# Performance Analysis of Heat Operated Ejector Refrigeration System with Natural Refrigerants R-717 and Propane

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**Abstract:** ***In present study a mathematical model is developed in*** *EES* ***software for single phase Ejector Refrigeration System. The model is then used to determine the performance of natural refrigerants R717 and Propane. The ejector cycle of cooling is very much suitable for the applications where large amount of low-grade heat is released in the environment while refrigeration may also be required in the same application, as it is often the case in the chemical and food processing plants and automobiles. Under such circumstances, non-mechanical, thermally activated ejector machines may represent an excellent mean of heat recovery for cooling. For validation of the mathematical / theoretical model, the performance for R11 was simulated on the computer program by varying the evaporator temperature from 277 to 289K, the boiler temperature from 336K to 358K, the condensing temperature from 298 to 303K and by choosing the area ratios (Ar) 4.0, 5.76 and 7.84. The theoretical performance computed using the model is compared with that of experimental data available in the literature. The calculations of the performance of R717 and Propane have been made taking the following operating temperatures.***

**Keywords:** EES, Refrigerant's, Efficiency, Ejector System

## 1. Introduction

At present most of the conventional cooling and refrigeration systems are based on mechanical vapor compression system. These vapor compression cycles are working on the high-grade mechanical and electrical energy. The high-grade mechanical and electrical energy is generated most of the time by the combustion of fossil fuels and thus contributes to an increase in greenhouse gases and generation of air pollutants. The jet ejector cycle also has the drawback as ejectors are designed to operate at a single optimum point. Deviation from this optimum point results in deterioration of the ejector performance. The diameters and lengths of various parts forming the nozzle, the diffuser and the suction chamber, together with the stream flow rate and properties, define the ejector capacity and performance. The ejector capacity is defined in terms of the flow rates of the motive steam and the entrained vapor. The sum of the motive and entrained vapor mass flow rates gives the mass flow rate of the compressed vapor. As for the ejector performance, it is defined in terms of entrainment, expansion and compression ratios. The entrainment ratio is the flow rate of the entrained vapor divided by the flow rate of the motive steam. The COP of the system can give the overall performance of the ejector system. The effect of various system parameters on COP is studied with the refrigerants R717 and Propane.

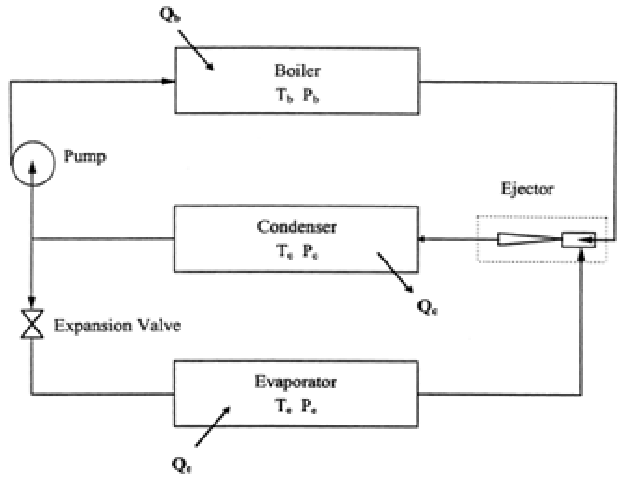


**Figure 1:** Schematic diagram of Ejector refrigeration system

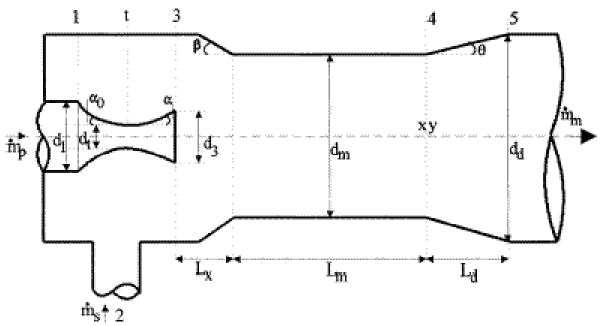

**Figure 2:** Schematic diagram of Ejector showing various sections

## 2. Themodynamic Analysis of the Ejector System

A system analysis of ejector refrigeration system is carried out in the present study. Governing equations based on the balance of mass, momentum and energy are derived for components of the system.

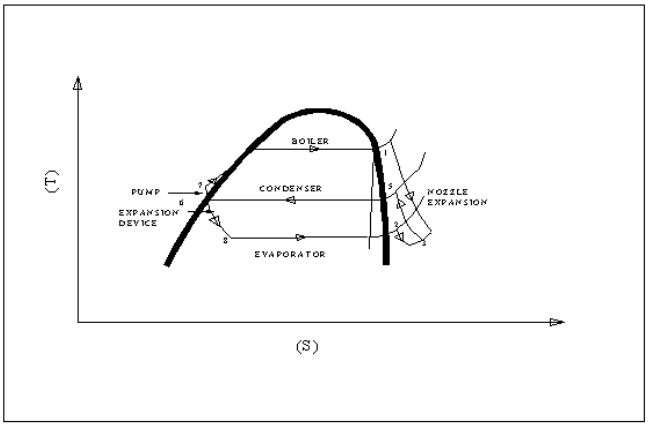


**Figure 3:** Ejector refrigeration system on T-S diagram

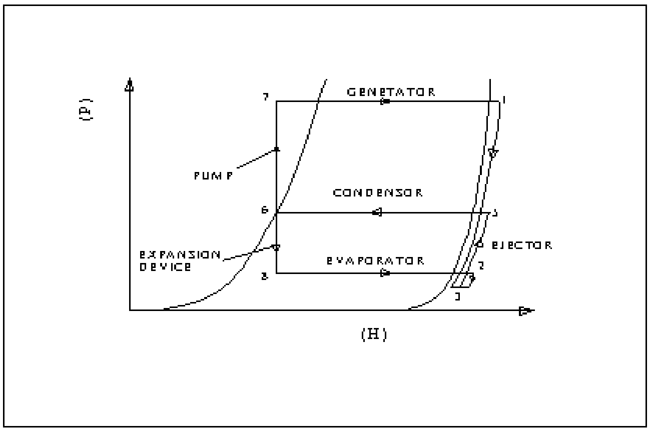


**Figure 4:** Ejector refrigeration system on P-H diagram

**Assumptions made for analysis**

1. The refrigerant was at all times in thermodynamic quasi-equilibrium.
2. Characteristics and velocities were constant over cross section (one-dimensional model of flow).
3. All fluid characteristics are uniform over the cross section after complete mixing at the exit of the mixing tube.
4. There is no external heat transfer.
5. Mixing occurs at constant pressure in the ejector-mixing region with the assumption that the fluid momentum is conserved.

**The condition of the fluid at various sections of ejector:**

Boiler side entry: - Tb; Vb=0 and Pb, Hb, Sb, are for saturated vapor at Tb

Evaporator side entry: - Te; Ve=0 and Pe, He, Se, are for saturated vapor at Te

Exit of primary nozzle: -

Primary fluid: - Pp3, Vp3, Hp3 (after expansion through nozzle)

Suction fluid: - Ps3, Vs3, Hs3 (after suction, applying chocking condition)

After mixing in mixing tube: - Pm, Vm, Hm

After normal shock: - Py, Vy, Hy

Exit of diffuser: - Pd, Vd, Hd

### 2.1 Computational procedure

The flow diagram in the figure indicates the brief logical procedure of the solution of above thermal analysis of ejector. For the given ejector geometry and the given operating conditions Tb, Tc, Te and Pb, Pc, Pe the above equations are solved by the prepared software. The chocking condition applied to the suction fluid at the entrance of the mixing chamber, the pressure at the chocking point Ps3 is determined through critical pressure ratio. Considering assumption of uniform pressure mixing the exit pressure of primary and suction fluid is also taken same, Pp3=Ps3. By the exit pressure and efficiencies of the nozzle flow, the condition of both primary and suction fluid is determined.

**The efficiencies of the Ejector:**
Primary nozzle Efficiency =95%
Suction Nozzle Efficiency =95%
Diffuser Efficiency: =95%
**The refrigerants taken for study:**
For validation of the program calculations: - R11
For performance analysis: - R717 and Propane
**The temperature parameters for study:**
Boiler temperatures: - Tb = 333K, 343K, and 353K,
Condenser temperatures: - Tc =298K to 313K in steps of 5K
Evaporator temperatures: - Te =268K to 278K in steps of 1K

## 3. Results and Discussion

**Reference calculations**

**For validation of the program w.r.t R11 and R717**

For validation of the mathematical / theoretical model, the performance for R11 was simulated on the computer program by varying the evaporator temperature from 277 to 289K, the boiler temperature from 336K to 358K, the condensing temperature from 298 to 303K and by choosing the area ratios (Ar) 4.0, 5.76 and 7.84. The theoretical performance computed using the model is compared with that of experimental data available in the work of Cizungu et al. (2001).

**Performance of R717 with Ejector of Ar=4.0**

For boiler temperature Tb=333K the COP of the system is varying from 0.06 to 0.34 for Tc= 298K and 0.01 to 0.14 for Tc=303. At these parameters the COP increases with increase in evaporator temperature or compression ratio. For condenser temperature 303K the COP values are low as given above, and if the condenser temperature further increased, COP becomes zero.

**Performance of R717 with Ejector of Ar=5.76**

For boiler temperature Tb=333K the COP of the system, at Tc=298K is 0.03 to 0.28 and at Tc=303K is less then 0.1. At these parameters the COP increases with increase in evaporator temperature or compression ratio. For condenser temperature Tc=308K and more the COP becomes zero.

**Performance of R717 with Ejector of Ar=7.84**

For boiler temperature Tb=333K the COP of the system, at Tc=298K is 0.02 to 0.27 and at Tc=303K is less than 0.1. For condenser temperature Tc=308K and 313K the COP becomes zero.

## 4. Result Discussion with Propane

**Performance of Propane with Ejector of Ar=4.0**
For boiler temperature Tb=333K the COP of the system is varying from 0.08 to 0.37. For condenser temperature Tc=303K the COP values are varying from 0.001 to 0.18.The COP values are less than 0.05 for Tc=308Kand if the condenser temperature further increased, COP becomes zero

**Performance of Propane with Ejector of Ar=5.76**
For boiler temperature Tb=333K the COP of the system, at Tc=298K is 0.07 to 0.38, at Tc=303K is 0.01 to 0.18, and less than 0.1 at Tc=308K,

**Performance of Propane with Ejector of Ar=7.84**
For boiler temperature Tb=333K the COP of the system, at Tc=298K is 0.1 to 0.57, at Tc=303K is 0.005 to 0.31, and at Tc=308K is 0.02 to 0.14. If the condenser temperature further increased, COP becomes zero.

### 4.1 Performance Comparison R717 and Propane

**Comparison for Area Ratio Ar=4**
The COP of the R717 is more then Propane, for Tb=333K, Tc=303K (0.04 to 0.15 more), and for Tb=353K, Tc=298K (0.01 to 0.025 more). For all other parameters the COP of propane is more, but not having much difference and it is almost same for Tb=343K, Tc=298K and Tb=353K, Tc=303K. For this area ratio the COP is not having much difference.

**Comparison for Area Ratio Ar=5.76**
The COP of propane is again more for the combinations of Tb, Tc: 333K, 298K (0.05 to 0.1 more); 333K, 303K (0.06 to 0.08 more); 343K, 303K (0.04 more); 353K, 308K (0.03 more). The COP is not significant difference for Tb, Tc: (343K, 298K; 353K, 298K; 353K, 303K). The difference in COP of the refrigerants is less for combination of high boiler temperature and low condenser temperatures. For low boiler temperatures and high condenser temperatures the COP of propane difference is more.

**Comparison for Area Ratio Ar=7.84**
For this ejector configuration at Tb=353K and Tc=298K the COP of propane is more than R717 but difference is small (0.02 to 0.05). For all other combinations of the parameters under study the COP of Propane is higher then the R717 and difference varies as, at Tb, Tc: 333K, 298K (0.08 to 0.3 more); 333K, 303K (0.1 to 0.2 more); 343K, 298K (0.05 to 0.1 more); 343K, 303K (0.05 to 0.1 more); 353K, 303K (0.04 to 0.05 more); 353K, 308K (0.04 more),

**Performance Comparison with VCRS**
From the analysis of the comparison data of Ejector Refrigeration system (ERS) and VCRS, it is observed that the COP of the ERS is not more then the 10% of COP VCRS under the parameters taken for study. Further it also indicates that the COP of ERS is very sensitive to the evaporator and condenser temperature, and it maximum performance is there for some fixed parameters.

## 5. Conclusion

In present work, the performance analysis of a heat operated ejector refrigeration system is done with natural refrigerants R717 and Propane. The discussion and analysis of the obtained results permit the following remarks:

1. The COP of propane is higher than R-717 for same ejector and temperature parameters.
2. The COP of R-717 is high for area ratio Ar=4.0, reduces at Ar=5.76 and Ar=7.84 by 0.03 to 0.05. The COP at Ar=5.76 is more than Ar=7.84 by 0.01.
3. The COP of Propane is high for area ratio Ar=7.84, reduces at Ar=5.76 and Ar=4.0 by 0.02 to 0.2. The COP at Ar=4.0 is more than Ar=5.76 by 0.01.
4. The COP for both, R717 and Propane is high for higher boiler temperature and low condenser temperatures.
5. The COP for both, R717 and Propane with ejector refrigeration system is very sensitive to the change in condenser temperature
6. The COP for both, R717 and Propane reduces with increase in the boiler or heat source temperature.
7. For low area ratio the COP of Propane and R717 is not having much difference but for high area ratios the propane is better than R717.

## 6. Scope for Future Work

- Performance analysis of these natural refrigerants with experimental ejector refrigeration system.
- The study for finding out the optimum geometry of the ejector with propane and other natural refrigerants.
- The similar performance analysis can be done with other natural refrigerants like Propylene etc.
- Performance comparison of the ejector refrigeration system with different natural refrigerant.

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