Review of Solar Ejector Expansion Refrigeration System

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ABSTRACT

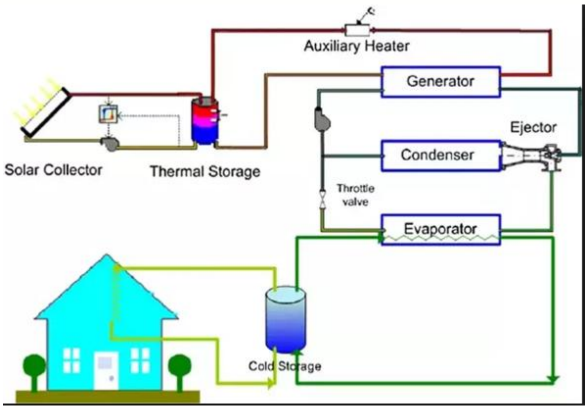
Refrigeration forms the basic essence of living comfort. SOLAR Ejector Expansion Refrigeration Cycle is not socommonly used method of refrigeration. It increases the efficiency by almost 45% over the basic cycle, utilising the energy wasted.This paper aims to showcase the real features of this method 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 byday. The cooling path is basically depends on the amount of solar radiation. The more amount of solarradiation directly increases the C.O.P. of the system and are used where good heat sink are available. A lowtemperature heat source could be used to drive the ejector refrigeration system, making this system suitable forintegration with the solar thermal energy.The system performance depends on the working fluid (refrigerant) chosen, operating conditionsand ejector geometry. An ejector refrigeration cycle, using natural working fluids generates good performanceand 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 asolution to the problem of feeding liquid water to replenish the reservoir of steam engine boilers. Since then, ejectorshave been studied intensively for a large number of different applications.Typical applications are reviewed with a special emphasis on how ejectors can be utilized toimprove the performance of air-conditioning and refrigeration systems. In the past, ejectors have mostly been usedin two different cycles for refrigeration purposes. In 1910, Leblanc introduced a cycle having a vapour jet ejector. Hissetup allowed pro-ducing a refrigeration effect by utilizing low-grade energy. Since steam was widely available atthat time, the so-called steam jet refrigeration systems became popular in air-conditioning of large buildings andrailroad cars. Nowadays, such cycles are used to harness solar heat or other low-grade heat sources. The patent byGay (1931) described how a two-phase ejector can be used to improve the performance of refrigeration systems byreducing the inherent throttling losses of the expansion valve.

Special emphasis is put on how ejectors are currently beingapplied to improve the performance of transcritical R744 systemsResidential and commercial air-conditioningconsumes over 15% of all electric energy generatedand creates two sources of environmental pollution:one is the ozone-depletion effect of traditionalrefrigerants belonging to CFC groups, and another isthe emission of greenhouse gases connected with



theelectricity generation. Additionally, with energy costrising constantly, industry is looking to reduceelectricity expenses as a means of lowering their fixedcosts in order to stay competitive. Instead of pressurizing therefrigerant by a mechanical compressor, a pumpcompresses the liquefied refrigerant, then heat isadded to evaporate it and

finally the refrigerant is recompressedin an ejector without any mechanicalenergy spent. The main difference between thiscycle and the conventional refrigeration cycle, is thatit requires three heat sources at different temperaturesrather than two, namely at the generator level, whichis the temperature of the solar energy, at a condensinglevel, which is the atmosphere temperature (heat sink)and the evaporator temperature required for coolingeffect. Thus, another type ofrefrigeration system currently being used is theabsorption type refrigeration system which is poweredfrom heat energy which, however, must be at a fairlyhigh temperature level. Still another type ofrefrigeration system is the ejector type refrigerationsystem which is likewise powered from heat energy ata fairly high temperature level. Thus, from theforegoing it can be realized it would be desirable toprovide a refrigeration system which could bepowered by heat energy at a lower temperature levelthan required by the present absorption type andejector type refrigeration systems.A solar-driven ejector refrigeration system has beenselected as a case study for a further detailedinvestigation. A low grade heat source could be used to drive the ejector refrigeration cycle, making thesystem suitable for the solar thermal collector. Systemperformance depends on the choice of working fluid(refrigerant), operating conditions and ejectorGeometry

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 1.08e14 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 area 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 utilise a high pressure stream to entrain and pressurise a low pressure stream. Ejector-based cooling systems (ECS) offer the advantage of sim-plicity 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 beingdeveloped. Ejector refrigeration system can be driven by the low grade thermal energy such as solar energy, wasteindustrial heat and geothermal energy where as Conventional vapour compression refrigeration system runs with thehelp of high grade mechanical energy and electrical energy. Ejector refrigeration system in its current phase ofdevelopment has a coefficient of performance very low than vapour compression systems but helps in saving theenergy. Keenan J.H., Neumann E.P. and Lustwerk F. in 1950[1] conducted an investigation of ejector design byanalysis and experiment. A one- dimensional method of analysis of ejector was presented. The analysis consideredmixing of primary and secondary streams at constant pressure and mixing of streams at constant area. For theanalytical 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 variousrefrigerants The results show that steam jet systems have very low coefficient of performance values, the systemusing R152a as refrigerant has better performance. Grazzini G. and Rocchetti A. in 2002 investigated thenumerical optimisation of a two-stage ejector refrigeration plant. A simulation program numerically searches themaximum 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 withenvironment friendly refrigerants (R134a, R152a, R290, R600a and R717) is made. Among the working fluidsconsidered, the system with 134a gives better performance.Kashyap S. in 2011[10] conducted a simulation program onthe basis of one dimensional mathematical model to analysis the performance of ejector refrigeration cycle withworking fluid R410a and also compared with performance of R134a. A performance comparison is made on variousoperating 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.

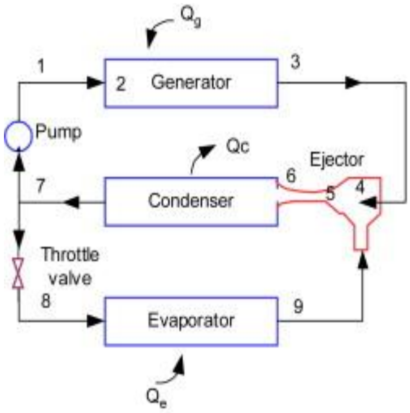
Under all other circumstances, the motive nozzle discharge pressure is, optimally,greater than that of the suction nozzle.The two-phase ejector refrigeration cycle enables the evaporator to be flooded with refrigerant, resulting in a higher refrigerant-side heat transfer coefficient. EERC expands the 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.

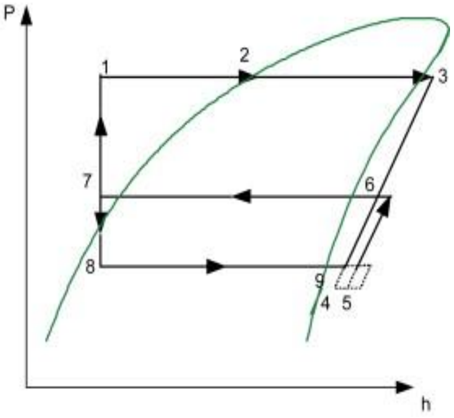
2.1. Ejector Working Principle

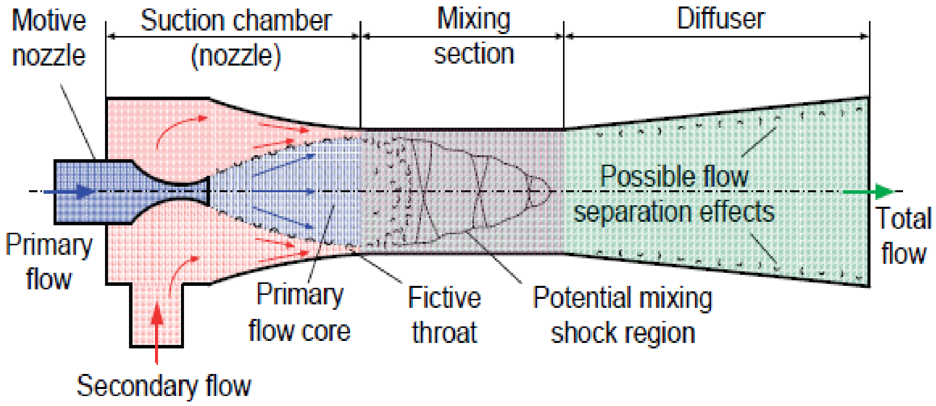
A typical ejector consists of a motive nozzle, a suction chamber, a mixing section, and adiffuser. The working principle of the ejector is based on converting internal energy and pressure related flow workcontained in the motive fluid stream into kinetic energy. The motive nozzle is typically of a converging-divergingdesign. 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. Flashingof the primary flow inside the nozzle might be delayed due to thermodynamic and hydrodynamic non-equilibriumeffects. The high-speed jet starts interacting with the secondary fluid inside the suction chamber. Momentum istransferred from the primary flow which results in an acceleration of the secondary flow. An additional suctionnozzle can be used to pre-accelerate the relatively stagnant suction flow. This helps to reduce excessive shearinglosses caused by large velocity differences between the two fluid streams. Depending on the operating conditionsboth the supersonic primary flow and the secondary flow might be choked inside the ejector. Due to static pressuredifferences it is possible for the primary flow core to fan out and to create a fictive throat in which the secondaryflow reaches sonic condition before both streams thoroughly mix in the subsequent mixing section. The mixingsection 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 atconstant pressure as a result of changes in cross-sectional area of the mixing section. The mixing process isfrequently accompanied by shock wave phenomena resulting in a considerable pressure rise. The total flow at theexit of the mixing

section can still have high flow velocities. Thus, a diffuser is used to recover the remainder of thekinetic 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 pressureratio and the mass entrainment ratio. The suction pressure ratio is defined as the ratio of diffuser exit pressure to thepressure 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 eachoperating point and the following equations. In the following nomenclatures in thissection (section), the numbers in the subscription refer to the conditionSubscription ‘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

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

The product of the isentropic efficiency of the nozzle (η_N) and the isentropic efficiency of the diffuser (η_D) may be referred to as the ejector isentropic efficiency (λ),

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

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 entrainmentratio, ω, and a coefficient of performance.Neglecting the work input to the pump, the thermal COP of the ejectorrefrigeration system is defined as the ratio between cooling capacity and necessary heat input, as :

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

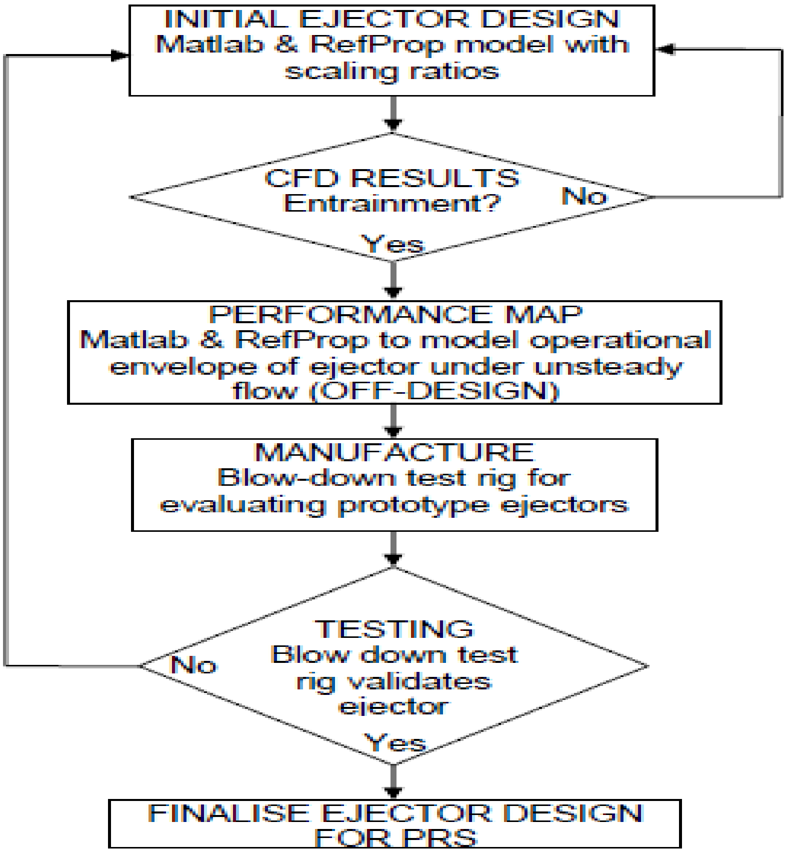
Entrainment ratio and cop are mainly the parameters used to measure the performance of the refrigerating system and they are the one which mainly describe the system output .They help in analysing the performance of the system under the proposed conditions i.e physical and external conditions.

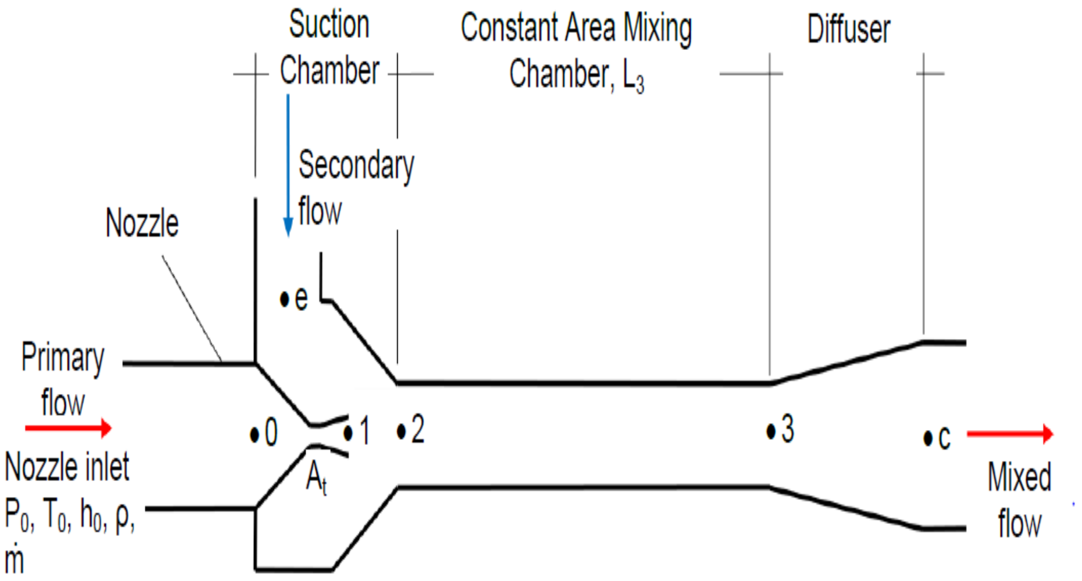
III.REFRIGERANT USED

There are several refrigerants are available whichcould be used in ejector air conditioning system. Manystudies were maderegarding ejector system in which are R-134a, R-717,R-718, or R-123 could be used as a working substancefor producing refrigerating effect. Some physical properties ofR-134a are given below due to which it is easy to choosethe refrigerant for this purpose. (1)It is stable, non-flammable and non-toxic. (2)The latent heat at -15℃ is 195 kJ/kg. (3)The leak may be detected by using a soap solutionof by electrode detector.

3.1.Working Steps

- The system consists of two loops, the powerloop and the refrigeration loop.
- In the power loop, low-grade heat, QG, is usedto evaporate high pressure Liquid refrigerant
- The high pressure vapour generated (primaryfluid) flows through the ejector where itaccelerates through the nozzle.
- The decrease in pressure that occurs inducesvapour from the evaporator (secondary fluid)at point 2.
- The fluid stream (mixed) then flows to thecondenser where it is condensed rejectingheat to the environment, Qc.
- A major portion of the liquid refrigerantexiting the condenser at point 4 is thenpumped to the generator for the completionof the power cycle.
- The remaining liquid refrigerant is expandedthrough an expansion device.


INITIAL EJECTOR DESIGN
Matlab & RefProp model with scaling ratios
CFD RESULTS
Entrainment?
No
Yes
PERFORMANCE MAP
Matlab & RefProp to model operational envelope of ejector under unsteady flow (OFF-DESIGN)
MANUFACTURE
Blow-down test rig for evaluating prototype ejectors
TESTING
Blow down test rig validates ejector
No
Yes
FINALISE EJECTOR DESIGN FOR PRS


Suction Chamber
Constant Area Mixing Chamber, L_3
Diffuser
Secondary flow
Nozzle
e
Primary flow
0
1
2
3
c
A_t
Nozzle inlet
P_0, T_0, h_0, ρ, $\dot{m}$
Mixed flow

. 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 thereis sufficient waste heat or in tri-generation systems.
- Rising energy costs that could encourage the more effective utilisation of waste heatand better thermal integration of processes in food manufacturing.
- Develop ejectors that can operate with other natural refrigerants apart from water,such as CO2 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 bytheoretical 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 DepletionPotential(ODP) & Global Warming Potential (GWP)solar driven refrigeration system shows a veryprospective alternative in refrigeration system. Solarenergy is available free & environment friendly. Alsosolar energy intensity is high in northern part of India that gives it the tremendous future potential asenvironment 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 scenarioof 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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