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Numerical investigation of the influences of nozzle convergence angle on the water ejector efficiency

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Abstract

Numerical investigations have been carried out on water ejector employing water as a working fluid. The effect of the convergence nozzle angle on its efficiency was investigated. The nozzle convergence angle in this study was varied as 12°, 14°, 16°, 18°, and 20°. Validation is achieved on selected test cases by the comparison between numerical simulations results and experimental measurements. The numerical results were found in good agreement with the experimental results. The water ejector with the nozzle convergence angle of 12° has the maximum efficiency.

Keywords: Water ejector, Nozzle convergence angle, Efficiency, Numerical simulation

1. Introduction

Ejector is also called jet pump or injector [1] which is a device to generate a vacuum in the system. The ejector can be considered as an alternative to replace the mechanical vacuum pump because ejector has a simple construction, no moving parts, low cost, low maintenance, do not need an additional energy source and can use water as the working fluid. Therefore, Ejectors have a wide variety of applications such as refrigeration system [2-3] heating system [4] PEM fuel cells [5] and vacuum drying system [6] and etc.

Ejector consists of four main components: the nozzle, the suction chamber, the throat or mixing chamber and the diffuser as shown in Figure 1. It is based on the venturi principle and theory of jets. It operates by passing primary fluid (called the motive fluid) at high pressure through a nozzle, that part of its potential energy (pressure) [7] is converted into kinetic energy (velocity). The high-velocity jet transports momentum to the outside fluid and causes a suction of the surrounding fluid (called the entrained fluid). The mixing of the motive fluid jet emerging from the nozzle and the entrained fluid in the mixing tube leads to the dispersion of one phase into another in the throat of the ejector. The diffuser section after the mixing chamber or throat helps in pressure recovery.

The nozzle is an essential component of the ejector, this allows the primary fluid to accelerate and assist in entraining the secondary flow. The design of nozzle has a critical role in the working of the ejector. Iran et al. [7] investigated ejectors with area ratios of 0.25, 0.35, and 0.53. Their experiments indicated that the ejectors with an area of 0.35 are the most efficient. Selvaraju et al. [8] designed miniature ejectors with nozzle exit to throat area ratios of approximately 2.6. This is comparable with other literature which gives ratios between 2.5 and 3.1. Vishnu et al. [9] investigated the various nozzle profiles on the performance of two-phase flow jet pump. The profiles employed were circular, conical, and elliptical. It found that the elliptical profile nozzle provides maximum efficiency. However, the convergence angle of the nozzle does not appear in the literature.

Until now and to the author knowledge, the research work on the water ejector is limited to the effect of nozzle convergence angle on water ejector efficiency. The computational fluid dynamic (CFD) analysis was conducted to investigate the effect of nozzle convergence angle.

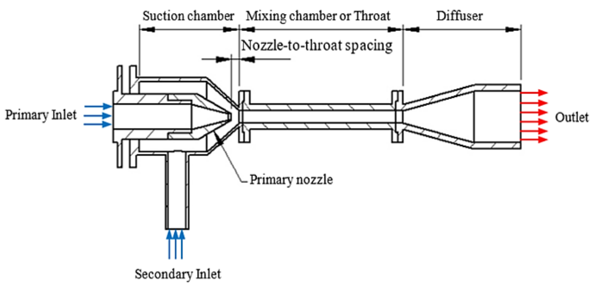

Figure 1 Schematic (not scaled) view of an ejector

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2. Numerical model and validation

2.1 Numerical modeling

In this study investigate the influence of nozzle convergence angle on the water ejector efficiency. The four nozzles were fabricated with four different nozzle convergence angles of 14°, 16°, 18°, and 20°. Three-dimensional simulations of the turbulent fully develop flows of fluid in the water ejector was carried out using the commercial computational fluid dynamic (CFD) software package, Solidworks Flow Simulation. The flow of water ejector was solved in steady state and the standard k-ε turbulence model are applied to model the turbulence characteristics of the flow. This paper assumed the mixture, which primary and secondary inlets are mixed, as single phase homogenous flow. Water (liquid) is used as the working fluid of the model. The schematic diagram of water ejector is shown in Figure 1 to understand the boundary conditions used in the present work. The inlet boundaries are defined as volume flow rate. Since the ejector geometry was down-flow and at atmospheric conditions, the gravity was taken in the negative X direction and the operating pressure was taken as 1 atm at the ejector outlet. All walls are assumed adiabatic and no-slip.

The CFD analysis is conducted in two steps. First, the same condition as that in the experiments is simulated. The CFD model is validated with the experimental data and then more data is analyzed.

2.2 Experimental validation

The experiments were conducted in the real scale water ejector. The nozzle used in this experiment has an angle of 14° that shown in Figure 3. In these experiments, water as the working fluid was considered. The water flow rate at the primary inlet is constant at 1.51 m^3/h. The water flow rate at the secondary inlet is varied between 0 to 2.25 m^3/h. The measured parameters were pressures at inlet and outlet of the ejector. The data obtained from these experiments then use as a basic validation of the CFD code.

The experimental setup is schematically shown in Figure 2. The ejector test system consists of a water ejector, two water tanks, a centrifugal pump, rotameter, a pressure gauge and a piping system, are shown in Figure 2. All geometries of the water ejector were designed to be easily fitted and interchanged with others. The water ejector test rig was a continuous circulation system. A centrifugal pump delivered water from a water tank passes through a control valve (V_1) for controlling the water (motive) pressure, and then water is divided into two branches. One of these branches passes through the bypass valve (V_2), which is used to control the water flow to the ejector. The other branch passes through a water rotameter, a bourdon type pressure gauge (P_m) and a water ejector. The primary flow rate (Q_p) is measured by a water rotameter at the exit of the centrifugal pump while the water pressure is measured using a pressure gauge. In the ejector, nozzle produces high-velocity jet and creates a vacuum in the suction chamber; hence, entrainment of secondary water from water tank 2 takes place. Secondary air pressure is measured by using vacuum pressure gauge (P_s). The secondary flow (Q_s) is measured with an orifice meter. Water from primary inlets and secondary inlets are mixed thoroughly in the throat or mixing chamber. The diffuser converts the energy of this mixture partially from kinetic to pressure. Then the mixture returns to the water

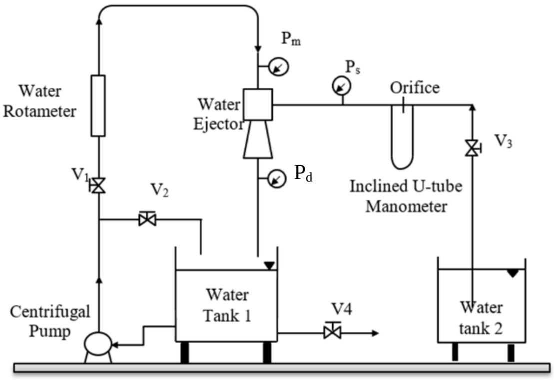

Figure 2 Schematic diagram of the water ejector test set up

tank. The mixture pressure is measured by a bourdon type pressure gauge (P_d).

The efficiency of ejector is generally considered to be a function of the parameters design is following [1]:

Flow ratio, *M* is calculated by secondary flow over primary flow:

$$M = \frac{Q_s}{Q_p}$$

where; Q_p is the primary (motive) flow rate , Q_s is the secondary (suction) flow rate.

In a specific situation, when the primary and secondary fluids have the same density, the volume flow ratio is the same as the mass flow ratio, *M*.

Pressure ratio, N is calculated by secondary flow pressure rise/primary flow pressure drop

$$N = \frac{P_d - P_s}{P_m - P_d}$$

where; P_m is primary (motive) pressure, P_s is secondary (suction) pressure, and P_d is discharge pressure.

Ejector efficiency (always less than 1), overall efficiency for the ejector pump η is found by:

$$\eta = \frac{The\, total\, energy increase of\ suction\ flow}{The\, total\, energy increase of\ driving\ flow} = M \times N$$

$$\eta = \frac{Q_s}{Q_p} \times \left(\frac{P_d - P_s}{P_m - P_d} \right)$$

3. Results

Figure 3(a) shows a comparison between experimental and CFD results of pressure ratio versus flow ratio curves in order to validate model, whereas and Figure 3(b) shows the corresponding efficiency versus flow ratio at water flow rate 1.51 m^3/h for the following configuration: area ratio of 0.2232, nozzle distance ratio(X) of 1.0. The error between experimental and CFD results is 8.93%. Therefore, CFD results agree well with the experimental results.

The results of the effect of changing nozzle convergence angles for the water ejector are shown in Figure 4. The maximum water ejector efficiency obtains for nozzle convergence angle of 12° and driving pressure of 276 kPa is approximate 35.27 % at a flow ratio of 0.99.

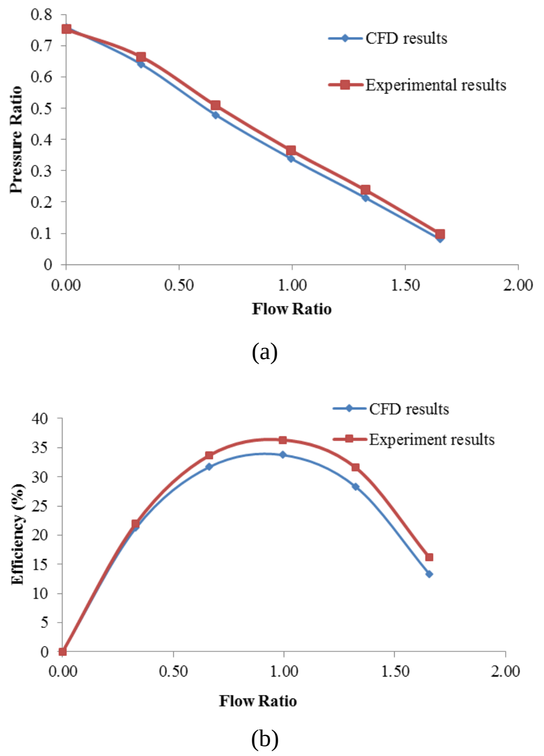

Figure 3 Comparison between experimental and CFD results (a) water ejector characteristic (b) efficiency curve

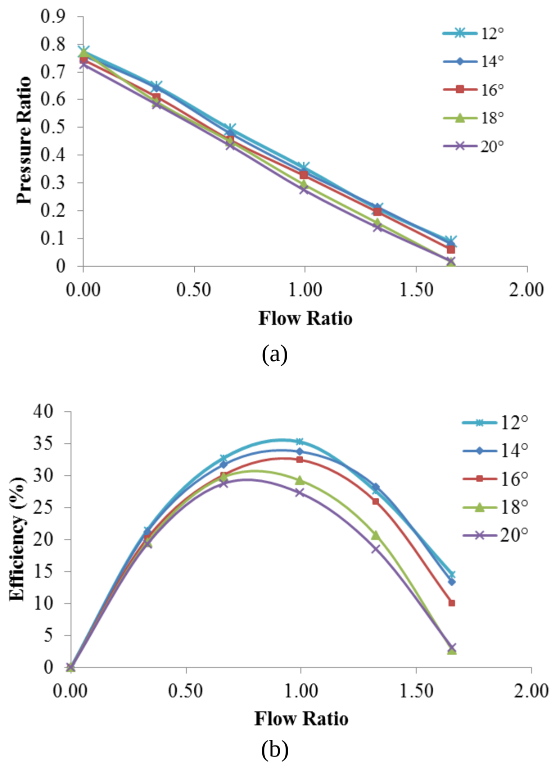

Figure 4 Water ejector efficiency curves for different nozzle convergence angles (a) water ejector characteristic (b) efficiency curve

4. Discussion

This better efficiency of nozzle convergence angle 12° compared with the efficiency of nozzle angle 20° because the energy losses occur when changing nozzle convergence angle. In general, accelerating a fluid causes less turbulence than decelerating it for a given ratio of diameter change.

5. Conclusions

Experimental investigation and CFD analysis of water ejector were conducted. The CFD results are in good agreement with experimental results. Thus, Commercial CFD software can be used to simulate the water ejector, and it is capable of predicting the efficiency of the water ejector to a satisfactory degree.

The water ejector with the nozzle convergence angle of 12° has the maximum efficiency. The variation of the nozzle convergence angle of 12°, 14°, 16°, 18°, and 20°has a small influence of on the water ejector efficiency.

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