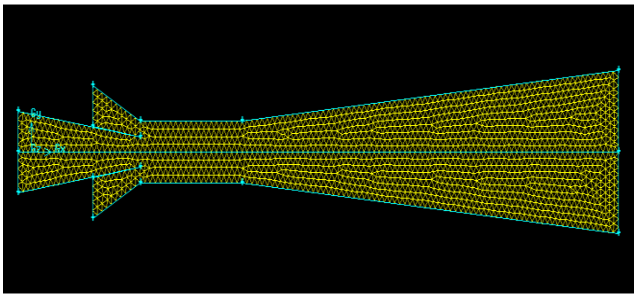
$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \tag{2}$$

$$\frac{\partial(\rho u_i u_j)}{\partial x_i} = \rho g_i - \frac{\partial P}{\partial x_j} + \frac{\partial(\tau_{ij} - \rho u_i u_j)}{\partial x_i} \tag{3}$$

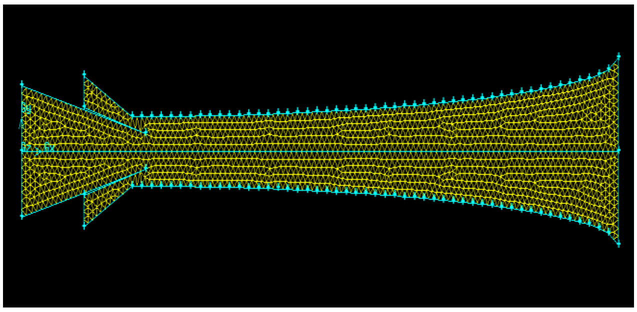
$$\frac{\partial(\rho C_P u_j T)}{\partial x_i} = \frac{\partial\left(\lambda \frac{\partial T}{\partial x_i} - \rho C_P u_j T\right)}{\partial x_i} + \mu\,\Phi \tag{4}$$

Where
τ_{ij} Symmetric stress tensor,

$\rho u_i u_j$, Reynolds stress
$\rho C_P u_j T$ Turbulent heat flux and
$\mu\ \Phi$ Viscous dissipation



(a)Conventional Model



(b)CRMC Based Model

Figure 2: Meshed Geometry for Conventional and CRMC Jet Pump

4. Results and Discussion

The simulated results have helped in understanding the local interactions between the two fluids, and recompression rate which in turn made it possible for a more reliable and accurate geometric design and operating conditions. Many numerical studies about supersonic ejectors have been reported since 1990s in predicting ejector performance and providing a better understanding of the flow and mixing processes within the ejector (Riffat et al [4], Ouzzane & Aidoun, Alexis &Rogdakis, Chunnanond &Aphornratana), pump (Beithou & Aybar [8]) and in mixing processes (Arbel et al). The jet ejectors are designed for ER =1. Fluent simulation shows that the jet ejector designed based on conventional method produces an ER = 0.774, whereas CRMC based jet ejector produces an ER = 0.85. In conventional jet ejector there is drop in ER since shock wave occurs at the end of constant area mixing chamber. Fig 3 shows the static pressure along the axis of the jet ejector. The presence of shock wave increases the static pressure. Since shock wave generation is an irreversible process, there is drop in efficiency of jet ejector. CRMC method eliminates the formation of shock wave in the mixing area. The cross sectional area of the mixing region of jet ejector is not constant. The mixing region and diffuser are replaced by a convergent and divergent diffuser.

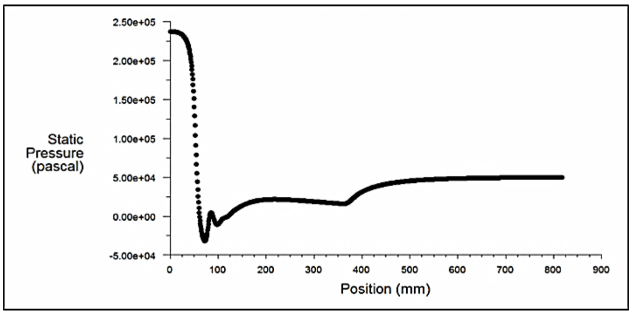


Figure 3: Static Pressure along the Axis of High Efficiency Conventional Jet Pump

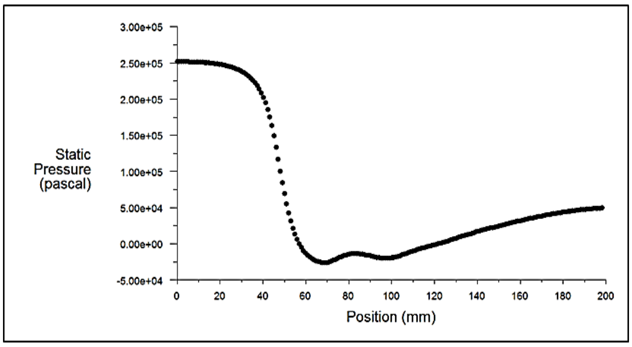
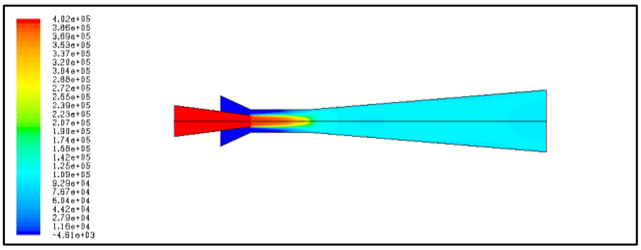
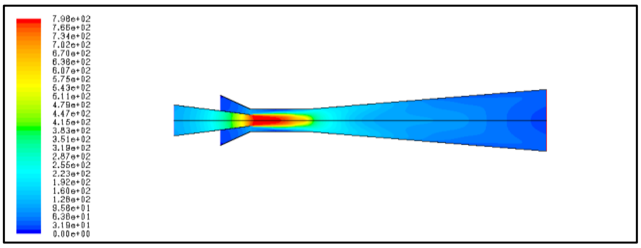


Figure 4: Static pressure along Axis of High Efficiency CRMC Jet Pump

The momentum of primary fluid is transferred at constant rate to secondary fluid by varying the cross section of the pipe. Fig (4) shows the static pressure along the axis of the jet ejector. The raise in the static pressure (pressure recovery from kinetic energy after mixing) occurs at constant rate.



(a) Pressure Contour for Conventional Jet Pump

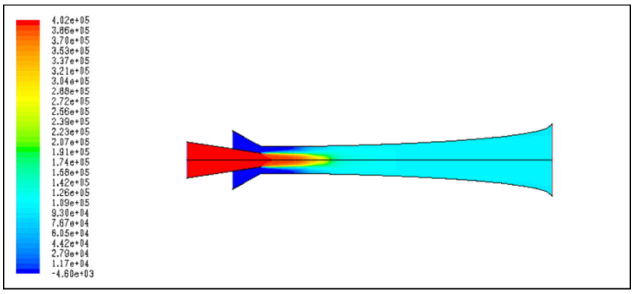


(b) Velocity Contour for Conventional Jet Pump

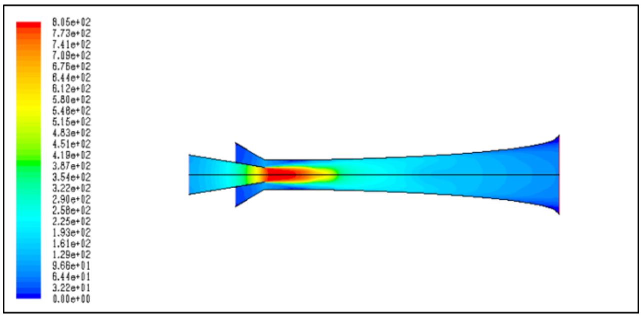
Figure 5: Pressure, Velocity Contours of Conventional Jet Pump

Figure (5) shows the pressure and velocity contour map inside the jet pump with conventional model. It is seen from the contour plot that the maximum flow velocity occurs at the exit of the primary nozzle of the compressor, after which the velocity decreases because of exchange of momentum and mixing with the secondary fluid stream. It is also observed that due to the boundary layer effect a velocity gradient is observed from the wall to the centre line flow of the jet compressor. The view shows the conversion of pressure energy to kinetic energy as the flow becomes supersonic. At the throat, due to momentum exchange with the secondary fluid the flow becomes almost sonic. Further, in the diffuser section the remaining kinetic energy is converted to pressure energy.

Figure (6) shows the pressure and velocity contour map inside the jet ejector. At the exit of the primary nozzle, it is observed that the flow has the maximum velocity similar to the maximum flow velocity is observed. Since the diffuser and throat profile is smooth as it leads the constant momentum transfer, lesser amount of momentum is exchanged with the motive fluid. Due to the minimum momentum difference, the loss of kinetic energy of the motive fluid during mixing is also minimized.



(a) Pressure Contour for CRMC Jet Pump



(b) Velocity Contour for CRMC Jet Pump

Figure 6: Pressure, Velocity Contours of High Efficiency CRMC Jet Pump

In the high efficiency jet pump, the static pressure is almost found constant for the entire mixing and the throat section after which it gradually rises in the diffuser section. This eliminates the shock process which occurs in the conventional method, avoiding the total pressure loss associated with the shock. The estimated pressure lift ratio using the CRMC method is found to increase by 40% over the conventional method.

Conclusion

In the present model, various losses have been analyzed and the performance of the jet pump has been improved by using changing the geometry of the throat and the diffuser profile. Based on that, pure mixing, kinetic energy losses have been reduced, which in turn increased the efficiency of the jet compressor. In the present numerical study, entrainment ratio (ER) is increased from 0.53 to 0.79 due to constant rate of momentum change throat and diffuser. This obviously, reduces the irreversibility's of the jet pump and shows good agreement with the theoretically designed value.

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