A Study of a Fluid Flow in the Jet Ejector System Used in Industrial Applications

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Abstract. Over time, numerous studies have been carried out for jet ejectors used in refrigeration systems for various industrial applications or in solar energy recovery. These ejectors use steam or water as a working fluid because the water has a low cost, chemical stability and is safe to use. Of course, depending on the application of these ejectors in the industry, other fluids can be used. When are made the ejectors, in addition to the selection of the refrigerant, which is very important, it is taken into account, as well as its constructive design has a strong influence on its performance. In general, the compression ratio depends on the nozzle and the diffuser geometry. Compared to other systems for industrial applications, ejector systems have some advantages: simplicity in construction, high spread and low cost. However, we cannot observe that they also have a lower coefficient of performance than conventional systems, which limited the widespread application of ejector systems.

1. Introduction
Recent studies have attempted to find a wider application of the ejector-type systems, generally being used in refrigeration and air conditioning applications, generally in applications that use small amounts of thermal energy, such as that based on solar energy and heat resulting from the various industrial processes [1].

Some studies have shown that by using a variable geometry of the ejectors a high performance can be obtained, implicitly they can be used in different operating conditions. If we simplistically analyze such a refrigeration system with ejector we can see that it consists of: pressure generator, evaporator, condenser, expansion vessel, ejector jet and a circulation pump [2,3].

In this system, the high-pressure fluid coming from the generator passes through the jet ejector and drives the low-pressure fluid from the evaporator. Both fluids are mixed in the center of the ejector and recover some of the pressure in the ejector diffuser; the fluid then goes into the condenser [4].

The condensate is divided into two parts: one part is pumped back to the generator, the other part flows through the expansion vessel and enters the evaporator, the cycle being resumed, the vapors flow again through the jet ejector, thus ending a system of refrigeration cycles [5].

If the whole cycle is examined, it can be seen that the system obtains heat from the heat source in the generator using the circulation pump, so the system produces a cooling effect in the evaporator and then dissipates the heat in the medium through the condenser, figure 1 [6].

From this study we conclude that the ejector is the key component in the refrigeration cycle, analysis and optimization of its design can improve the overall performance of the system. The graph with the flow parameters in an ejector considered ideal is also presented in figure 1.
In this paper we propose to analyze the process inside the jet ejector and thus following this analysis we can optimize its geometric parameters. Thus, the variation of the working fluid flow parameters inside is analyzed, following the entire behavior from the inlet to the fluid outlet from the ejector.

2. Analysis setup
Steam jet ejectors are technological devices that generate vacuum, as we said before, they are found in various applications in the industry. Due to the fact that they have no moving parts, do not require expensive maintenance, can be made of almost any material and can be used in any industrial application [7].

As we have established the cheapest working fluids are water and steam. They can be used successfully in petrochemical processes, thermal compressors, in the food industry for the deodorization of cooking oil and in any other system that uses vacuum.

Therefore, an ejector can be explained as a type of vacuum pump or compressor. In a steam jet ejector, the suction chamber is connected to the diffuser and the steam nozzle by means of flanges. The Venturi diffuser is also composed of two conical areas joined in the middle by means of flanges.

The characteristic dimensions of the main components are necessary to be able to configure the whole system according to our needs, figure 2 [8].

As the air is entrained by the steam under pressure, the mixture passes through the ejector into a Venturi-type diffuser. In the nozzle, its velocity energy is converted into pressure energy, which helps to discharge the mixture at a predetermined outlet pressure. This outlet of the mixture can be discharged into the atmosphere or sent on to a condenser.

As we established in the introduction, the steam jet vacuum systems combine ejectors, capacitors and interconnecting pipes to ensure phase ejection. These systems operate on the ejector-Venturi principle, which relies on the impulse of a high-velocity steam jet to move air and other gases from a pipe or connecting vessel [9].

Figure 3 exemplifies all these components of such an ejector type.
If we analyze the nozzle through which the steam is sent under pressure, we see that it is composed of several components: steam inlet chamber through which the steam is introduced, this chamber is provided with a stopper to prevent steam from leaving this chamber. If necessary, it can be replaced with a pipe through which another working fluid enters, so that there is a premix in this first chamber.

If is necessary, the initial nozzle can be provided with an extension pipe for the whole assembly, figure 4 on which the converging nozzle is assembled from the final section. The extension piece is required to control the discharge of the pressure jet into the vacuum chamber [8].

![Figure 3. Pressured steam nozzle.](image3)

All this initial assembly is connected to the whole assembly by a connecting flange which is threaded to one end of the suction chamber. This nozzle sends the pressure steam further into the suction chamber, creates a vacuum involving another fluid and mixes them so that the resulting fluid is then passed through the Venturi diffuser.

3. Results and discussion
From a constructive point of view, we have in figure 4 a section through the ejector assembly. As mentioned above, the initial high-pressure nozzle is assembled by the mixing chamber by means of the flange with screws and nuts, as well as the assembly of the two sections of the Venturi nozzle, as well as the connection between it and the pipe system.

Because the capacity of a single ejector is determined by its size, a single unit has practical limits on the total compression and flow it can provide. For higher compression, two or more ejectors can be arranged in series. For greater fluid flow capacity, two or more ejectors must be arranged in parallel.

In a multi-stage system, capacitors are usually used between successive ejectors. By condensing the vapor before sending the flow to the next step, the fluid load is reduced. This allows the use of smaller ejectors and thus reduces the main consumption of liquid.

This paper analyzes the flow of the working fluid, and with the help of multiple extensions it can be controlled and analyzed from several points of view and thus to better realize the optimal position of the steam nozzle.

![Figure 4. Dimensional elements of the ejector.](image4)
In figure 5 several positions for discharging the steam nozzle under pressure were established. It started from the discharge before the beginning of the cone of the Venturi tube. The distances established for the nozzle being 17, 32, 37, 42 and 47 mm. Figure 6 shows how the nozzle looks at the size of 32 mm, practically this being aligned with the outer size of the diffusion tube.

![Figure 5](image1.png) ![Figure 6](image2.png)

**Figure 5.** The positions of the ejector head analyzed in the application.  
**Figure 6.** Analysis of fluid flow in the steam outlet area.

In this paper, an analysis was performed by a specialized program SolidWorks which has a module that can analyze the flow of fluids through different geometries. After the three-dimensional realization of the whole assembly, a real situation was simulated by which a steam was sent with a pressure of 10 bar through the initial nozzle [10].

The secondary liquid that is absorbed into the suction chamber has a pressure close to atmospheric pressure. As mentioned, this pressurized steam is mixed with the fluid which is sucked through the suction chamber and sent through the divergent convergent nozzle into the system.

![Figure 7](image3.png)

**Figure 7.** Analysis of flow parameters on the entire section of the ejector:  
(a) Velocities distribution; (b) Pressures distribution.

Figure 7(a) shows the velocities distribution through the entire ejector and in figure 7(b) is presented the pressures distribution graph along the entire length of the ejector from the steam inlet to the nozzle until its final exit from the diffuser.

After initial analysis I set out to do a simulation of fluid flow which is input 5 bar but to follow the flow only in the download, such as shown in figure 6 was taken away 80 in the axis and have taken parameters flow. This area was chosen because it has the highest pressures and velocities according to the first simulations at the inlet pressure of the working bar of 10 bar.
Figure 8. Fluid flow analysis in the nozzle discharge area:
(a) Velocities distribution; (b) Pressures distribution.

Thus, they could be extracted from the suction pressure analysis in relation to the equivalent vapor load calculated at room temperature. The characteristic curves of the flow parameters related to the main axis of the ejector over a distance of 80 mm from the working fluid in the nozzle are shown in figure 8. The pressure and velocity distribution along this distance was simulated at the working pressure of 5 bar.

In the first interval we can observe an increase of the initial fluid velocity through the pressure nozzle, as the fluid velocity increases, the initial pressure decreases constantly along the initial assembly. In the mixing chamber, there is an approximately constant level of the respective velocities for pressures, because here it achieves a relaxation of the steam initially introduced in the ejector.

A third section is due to the Venturi type at the end of this section, the pressure will decrease and the velocity will increase in this area due to its divergent convergent section, and in the final section it will relax following these fluids to be sent further in the installation.

4. Conclusions
We concluded that the ejector size is the most important parameter for the efficient performance of the ejector system. The dimensions of the single-stage ejector presented in this paper provide better performance.

A smaller outlet area of the nozzle can avoid the loss of shock wave energy, the study on the five dimensions can show us the optimal position for different cases. It is also important to choose the Venturi diffuser properly so that the entire ejector is as efficient as possible.

As previously mentioned, the main advantages of steam jet ejectors compared to other types of vacuum units are primarily low cost, they do not require moving parts, which leads to their simple construction. Due to their simplicity, these ejectors are reliable, maintenance is simple and easy to build.

The ejection units can be made of any material that offers good resistance to corrosion and erosion, being easy to install, does not require special foundations or special fasteners. However, the parameters of the ejectors may differ for their different geometries under the same operating conditions.

To optimize these installations, steam jet systems generally combine several ejectors, capacitors and interconnecting pipes to ensure a control of the duty and pressure of the working fluids, thus an optimization of them, while maintaining low costs.

5. References
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