OPTIMIZATION OF A HIGH-EFFICIENCY JET EJECTOR BY
COMPUTATIONAL FLUID DYNAMICS SOFTWARE

A Thesis

by

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ABSTRACT

Optimization of a High-Efficiency Jet Ejector by Computational Fluid Dynamics Software. (May 2005)
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Research was performed to optimize high-efficiency jet ejector geometry (Holtzapple, 2001) by varying nozzle diameter ratios from 0.03 to 0.21, and motive velocities from Mach 0.39 to 1.97. The high-efficiency jet ejector was simulated by Fluent Computational Fluid Dynamics (CFD) software. A conventional finite-volume scheme was utilized to solve two-dimensional transport equations with the standard $k$-$
\theta$ turbulence model (Kim et. al., 1999). In this study of a constant-area jet ejector, all parameters were expressed in dimensionless terms. The objective of this study was to investigate the optimum length, throat diameter, nozzle position, and inlet curvature of the convergence section. Also, the optimum compression ratio and efficiency were determined.

By comparing simulation results to an experiment, CFD modeling has shown high-quality results. The overall deviation was 8.19%, thus confirming the model accuracy. Dimensionless analysis was performed to make the research results applicable to any fluid, operating pressure, and geometric scale. A multi-stage jet ejector system with a total 1.2 compression ratio was analyzed to present how the research results may be used to solve an actual design problem.

The results from the optimization study indicate that the jet ejector efficiency improves significantly compared to a conventional jet-ejector design. In cases with a subsonic motive velocity, the efficiency of the jet ejector is greater than 90%. A high compression ratio can be achieved with a large nozzle diameter ratio. Dimensionless group analysis reveals that the research results are valid for any fluid, operating pressure, and geometric scale for a given motive-stream Mach number and Reynolds ratio between the motive and propelled streams. For a given Reynolds ratio and motive-stream Mach number, the dimensionless outlet pressure and throat pressure are expressed as $C_p$ and $C_{pm}$, respectively.

A multi-stage jet ejector system with a total 1.2 compression ratio was analyzed based on the optimization results. The result indicates that the system requires a lot of high-pressure motive steam, which is uneconomic. A high-efficiency jet ejector with mixing vanes is proposed to reduce the motive-steam consumption and is recommended for further study.
INTRODUCTION

Jet ejectors are the simplest devices among all compressors and vacuum pumps. They do not contain any moving parts, lubricants or seals; therefore, they are considered as highly reliable devices with low capital and maintenance costs. Furthermore, most jet ejectors use steam or compressed air as the motive fluid, which is easily found in chemical plants. Due to their simplicity and high reliability, they are widely used in chemical industrial processes; however, jet ejectors have a low efficiency.

Many factors affect jet ejector performance, including the fluid molecular weight, feed temperature, mixing tube length, nozzle position, throat dimension, motive velocity, Reynolds number, pressure ratio, and specific heat ratio (DeFrate and Hoerl (1959); and Kim et al. (1999)).

Previous research by Riffat and Omer (2001) and Da-Wen and Eames (1995) attempted to study the effect of nozzle position on jet ejector performance. They found that the nozzle position had a great effect on the jet ejector performance, as it determines the distance over which the motive and propelled stream are completely mixed. ESDU (1986) suggested that the nozzle should be placed between 0.5 and 1.0 length of throat diameter before the entrance of the throat section. Holton (1951) studied the effect of fluid molecular weight, whereas Holton and Schultz (1951) studied the effect of fluid temperature.

This thesis follows the style of the AIChE Journal.

A number of researchers made an effort to understand the effect of jet ejector geometry on jet ejector performance. For example, Kroll (1947) investigated the effect of convergence, divergence, length, and diameter of the throat section, nozzle position, induced fluid entrance, and motive velocity. Croft and Lilley (1976) investigated the optimum length and diameter of the throat section, nozzle position, and angle of divergence.

A few literature researchers have studied the effect of nozzle diameter on jet ejector performance. This is a major focus of our proposal. The optimum length and diameter of the throat section, the nozzle position, and the radius of the inlet curvature before a convergence section in a constant-area jet ejector design are investigated for each individual nozzle diameter. The nozzle diameter ratio, defined by $Dn/Dp$, is varied from 0.03 to 0.23. The motive velocity at nozzle exit is varied from Mach 0.39 to 1.98. The back pressure of the ejector is maintained constant at 101.3 kPa. Steam is used as a working fluid.

In this research, the optimum jet-ejector geometry for each nozzle diameter ratio and motive velocity was investigated using Fluent computational fluid dynamic (CFD) software. CFD software has been proved by a number of researchers (Riffat and Everitt, 1999; Hoggarth, 1970; Riffat et al., 1996; Talpallikar et al., 1998; Neve, 1993) as a powerful tool for predicting flow fields inside jet ejectors. Fluent uses a mass-average segregated solver to solve the fundamental transport equations such as continuity, momentum conservation, and momentum conservation for incompressible, Newtonian fluid (the Navier-Stokes equation). The governing equations are discretized in space using a finite volume differencing formulation, based upon an unstructured grid system. The standard $k$-$\varepsilon$ turbulent method is employed to solve the governing equations. The reliability of CFD modeling is examined by comparing a simulation result with an experiment result, which was done by Manohar Vishwanathappa, a graduate chemical engineering student at Texas A&M University. The deviation between both results is 8.19%, thus confirms the model reliability.

Finally, a multi-stage jet ejector system with a total 1.2 compression ratio is analyzed to demonstrate the implementation of the research to solve an actual design problem.
OBJECTIVES

The main objective of this research is to optimize the geometry of a conventional constant-area jet ejector design using Fluent CFD software. The research varies motive velocity and nozzle diameter ratio.

There are four specific research goals in this optimization study:

1. Determine the optimum entrainment ratio.
2. Optimize the throat section, including the length and diameter, the nozzle position, and the radius of inlet curvature before the convergence section.
3. Evaluate the dimensionless pressure of the propelled stream and motive stream, and the efficiency of the optimum design.
4. Analyze a multi-stage jet ejector system with 1.2 compression ratio based on the research results.

The second objective is to verify the reliability of CFD modeling. There are three specific research goals:
1. Verify the accuracy of CFD modeling by comparing a simulation result with an experimental result, which was done by Manohar Vishwanathappa, a graduate chemical engineering student at Texas A&M University.
2. Determine the effect of grid size by comparing between a coarser and a finer grid-size model with various numbers of iterations.
3. Verify the CFD model consistency by studying the effect of potential boundary conditions on simulation results.

By working closely with Ganesh Mohan, a graduate mechanical engineering student at Texas A&M University, the third objective is to implement dimensionless group analysis in the research. The specific research goal follows

1. Investigate a fluid dimensionless variable to make the research result valid for any fluid, operating pressure condition, and geometric scale.

LITERATURE REVIEW

Design and Optimization
In the past, when engineers designed jet ejectors, either a “rule-of-thumb” or “trial-and-error” approach was used. Both approaches may provide unsatisfactory performance, and thus consume too much power, material, and labor.

Conventional jet ejectors are classified by the dimension of the convergence section. There are two types:
1. Constant-pressure jet ejector
2. Constant-area jet ejector

DeFrate and Hoerl (1959) and Kim et al. (1999) discovered that the constant-pressure configuration provides a better performance than the constant-area configuration, because turbulent mixing in the jet-ejector is achieved more actively under an adverse pressure gradient, which occurs in the constant-area jet ejector, rather than under constant pressure (Kim et al., 1999). Stronger turbulent mixing dissipates the ejector performance. DeFrate and Hoerl (1959) provided the mathematical functions, which are valid for both configurations. The mathematical functions are used to calculate:
1. Optimum motive- and propelled-stream velocity as a function of expansion ratio for an arbitrary molecular
weight and temperature
2. Area ratio \((D_n/D_t)\) as a function of entrainment ratio

The jet ejector is classified into two types depending on its convergence configuration:
1. Constant-pressure jet ejector
2. Constant-area jet ejector

The different between both types is shown in Figure 1.

![Jet ejector type](image)

**Figure 1.** Jet ejector type.

The jet ejector performance is mainly affected by mixing, turbulence, friction, separation, and energy consumption in the suction of the propelled stream. To maximize jet ejector performance, enhancing turbulent mixing should be a major consideration. The literatures indicate that the nozzle geometry should be well-designed to boost the tangential shear interaction between the propelled and motive stream. Also both streams should blend completely inside the throat. The jet ejector should be designed properly to diminish turbulence effects. Each part of a jet ejector is explained in the following section. Figure 2 indicates the geometric symbols used in the following section.

![Symbols in jet ejector](image)

**Figure 2.** Symbols in jet ejector (Kroll, 1947).

**Convergence Section**

According to Kroll (1947), Engdahl and Holton (1943); Mellanby (1928); Watson (1933) found that the best design for the convergence section is a well-rounded, bell-mouthed entry. A conical or tapered entry is recommended to have an angle, \(\alpha\), greater than 20 degrees, because the nozzle jet, which has a general angle of about 20 degrees, will not create objectionable shock and eddy losses at the convergence inlet (Mellanby, 1928). Watson (1933) did an experiment and stated that 25 degrees is about the best convergence angle.
Regarding the well-rounded geometry, a conical entry reduces the flow 2%, whereas a coupling and sharp entry reduce the flow 4 and 11%, respectively (Bailey, Wood (1933); Engdahl, and Holton (1943); Stern (1932) (also cited in Kroll (1947)).

**Throat Section**

Kroll (1947) also discusses that Mellanby (1928) and Watson (1933) reported that diffusers with a throat section created a greater vacuum than diffusers without a throat section. Mellanby (1928) also showed that a parallel throat throughout is inferior, but still much better than no parallel throat at all.

The length of the throat section must be designed properly. It should be sufficiently long to create a uniform velocity profile before the entrance of the divergence section. The uniform velocity decreases the total energy losses in the divergence section, thus obtaining better high-pressure recovery (Berge et al., 2000) (also cited in Kroll (1947)).

Two literature sources cited in Kroll (1947) (Duperow and Bossart, (1927); and Keenan and Neumann, (1942)) reported that an optimum throat length is about 7 times the throat diameter, whereas Engdahl (1943) came across with another optimum value of 7.5 times the throat diameter. Additionally, lengths of 5 to 10 times the throat diameter provided within 3% of optimum performance. Although the optimum length increased slightly with pressure and throat diameter, the increase was less than 1 diameter even when these factors were doubled (Keenan and Newmann, 1942). Engdahl (1943) reported that any length between 4 and 14 throat diameters will give within 4% of optimum performance. According to many literature sources, the length should be 7 to 9 times the throat diameter for the best performance.

The optimal throat diameter is sensitive to jet ejector parameters, especially the entrainment ratio. A small change in throat diameter creates a huge change in the entrainment ratio. If the throat area is too large, fluid leaks back into system; if it is too small, choking occurs. So, the throat diameter must be designed properly to obtain the best performance.

**Divergence Section**

Kroll (1947) indicated that the angle of the divergent section, \( \theta \), is usually 4 to 10 degrees. Too rapid a divergence immediately after the throat is not recommended (Kroll, 1947). The divergent length, say from 4 to 8 times the throat diameter, is desired for pressure recovery. The length, however, may be as short as twice the throat diameter if necessary. It was discovered that eliminating the divergence section reduced the entrainment ratio \( (M_{in}/M_p) \) by about 20%.

**Nozzle**

Two factors of the nozzle influence jet ejector performance:
1. Nozzle design
2. Nozzle position

Fewer researchers have studied the effect of nozzle design on jet ejector performance than nozzle position. Hill and Hedges (1974) studied the influence of nozzle design on jet ejector performance. In their experiment, two conically diverging nozzles were tested, but differing in the divergence angle. The exit and throat diameters of the nozzle were fixed in both cases. The experimental results show that the overall jet ejector performance was not influenced by the nozzle design. According to Kroll (1947), a study done by Engdahl and Holton (1943) confirms the above statement. They found that the nozzle, which was designed by conventional methods for a specific pressure, performed only slightly better than a simple straight-hole nozzle at pressure up to 170 psig. Also, a machined nozzle with a convergence section and a 10 degree angle of divergence was only 3 to 6%
better than a 100-psig small pipe-cap nozzle made by drilling a hole in a standard pipe cap. However, altering the nozzle design affects the motive stream velocity. This was studied explicitly by Berkeley (1957). He also found that under normal circumstances, the expansion of motive stream in the ejector of a well-designed nozzle is almost always a fairly efficient part of the overall flow process. Therefore, very little energy is lost in the nozzle. But the task of efficiently converting velocity back into pressure is very difficult because energy is lost in this process. Additionally, Kroll (1947) reported that a poorly shaped nozzle causes unnecessary shock losses and useless lateral expansion, which decrease jet ejector efficiency tremendously.

The position of the nozzle has a greater effect on jet ejector performance than its design. A number of researchers investigated the optimum position of the nozzle in a jet ejector. Croft and Lilley (1976); and Kim et al. (1999) report that turbulence in the mixing tube decreases when the nozzle is placed right at the entrance of the throat section; however, Croft and Lilley (1976) also discovered that when the nozzle moves closer to the mixing tube, the entrainment ratio decreases. ESDU (1986) recommends placing the nozzle exit between 0.5 and 1.0 lengths of throat diameter upstream of the mixing chamber. Not only the jet ejector performance, but also the mixing distance of the motive and propelled streams is affected by the nozzle position. Kroll (1947) has suggested that nozzle position should be adjustable to obtain the best performance using field adjustments. Further, it is important to have the nozzle centered with the throat tube. He also recommended that the nozzle should be cleaned as often as possible for best performance.

**Entrainment Ratio**

An experiment conducted by Mellanby (1928) concluded that for all practical purposes, the entrainment ratio is independent of the inlet position of the propelled stream. Holton (1951) discovered that the entrainment ration is a function of the molecular weight of the fluid, but independent of pressure, and jet ejector design. Figure 3 shows the correlation between the entrainment ratio and molecular weight. Furthermore, Holton and Schulz (1951) discovered that the entrainment ratio is a linear function of operating temperature, but independent of pressure and jet ejector design. Figure 4 displays the effect of the operating temperature on the entrainment ratio.

\[
\text{Entrainment Ratio} = \frac{\text{mass flow rate of the propelled stream}}{\text{mass flow rate of the motive stream}}
\]  

Kroll (1947) had summarized the results of optimized jet ejector geometry from a number of literature sources (see Table 1).
Figure 3. Entrainment ratio as a function of molecular weight (Holton, 1951).

![Graph showing Entrainment Ratio as a function of Gas Temperature (F)](image)

Figure 4. Entrainment ratio as a linear function of temperature for air and steam (Holton and Schultz, 1951).

Table 1. Summary of literature results about the optimization of the jet ejector (Kroll, 1947).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Length of</th>
<th>Angle of Diffuser (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Throat</td>
<td>Divergence</td>
</tr>
<tr>
<td>Air-Jet Air Pumps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>$T$</td>
<td>$R$</td>
</tr>
<tr>
<td>Keenan and Neumann (1942)</td>
<td>$7D_T$</td>
<td>-</td>
</tr>
<tr>
<td>Mellanby (1928)</td>
<td>$4D_T$</td>
<td>$10D_T$</td>
</tr>
<tr>
<td>Kravath (1940)</td>
<td>$1D_T$</td>
<td>$12D_T$</td>
</tr>
<tr>
<td>Miller (1940)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SteamJet Air Pumps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DuPerow and Bossart (1927)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Royds and Johnson (1941)</td>
<td>$10D_T$</td>
<td>$15D_T$</td>
</tr>
<tr>
<td>Langhaar (1946)</td>
<td>$3D_T$</td>
<td>$4D_T$</td>
</tr>
<tr>
<td>Watson (1933)</td>
<td>$2D_T$</td>
<td>$6.7D_T$</td>
</tr>
</tbody>
</table>
Operating and Maintenance

A number of literature references state that pressure is the most critical variable when operating the jet ejector. The actual operating pressure should be evaluated closely during the operation. A jet ejector will not operate properly, causing a broken or unstable vacuum, if it is even a few hundred pascal below its design motive pressure (Knight, 1959). Due to that reason, a steam pressure gage is highly recommended to be located on the steam chest of the ejectors to measure the inlet pressure of the propelled stream.

Three principles should always be followed for controlling steam jet ejectors (Knight, 1959):

1. Each jet ejector in a system operates along a fixed curve of suction pressure versus capacity for a given discharge pressure.
2. Each jet ejector has a fixed minimum suction pressure for a given discharge pressure, below which the jet ejector flow will be disrupted i.e., a pressure at which vapor flow in the diffuser will be reversed, operation below the break pressure is unstable, but if suction pressure increases above the break pressure, a greater pressure is attained at which stable operation returns, with normal flow in the diffuser.
3. Each jet ejector has a maximum discharge pressure for a given load, above which the jet ejector flow will be disrupted. Knight (1959) also presented five ways for automatically controlling the pressure. The advantage and disadvantage of each approach were discussed in the literature.

Finally, Berkeley (1957) introduced six variables that should be considered when selecting a particular design of a steam jet ejector:
1. Suction pressure required
2. Amount of steam available
3. Amount of water available
4. Fluid to be evacuated
5. Equipment cost
6. Installation cost

Internal Flow Field

To enhance jet ejector performance, understanding the flow field mechanism inside the jet ejector is useful. Reinke et al. (2002) found that further away from the nozzle exit, the velocity profile is more uniform across the cross section. Because the viscous action of the jet fluid transfers its kinetic energy to the surroundings, fluid moves slower as the distance increases. The internal behavior of the jet ejector – particularly in the mixing section between the primary and secondary flows and also the effect of nozzle axial position – were studied by Croft and Lilley (1976). The energy contours, which are presented in the literature, reveal that at the mixing point, there is a high rate of thermal energy generation due to the high turbulence length scale in the mixing position. Also, the turbulent length scale decreases gradually through the throat section. This indicates that energy transfers from the motive stream to the propelled stream quickly. Turbulence length scale is a physical quantity related to the size of the large eddies containing energy in turbulent flows (Fluent, 2001). In fully developed flows in pipe, the turbulence length scale is restricted by the pipe diameter.

The flow velocity, temperature, and pressure inside the throat section – an effect of these parameters on the jet ejector performance inside the throat section – were studied by Djebedjian et al. (2000). The velocity distribution indicates the degree of mixing between motive and propelled streams and the quantity of entrained fluid. The length of the mixing tube creates a huge effect for producing a uniform velocity profile at the entrance of the divergence section. The fluid velocity profile inside the throat section is presented in Figure 5A. The pressure increases significantly in the throat and the divergence section as shown in Figure 5B. The static temperature increases because heat is generated from kinetic energy losses in an energy-exchange process. As the fluid velocity decreases, the static temperature increases. The static temperature profile inside the throat section is presented in Figure 5C. The profiles of the fluid velocity and the static temperature are identical but
opposite direction in magnitude.

**Figure 5.** Flow variable profile inside the throat section, A) velocity, B) pressure, C) temperature (Djebedjian et al., 2000).

**Shock Wave**

When the motive-stream velocity exceeds the speed of sound, shock waves are unavoidable inside jet ejectors. Shock waves convert velocity back to pressure, but in an inefficient manner. Shock waves are more severe as the fluid velocity at the diffuser entrance increases. Generally, the motive stream is accelerated to a supersonic velocity through the convergent-divergent nozzle. Then, inside the throat section, the propelled stream is induced by a strong shear force with the motive stream leading to the resulting deceleration of the motive stream. The shock wave occurs in this step. The shock wave system interacts with the boundary layer along the jet ejector surface. The flow inside the ejector is exposed to a strong invicid-viscous interaction. The operating characteristics and performance of a supersonic ejector are difficult to predict using conventional gas dynamic theory. Consequently, the discharge pressure is limited to a certain value. DeFrate and Hoerl (1959) provided mathematical formulations to calculate pressure before and after the shock wave in the throat section, and the subsonic Mach number after the shock occurs. Kim et al. (1999) researched the shock wave inside jet ejectors explicitly. They studied the effect of throat area on the shock wave (see Figure 6). As the area of the throat section increases, a Mach stem reduces to an oblique shock wave. Reflections of the oblique shock result in a multiple oblique shock system (Kim et al., 1999). Mach stem is a shock front formed by the fusion of the incident and reflected shock fronts from an explosion. In an ideal case, the mach stem is perpendicular to the reflecting surface and slightly forward. They also found that the throat dimension strongly affects the shock system inside the mixing tube. Their result indicates that the interaction between the shock system and the wall boundary layer in a constant-pressure jet ejector is noticeably stronger than a constant-area jet ejector. Therefore, it is expected that the flow would be subject to a stronger turbulence field in a constant-pressure (Figures 6A – D), rather than constant-area geometry (Figure 6E). This reduces the jet ejector performance significantly.
The shock wave occurs when the fluid velocity decreases to subsonic velocity. The pressure gradient changes suddenly in the shock wave area. Figure 7 illustrates the shock wave occurring inside the jet ejector.

Figure 6. Iso-Mach contours for various ejector throat area ratios (Kim et al. 1999).

Figure 7. Variation in stream pressure and velocity as a function of location along the ejector (El-Dessouky et al., 2002).
THEORY

Conventional Jet Ejector

Jet ejectors are popular in the chemical process industries because of their simplicity and high reliability. In most cases, they provide the greatest option to generate a vacuum in processes. Their capacity ranges from very small to enormous. Due to their simplicity, conventional 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 (Mains and Richenberg, 1967).

Jet ejectors provide numerous advantages, which are summarized below:
1. Jet ejectors do not require extensive maintenance, because there are no moving parts to break or wear.
2. Jet ejectors have lower capital cost comparing to the other devices, due to their simple design.
3. Jet ejectors are easily installed, so they may be placed in inaccessible places without any constant deliberation.

On the other hand, the major disadvantages of jet ejector follow:
1. Jet ejectors are designed to perform at a particular optimum point. Deviation from this optimum point can dramatically reduce ejector efficiency.
2. Jet ejectors have very low thermal efficiency.

Jet Ejector Application

Due to their simplicity, jet ejectors have been used for various purposes. A number of the principle applications are listed below (Schmitt, 1975).
1. Extraction: suction of the induced fluid.
2. Compression: compression of the induced fluid discharged at the expansion pressure of the driving fluid.
3. Ventilation and air conditioning: extraction and discharge of gas with small differences in compression near atmospheric pressure.
4. Propulsion or lifting: intermediate compression of the fluid discharged at a certain adaptation velocity.
5. Uniform mixing of two streams: providing a uniform concentration or temperature in a chemical reaction.
6. Conveyance: pneumatic or hydraulic transport of products in powder form or fractions.

Operating Principle

As shown in Figure 8, the conventional jet ejector design has four major sections:
1. nozzle
2. suction chamber
3. throat
4. diffuser

Figure 8. Conventional jet ejector design.
The operating principle of ejectors is described below:
1. A subsonic motive stream enters the nozzle at Point 1. The stream flows in the converging section of the nozzle, its velocity increases and its pressure decreases. At the nozzle throat, the stream reaches sonic velocity. In the diverging section of the nozzle, the increase in cross-sectional area decreases the shock wave pressure and its velocity increases to supersonic velocity.
2. The entrained fluid enters the ejector, flowing to Point 2. Its velocity increases and its pressure decreases.
3. The motive stream and entrained stream mix within the suction chamber and the converging section of the diffuser, or they flow as two separate streams and mix together in the throat section.
4. In either case, there is a shock wave inside the throat section. The shock results from the reduced mixture velocity to a subsonic condition and the back pressure resistance of the condenser at Point 3.
5. The mixture flows into the diverging section of the diffuser. The kinetic energy of the mixture is transformed into pressure energy. The pressure of the emerging fluid is slightly higher than the condenser pressure, Point 5 (El-Dessouky et al., 2002).

All jet ejectors, no matter how many stages and whether they are condensing or not condensing, operate on this principle, each stage being another compressor (Mains and Richenberg, 1967).

**High-Efficiency Jet Ejector**

A high-efficiency jet ejector is proposed to increase the efficiency of conventional jet ejectors. In a conventional jet ejector, the high-velocity motive stream is fed to the jet ejector in a horizontal direction, whereas the propelled stream flows into the jet ejector in a vertical direction; thus, the horizontal momentum of both streams is extremely different at the mixing point. This causes turbulence resulting in a lot of energy losses inside the conventional jet ejector, which decreases its performance. A conventional jet ejector is displayed in Figure 9A. To enhance the jet ejector performance, the momentum difference of both streams at the mixing position should be minimized. Following this concept, a high-efficiency jet ejector is generated by placing the nozzle right at the entrance of the throat section rather than the jet ejector inlet. From this modification, the propelled stream is accelerated through the converging section before mixing with the high-velocity motive stream. Consequently, two streams with nearly identical velocities are mixed, which is inherently efficient (Holtzapple, 2001). Because it is a high-efficiency device, when built in multiple stages or a cascade, the overall efficiency can be high (Holtzapple, 2001). A high-efficiency jet ejector is displayed in Figure 9B.
Figure 9. Jet ejector design. A) conventional design, B) high-efficiency design.