

## **Review of Solar Ejector Expansion Refrigeration System**

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### **ABSTRACT**

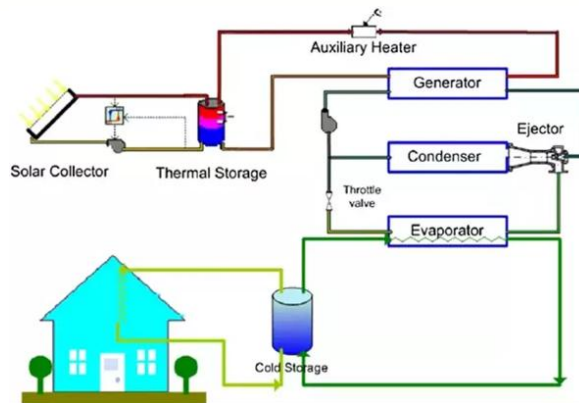
Refrigeration forms the basic essence of living comfort. SOLAR Ejector Expansion Refrigeration Cycle is not so commonly used method of refrigeration. It increases the efficiency by almost 45% over the basic cycle, utilising the energy wasted. This paper aims to showcase the real features of this method in a hope that it finds its way out in the commercial industry. In RECENT SCENARIO, the use of solar energy for the refrigeration purpose has been increasing day by day. The cooling path is basically depends on the amount of solar radiation. The more amount of solar radiation directly increases the C.O.P. of the system and are used where good heat sink are available. A low temperature heat source could be used to drive the ejector refrigeration system, making this system suitable for integration with the solar thermal energy. The system performance depends on the working fluid (refrigerant) chosen, operating conditions and ejector geometry. An ejector refrigeration cycle, using natural working fluids generates good performance and lower environmental impact, rather than traditional working fluids. The most significant losses in the system are in solar collector and ejector. SOLAR Ejector refrigeration is solar driven technology which utilizes low grade energy for its operation.

**Keyword:** *cop, constant pressure ejector, low grade energy, solar ejector expansion refrigeration system .*

### **I INTRODUCTION**

Henry Giffard invented the condensing-type injector in 1858. The background of Giffard's invention was to find a solution to the problem of feeding liquid water to replenish the reservoir of steam engine boilers. Since then, ejectors have been studied intensively for a large number of different applications. Typical applications are reviewed with a special emphasis on how ejectors can be utilized to improve the performance of air-conditioning and refrigeration systems. In the past, ejectors have mostly been used in two different cycles for refrigeration purposes. In 1910, Leblanc introduced a cycle having a vapour jet ejector. His setup allowed producing a refrigeration effect by utilizing low-grade energy. Since steam was widely available at that time, the so-called steam jet refrigeration systems became popular in air-conditioning of large buildings and railroad cars. Nowadays, such cycles are used to harness solar heat or other low-grade heat sources. The patent by Gay (1931) described how a two-phase ejector can be used to improve the performance of refrigeration systems by reducing the inherent throttling losses of the expansion valve.

Special emphasis is put on how ejectors are currently being applied to improve the performance of transcritical R744 systems. Residential and commercial air-conditioning consumes over 15% of all electric energy generated and creates two sources of environmental pollution: one is the ozone-depletion effect of traditional refrigerants belonging to CFC groups, and another is the emission of greenhouse gases connected with



the electricity generation. Additionally, with energy costing constantly, industry is looking to reduce electricity expenses as a means of lowering their fixed costs in order to stay competitive. Instead of pressurizing the refrigerant by a mechanical compressor, a pump compresses the liquefied refrigerant, then heat is added to evaporate it and

finally the refrigerant is recompressed in an ejector without any mechanical energy spent. The main difference between this cycle and the conventional refrigeration cycle, is that it requires three heat sources at different temperatures rather than two, namely at the generator level, which is the temperature of the solar energy, at a condensing level, which is the atmosphere temperature (heat sink) and the evaporator temperature required for cooling effect. Thus, another type of refrigeration system currently being used is the absorption type refrigeration system which is powered from heat energy which, however, must be at a fairly high temperature level. Still another type of refrigeration system is the ejector type refrigeration system which is likewise powered from heat energy at a fairly high temperature level. Thus, from the foregoing it can be realized it would be desirable to provide a refrigeration system which could be powered by heat energy at a lower temperature level than required by the present absorption type and ejector type refrigeration systems. A solar-driven ejector refrigeration system has been selected as a case study for a further detailed investigation. A low grade heat source could be used to drive the ejector refrigeration cycle, making the system suitable for the solar thermal collector. System performance depends on the choice of working fluid (refrigerant), operating conditions and ejector geometry

Cooling systems are necessary in mid-latitude sunny regions where a plentiful supply of solar radiation can be exploited. Solar thermal energy is the most abundant source of renewable energy available where approximately  $1.08 \times 10^{14}$  kW reaches the earth's surface (Thirugnanasambandam et al., 2010). A thermally driven cooling system, like the Pulsed Refrigeration System (PRS) described here, would be well-suited in rural areas without access to grid electricity and could also reduce power consumption in urban areas. Concentrating solar collectors or industrial processes that produce significant amounts of low grade thermal energy can be used as a heat source. Ejectors have no moving parts and utilize a high pressure stream to entrain and pressurise a low pressure stream. Ejector-based cooling systems (ECS) offer the advantage of simplicity by eliminating the need for a

compressor in the refrigeration part of the cycle. Most ejector based systems, whether driven by solar or waste heat, require the refrigerant to be circulated either by an electric pump, a significant pressure head between the cold and hot side. An ejector compresses the flow rather than a conventional compressor. The compact design lends itself to small scale applications such as high powered electronic component cooling or household refrigerators.

## **II.SOLAR POWERED REFRIGERATION**

Solar energy can be utilised as a thermal heat source or converted to electrical energy to power a refrigeration cycle. Such systems are more complex than conventional VCR systems and often do not increase the COP however are able to reduce electrical power consumption. The energy savings result in a decreased load on the electricity grid.

The demand of energy is increasing day-by- day. To meet the demands of energy new techniques are being developed. Ejector refrigeration system can be driven by the low grade thermal energy such as solar energy, waste industrial heat and geothermal energy where as Conventional vapour compression refrigeration system runs with the help of high grade mechanical energy and electrical energy. Ejector refrigeration system in its current phase of development has a coefficient of performance very low than vapour compression systems but helps in saving the energy. Keenan J.H., Neumann E.P. and Lustwerk F. in 1950[1] conducted an investigation of ejector design by analysis and experiment. A one- dimensional method of analysis of ejector was presented. The analysis considered mixing of primary and secondary streams at constant pressure and mixing of streams at constant area. For the analytical condition considered, better performance obtained when constant pressure mixing is employed. Sun D.W. in 1999[2] did comparative study of the performance of an ejector refrigeration cycle operating with various refrigerants. The results show that steam jet systems have very low coefficient of performance values, the system using R152a as refrigerant has better performance. Grazzini G. and Rocchetti A. in 2002 investigated the numerical optimisation of a two-stage ejector refrigeration plant. A simulation program numerically searches the maximum coefficient of performance at given external inlet fluid temperatures as a function of mass flows, dimensions and temperature differences in the heat exchangers. Comparison of performance of the system with environment friendly refrigerants (R134a, R152a, R290, R600a and R717) is made. Among the working fluids considered, the system with 134a gives better performance. Kashyap S. in 2011[10] conducted a simulation program on the basis of one dimensional mathematical model to analyse the performance of ejector refrigeration cycle with working fluid R410a and also compared with performance of R134a. A performance comparison is made on various operating condition and ejector geometry. The results showed that performance of R134a is better than R410a. Theoretically, in a refrigeration cycle, the pressure drop is considered as an isenthalpic process where the enthalpy remains constant. However, isenthalpic process causes a decrease in the evaporator cooling capacity due to energy loss in the throttling process. An efficiency-enhancing alternative was proposed to recover this energy loss, which uses an ejector that can be used to generate isentropic condition where the entropy remains constant in the throttling process. This method uses a two-phase ejector as an expansion device while the conventional refrigeration cycle uses an expansion valve. A

typical ejector consists of a motive nozzle, a suction nozzle or receiving chamber, a mixing section and a diffuser. High pressure motive stream expands in the motive nozzle and its internal energy converts to kinetic energy. The high speed motive stream entrains low pressure suction stream into the mixing section. Both streams exchange momentum, kinetic and internal energies in the mixing section and become one stream with almost uniform pressure and speed. The stream converts its kinetic energy into internal energy in the diffuser to reach a pressure higher than the suction stream inlet pressure.

Under all other circumstances, the motive nozzle discharge pressure is, optimally, greater than that of the suction nozzle. The two-phase ejector refrigeration cycle enables the evaporator to be flooded with refrigerant, resulting in a higher refrigerant-side heat transfer coefficient. EERC expands the liquid refrigerant in two steps. The first step is through a specifically designed nozzle where the liquid is used to increase the pressure of the gas returning to the compressor. After this stage, the liquid refrigerant is collected in a receiver where it is metered into the evaporator by conventional methods.

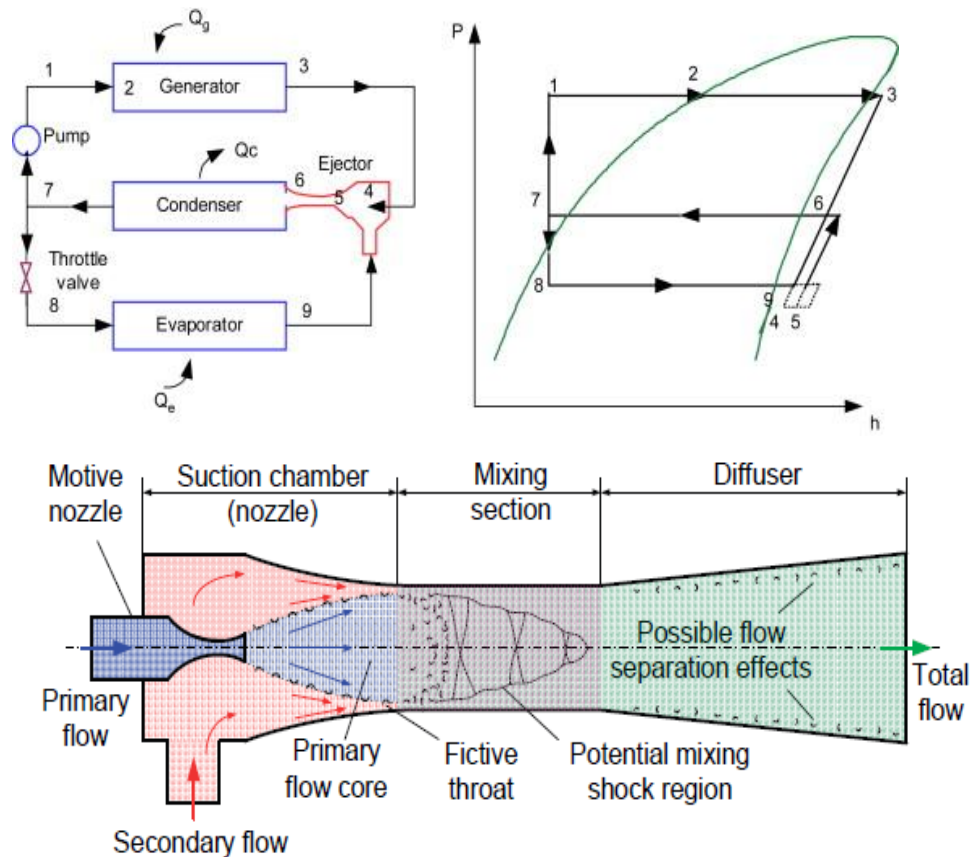
## 2.1. Ejector Working Principle

A typical ejector consists of a motive nozzle, a suction chamber, a mixing section, and a diffuser. The working principle of the ejector is based on converting internal energy and pressure related flow work contained in the motive fluid stream into kinetic energy. The motive nozzle is typically of a converging-diverging design. This allows the high-speed jet exiting the nozzle to become supersonic.

Depending on the state of the primary fluid, the flow at the exit of the motive nozzle might be two-phase. Flashing of the primary flow inside the nozzle might be delayed due to thermodynamic and hydrodynamic non-equilibrium effects. The high-speed jet starts interacting with the secondary fluid inside the suction chamber. Momentum is transferred from the primary flow which results in an acceleration of the secondary flow. An additional suction nozzle can be used to pre-accelerate the relatively stagnant suction flow. This helps to reduce excessive shearing losses caused by large velocity differences between the two fluid streams. Depending on the operating conditions both the supersonic primary flow and the secondary flow might be choked inside the ejector. Due to static pressure differences it is possible for the primary flow core to fan out and to create a fictive throat in which the secondary flow reaches sonic condition before both streams thoroughly mix in the subsequent mixing section. The mixing section can be designed as a segment having a constant cross-sectional area but often has a tapered inlet section. Most simulation models either assume mixing at constant area associated with pressure changes or mixing at constant pressure as a result of changes in cross-sectional area of the mixing section. The mixing process is frequently accompanied by shock wave phenomena resulting in a considerable pressure rise. The total flow at the exit of the mixing

section can still have high flow velocities. Thus, a diffuser is used to recover the remainder of the kinetic energy and to convert it into potential energy, thereby increasing the static pressure. Therefore, the ejector acts as a motive-flow driven fluid pump used to elevate the pressure of the entrained fluid. The two major characteristics which can be used to determine the performance of an ejector are the suction pressure ratio and the mass entrainment ratio. The suction pressure ratio is defined as the ratio of diffuser exit pressure to the pressure of the

suction flow entering the ejector. The mass entrainment ratio is defined as the ratio of suction massflow rate to motive mass flow rate.



## 2.2. An Ejector Refrigeration Cycle

The processes of the ejector refrigeration subsystem are represented in a pressure-enthalpy diagram. The model of the ejector refrigeration subsystem is based on the thermodynamic states in each operating point and the following equations. In the following nomenclatures in this section (section), the numbers in the subscription refer to the condition. Subscription 'm' refers to the condition in the mixing chamber of the ejector, Subscription 'g' refers to the condition in the generator, Subscription 'c' refers to the condition in the condenser, Subscription 'e' refers to the condition in the evaporator, Subscription 'is' refers to the isentropic condition.

## 2.3. Entrainment Ratio and Coefficient of Performance

The mass ratio or so called the entrainment ratio can be written as,1

$$\omega = \frac{m_e}{m_g} = \sqrt{\{(\eta_N * \eta_d) * \left(\frac{h_N - h_{4,is}}{h_{6,is} - h_5}\right)\}} - 1$$

The product of the isentropic efficiency of the nozzle ( $\eta_N$ ) and the isentropic efficiency of the diffuser ( $\eta_D$ ) may be referred to as the ejector isentropic efficiency ( $\lambda$ ),

$$\lambda = \eta_N * \eta_D$$

Another important criterion for the ejector is the compression ratio, which is defined as the pressure ratio

between the condenser and the evaporator  $r_p = \frac{p_c}{p_e}$

The efficiency of the ejector cooling subsystem is generally expressed in terms of both the entrainment ratio,  $\omega$ , and a coefficient of performance. Neglecting the work input to the pump, the thermal COP of the ejector refrigeration system is defined as the ratio between cooling capacity and necessary heat input, as :

$$COP_{eje} = \frac{Q_e}{Q_c} COP_{eje} = \frac{m_e(h_9 - h_8)}{m_g(h_3 - h_1)}$$

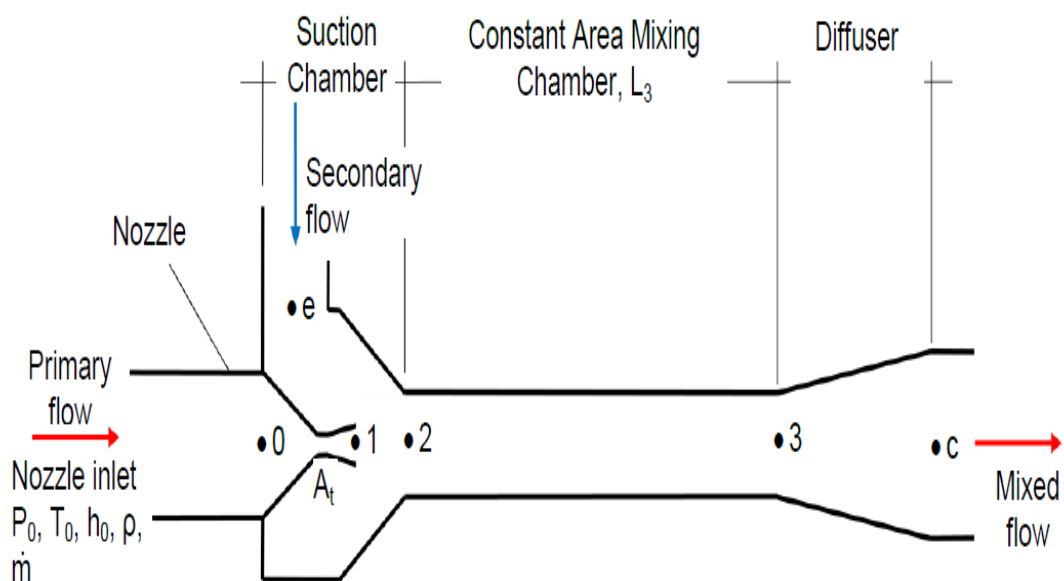
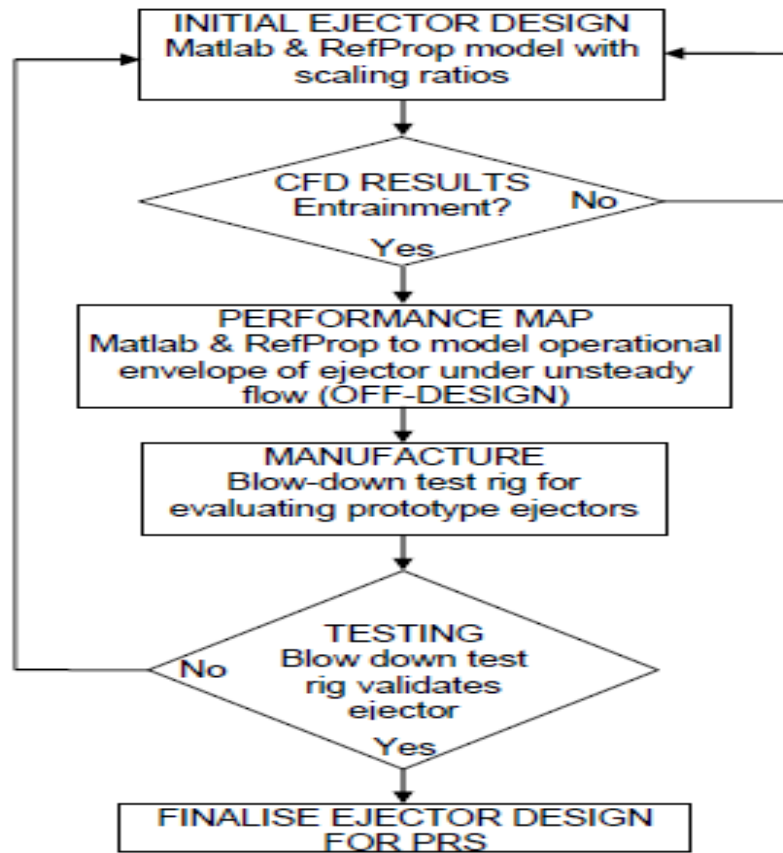
Entrainment ratio and cop are mainly the parameters used to measure the performance of the refrigerating system and they are the one which mainly describe the system output .They help in analysing the performance of the system under the proposed conditions i.e physical and external conditions.

### **III.REFRIGERANT USED**

There are several refrigerants are available which could be used in ejector air conditioning system. Many studies were made regarding ejector system in which are R-134a, R-717, R-718, or R-123 could be used as a working substance for producing refrigerating effect. Some physical properties of R-134a are given below due to which it is easy to choose the refrigerant for this purpose. (1) It is stable, non-flammable and non-toxic. (2) The latent heat at -15°C is 195 kJ/kg. (3) The leak may be detected by using a soap solution of by electrode detector.

#### **3.1.Working Steps**

- The system consists of two loops, the power loop and the refrigeration loop.
- In the power loop, low-grade heat, QG, is used to evaporate high pressure Liquid refrigerant
- The high pressure vapour generated (primary fluid) flows through the ejector where it accelerates through the nozzle.
- The decrease in pressure that occurs induces vapour from the evaporator (secondary fluid) at point 2.
- The fluid stream (mixed) then flows to the condenser where it is condensed rejecting heat to the environment, Qc.
- A major portion of the liquid refrigerant exiting the condenser at point 4 is then pumped to the generator for the completion of the power cycle.
- The remaining liquid refrigerant is expanded through an expansion device.



## **. EJECTOR DESIGN**

An ejector consists of four main components; the nozzle at the primary inlet, the suction chamber housing the secondary inlet, the constant-area mixing chamber and the recovery diffuser. The primary flow isentropically expands and accelerates through the convergent-divergent nozzle to reach supersonic velocity (process 0-1). The secondary flow is entrained into the lower pressure suction chamber (point e). The primary and secondary flows then mix in the mixing chamber (process 2-3) where a shock wave forms and pressure is mostly recovered. The resulting stream regains pressure in the diffuser (process 3-c). The process of optimising the ejector design is presented in the flow chart:

## **V .KEY DRIVERS TO ENCOURAGE UPTAKE**

The main drivers to encourage uptake of the technology are:

- Successful demonstration of the benefits of the technology in applications where there is sufficient waste heat or in tri-generation systems.
- Rising energy costs that could encourage the more effective utilisation of waste heat and better thermal integration of processes in food manufacturing.
- Develop ejectors that can operate with other natural refrigerants apart from water, such as CO<sub>2</sub> and hydrocarbons, to extend the range of applications to below 0°C.

To simplify the theoretical model of the ejector expansion refrigeration cycle, the following assumptions are made:

1. Neglect the pressure drop in the gas cooler and evaporator and the connection tubes.
2. No heat losses to the environment from the system, except the heat rejection in the gas cooler.
3. The vapour stream from the separator is saturated vapour and the liquid stream from the separator is saturated liquid.
4. The flow across the expansion valve or the throttle valves is isenthalpic.
5. The compressor has a given isentropic efficiency.
6. The evaporator has a given outlet superheat and the gas cooler has a given outlet temperature.
7. The flow in the ejector is considered a one-dimensional homogeneous equilibrium flow.
8. Both the motive stream and the suction stream reach the same pressure at the inlet of the constant area mixing section of the ejector. There is no mixing between the two streams before the inlet of the constant area mixing section.
9. The expansion efficiencies of the motive stream and suction stream are given constants. The diffuser of the ejector also has a given efficiency.

## **VI CONCLUSION**

An ejector expansion refrigeration cycle is proposed to reduce the expansion process losses of the basic refrigeration cycle. A constant pressure-mixing model for the ejector was used to perform a thermodynamic cycle analysis of the ejector expansion refrigeration cycle. The effect of the entrainment ratio and the pressure drop in the receiving section of the ejector on the relative performance of the ejector expansion cycle was found



by theoretical model. It was found that the SOLAR ejector expansion cycle improves the COP by more than 45% compared to the basic cycle for typical air conditioning application. Considering the impact of Ozone Depletion Potential (ODP) & Global Warming Potential (GWP) solar driven refrigeration system shows a very prospective alternative in refrigeration system. Solar energy is available free & environment friendly. Also solar energy intensity is high in northern part of India that gives it the tremendous future potential as environment friendly energy source. By eliminating a compressor, the pulsed refrigeration system described here reduces system complexity. An optimised ejector would make possible a pump-free cooling system driven either by waste heat or solar energy. Use of solar driven ejector cycle which is environment friendly and the use of refrigerant r134a makes it more than a desired system as per the current scenario of what the real debate is all about. Addition of compressor increases the COP of the system and can be used for commercial purpose.

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