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Improving the efficiency of a jet pump using an elliptical nozzle

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This note presents a unique means of increasing the efficiency of a jet pump. Much research has been devoted to the study of elliptical nozzles on jets and their ability to increase the amount of fluid entrainment over round jets with equal perimeters. Since the efficiency of a jet pump is directly related to the ability of the primary jet to entrain fluid, a jet pump is an obvious potential application of these elliptical nozzles. In this study, the efficiency of a jet pump is measured using a jet with a round cross section and a jet with an elliptical cross section that has a 3:1 aspect ratio. At high flowrates, the jet pump using the elliptical jet is shown to have an efficiency that is approximately a factor of 6 greater than the pump using the round jet. © *1999 American Institute of Physics.* [S0034-6748(99)03212-8]

I. INTRODUCTION

The jet pump, or ejector, is commonly used in industrial applications for pumping large volumes of gases at relatively low pressures, such as exhaust fume products of chemical or thermal reactions. The primary advantages of a jet pump over other types of pumps include an increased mechanical life expectancy (no moving parts) and its simple construction. The traditional jet pump produces fluid movement primarily by entrainment. Specifically, the viscous friction of the injected jet fluid drags the surrounding fluid downstream.[1,2]

The traditional jet pump design is illustrated in Fig. 1. It consists of (1) a round jet that is the driving force of the device, (2) the entrainment port which allows connection of the induced suction to an outside device, and (3) the discharge section which is designed to optimize the conversion of jet force to entrainment suction. In the literature reviewed, all jet pumps have been constructed with round jets (i.e., jets produced with nozzles having round cross sections).

II. BACKGROUND

Entrainment of fluid by a round jet is primarily caused by the induced viscous drag of the jet on the surrounding fluid and is a function of the jet's perimeter. Thus, with no other phenomena occurring, a round and an elliptical jet with equal perimeter and mass flowrate would have equal entrainment. However, Gutmark and Ho show that elliptical jets (i.e., jets produced with nozzles having elliptical cross sections) with small aspect ratios can entrain up to eight times more mass of the surrounding fluid than a round jet.[3] Because Gutmark and Ho find that an elliptical jet has a significantly increased ability to entrain surrounding fluid when compared to a round jet with the same perimeter, another entrainment mechanism must be present. They show that this mechanism is related to the production of elliptical vortices from the elliptical jets that cyclically change the orientation of their major and minor axes as they travel downstream. Schadow *et al.* show that the switching of the major and minor axes of the vortices as they travel downstream produces azimuthal instabilities.[4] These instabilities lead to small scale fluctuations that promote mixing and entrainment of the jet fluid with the surrounding fluid.

Both Gutmark and Ho and Schadow *et al.* use probes, such as hot-wire anemometers, to determine the changes in mass flow rate, due to entrainment of a free jet. For these studies, a free jet is defined as one that is exhausts directly into the atmosphere without any potential interference by surrounding physical barriers (i.e., not placed inside of an confining apparatus). The jet pump is a practical application that functions primarily on the ability of a jet to entrain the surrounding fluid. The purpose of this study is to determine if the increased entrainment of an elliptical jet found by of Gutmark and Ho and Schadow *et al.* can be applied to a practical jet pump which inherently places the jet in a confined geometry.

The efficiency of a jet pump is defined as the ratio of the energy available from the jet fluid to the energy expended by the entrained fluid.[5] Calculation of the energy at a location

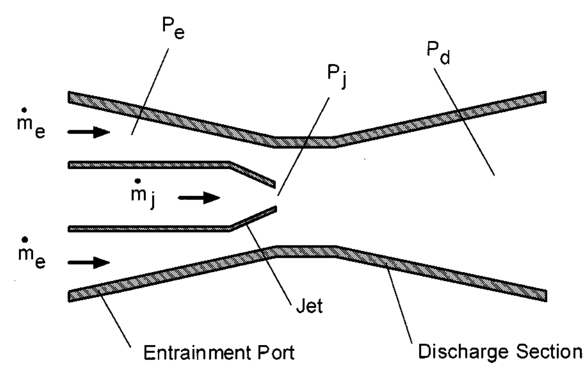

FIG. 1. Traditional jet pump configuration. The jet and entrainment mass flow rates are illustrated by $\dot{m}_j$ and $\dot{m}_e$ respectively. P_e, P_j, and P_d are the entrainment, jet and discharge pressures.

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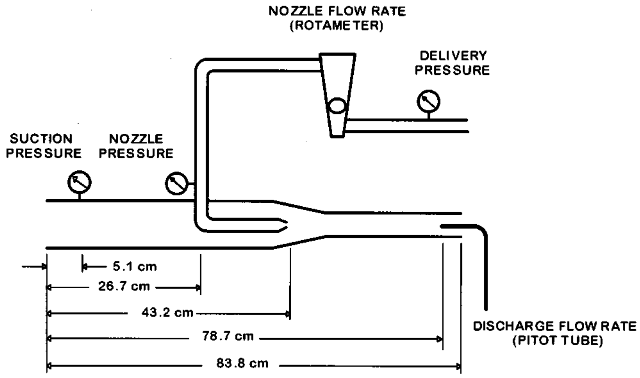

FIG. 2. Schematic of experimental setup.

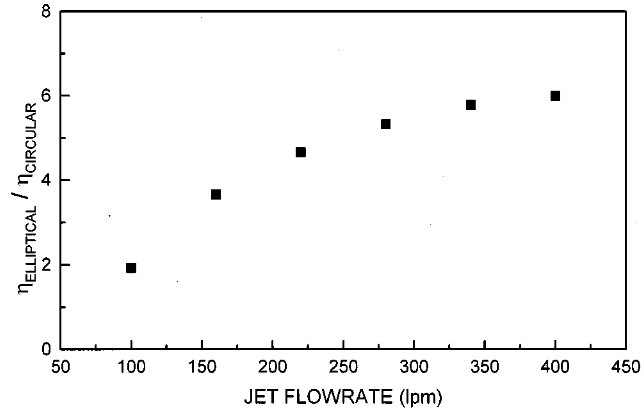

FIG. 3. Plot showing the ratio of the efficiency of the jet pump with the elliptical nozzle to the efficiency of the jet pump with the circular nozzle as a function of the volumetric flow rate of the jet under standard atmospheric conditions.

within the pump is simply the change in enthalpy multiplied by the mass flowrate, $\dot{m}$.

$$E=(\Delta h)\dot{m}.$$

The change in enthalpy of a gas is typically expressed as $\Delta h=\Delta u+\Delta P/\rho$, where Δu is the change in the internal energy and $\Delta P/\rho$ is change in the energy due to the driving pressure head. For fluids that behave as ideal gases, the change in internal energy is a function of the change in temperature only, i.e., $\Delta u=f(\Delta T)$. Since the temperature difference between the fluid exiting the jet and the fluid entering the entrainment port is negligible, the internal energy component of the equation can be neglected. Thus, the enthalpy expression for the driving force of the pump is a function of head pressure only:

$$\Delta h=\frac{\Delta P}{\rho_d},$$

where ρ_d is the density of the fluid at the discharge location.

With the assumption of an ideal gas we know that:

$$\rho_d=\frac{P_d}{RT},$$

where P_d is the pressure at the discharge location, R is the gas constant for the fluid, and T is the temperature of the fluid at the discharge location.

Therefore, the energy, E, between the discharge location and any other location in the system is

$$E=\dot{m}\frac{(\Delta P)RT}{P_d}.$$

Finally, the pump efficiency ratio, η, is the ratio of energy available at the suction port to that expended by the jet.[6]

$$\eta=\frac{\dot{m}_e(P_d-P_e)}{\dot{m}_j(P_j-P_d)},$$

where $\dot{m}_e$ is the mass flowrate at the entertainment area, P_d is the discharge pressure, P_e is the entrainment pressure, $\dot{m}_j$ is the mass flowrate at the jet, and P_j is the pressure at the jet exit.

III. RESULTS

The jet pump for this study is designed closely to known optimal specifications[5,7] and is constructed from PVC piping and fittings. The pump consists of a 5.08 cm diameter suction section, an inlet contraction section with an area ratio of 4:1, and a 2.54 cm diameter mixing section. Both the nozzle with the circular cross-sectional area and the nozzle with the elliptical cross-sectional area have exit perimeters of 4.0 cm. Following the findings of Gutmark and Ho an the elliptical jet has an aspect ratio of 3:1 using the assumption that the optimal aspect ratio for maximum entrainment for a free elliptical jet is also the optimal aspect ratio of maximum entrainment for an enclosed elliptical jet.

The experimental test setup is shown in Fig. 2. Compressed air is supplied to the jet pump and a rotameter is used to measure and regulate the flow at the jet. The delivery

TABLE I. Tabular results showing measurements obtained during the experimental comparison of the efficiency of the jet pump with a circular jet to the efficiency of a jet pump with an elliptical jet.

Nozzle flow rate (lpm)	Nozzle pressure (kPa)		Suction pressure (Pa)		Discharge flow rate (lpm)		Efficiency ratio
	Circular	Elliptical	Circular	Elliptical	Circular	Elliptical	
100	2.7	2.7	−14.9	−32.4	43.0	70.2	1.93
160	4.1	4.1	−42.3	−79.7	70.2	117.7	3.66
220	6.9	7.6	−82.1	−166.8	95.1	172.1	4.66
280	11.0	11.4	−144.4	−273.9	133.6	226.4	5.32
340	16.5	17.0	−221.6	−430.7	165.3	280.8	5.79
400	24.1	24.5	−331.1	−634.9	212.9	360.0	6.01

pressure of the jet is measured using a pressure gage. The nozzle pressure was determined using a second pressure gage, located on the horizontal run of the nozzle section. The suction pressure was measured with a pressure tap in the suction section of the jet pump using a manometer. A Pitot tube was used to measure the velocity pressure of the mixture of the jet and entrained flow in the mixing throat. The results of these tests are shown in Table I.

Figure 3 is a plot of the ratio of the efficiency of the jet pump with the elliptical nozzle to the efficiency of the jet pump with the circular nozzle as the volumetric flowrate of the jet is increased from 100 to 400 lpm under standard atmospheric conditions. The jet pump using the elliptical jet has an efficiency that ranges from approximately a factor of 2 greater that the pump using a circular jet at 100 lpm to a factor of 6 greater at a flowrate of 400 lpm.

This preliminary experiment shows that the efficiency of a jet pump can be significantly improved by simply replacing the jet nozzle that has a round cross section with a jet nozzle that has an elliptical cross section. Although Gutmark and Ho find the nozzle with a 3:1 aspect ratio optimal for jets exiting to ambient surroundings, more experiments are needed to determine if this nozzle geometry is optimal for internal flows. Further study is also required to determine if the diffuser design in the discharge section, which is optimized for circular jets, is appropriate for an elliptical jet.

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