An analysis of the performance of an ejector refrigeration cycle working with R134a

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Abstract. In the context of recent developments in the field of energy, the aspect related to energy consumption is of great importance for specialists. Many industries rely on refrigeration technologies, a great challenge being expressed by attempts in energy savings in this sector. In this respect, efforts oriented towards efficient industrial refrigeration systems have revealed the necessity of a proper design. The most commonly used method of cooling is based on vapor compression cycles. Compared to vapor compression refrigeration systems, an ejector refrigeration system shows an inferior performance, indicated by the Coefficient of Performance of the cycle, but it is more attractive from energy saving point of view. In this respect, the present study deals with a theoretically analysis of an Ejector Refrigeration System, started with the presentation of the typical ejector design. It is stated that ejector refrigeration is a thermally driven system which requires low grade thermal energy for its working. After a short description of the analyzed system, are given equations for thermal loads and Coefficient of Performance calculation, on First Law basis. The working fluid considered in this research is Freon R134a. The developed study is focused on the effect of generating temperature variation on the Coefficient of Performance (COP) and on the work input to the pump when the cooling effect, the condensation temperature, the evaporation temperature and the reference state temperature are kept constant. Are obtained results in the following conditions: the condensation temperature is \( t_c = 33^\circ C \), the evaporation temperature is \( t_e = 3^\circ C \), the reference state temperature is \( t_o = 23^\circ C \). The generating temperature varies in the range \( 82 \div 92^\circ C \) and the cooling effect is 1 kW. Also, are known the isentropic efficiencies of the ejector, which are 0.90, and the isentropic efficiency of the pump, which is 0.75. Calculation will reveal that the Coefficient of Performance is increasing together with the increase of the generating temperature values, the best COP value being 0.178, in the considered range for the mentioned temperature. In the same time, the generating temperature increase leads to the increase of the work input to the pump.

1. Introduction

Refrigeration is a sector which is making possible our modern life. In the framework of global temperature increase, our dependency on refrigeration systems will be stronger in the next decades. Refrigeration systems are welcome not only when we talk about food industry, refrigerators are used in different applications such as ensuring of thermal comfort, medical procedures or industrial sectors. The environmental degradation resulted from refrigeration use comes mainly from generating the electricity needed to run them and from leakage of refrigerants. Expected new technologies, which will solve in a way the actual environmental impact of refrigeration, should be defined by an improved
working performance, coming from less combustion of primary energy and mitigation of the ozone damaging and global warming.

Ejector refrigeration systems (ERS) are thermally driven technologies which have been used for cooling applications for many years. These systems are similar to vapor compression refrigeration systems, which are one of the most common types of refrigeration systems; here, instead of the compressor will work an ejector, a generator and a small pump [1].

Ejector refrigeration systems offer advantages of simplicity in construction, installation and maintenance, no moving parts, high reliability and low cost. For this reason, they are more attractive than vapor compression refrigeration systems.

Compared to vapor compression refrigeration systems, ejector refrigeration system offers a lower Coefficient of Performance, but it is more attractive in energy saving [2].

Lately, have been done attempts to extend the penetration of ERS in refrigeration and air conditioning sector by the use of low-grade thermal energy, such as solar energy and waste heat, in the system; thus will be possible to fight against environmental issues, to reduce CO$_2$ emission from the combustion of fossil fuels [3].

Ejectors are simple pieces of equipment. Their working principle is based on the conversion of internal energy and pressure related flow work contained in the motive fluid stream into kinetic energy [4]. A typical ejector consists of a driving nozzle, a suction nozzle, a mixing section and a diffuser, as seen in figure 1. The performance of an ejector is evaluated by dealing with one dimensional governing equation specific to each component part. The below assumptions are considered in this assessment [5]:

- the flow is one-dimensional and steady,
- driving flow and suction flow are considered to be ideal gases,
- the thermo physical properties are constant,
- chock occurs inside the driving nozzle, suction nozzle and mixing section,
- entropy losses during the shock wave or mixing are assessed by the use of different coefficients,
- friction losses along the pipe are neglected.

Figure 1. A Typical ejector design.

2. Methods and materials
The ejector is the main component part of the basic ejector refrigeration system. A low grade heat ($Q_g$) is used in the generator to evaporate the liquid refrigerant having a high pressure. The high pressure refrigerant vapors of state 2, known as primary fluid, enter and expand through the nozzle. Results a reduction in the pressure which enables the entrainment of vapors from evaporator of state 3, known
as the secondary fluid. In the mixing chamber occurs the mix of the two fluids, before entering the diffuser section where the flow decelerates and takes place pressure recovery. Then, the mixed fluid flows into the condenser where condenses into liquid by evacuating heat to the environment \(Q_c\). Resulted liquid of state 5 is divided into two parts: one is pumped back into the generator and the other goes into the evaporator with state 6, after being first expanded through an expansion device. The low pressure liquid refrigerant evaporates in the evaporator producing the cooling effect \(Q_o\); resulted vapors of state 3 enter in the ejector. The described system is given in figure 2

\[ Q_o = m_o (h_3 - h_6) \]  
(1)  

\[ Q_g = m_g (h_2 - h_1) \]  
(2)  

\[ Q_c = m_c (h_4 - h_5) \]  
(3)  

\[ W_p = m_p (h_1 - h_5) \]  
(4)  

Above, \(m\) – mass flow rate (kg/s), \(h\) – enthalpy (kJ/kg), \(Q\) – heat load (kW), \(W_p\) - pumping work (kJ/s)

The efficiency of the ejector refrigeration cycle is assessed by the help of COP (Coefficient of Performance), defined as the ratio between the cooling effect and energy input of the cycle (the sum between the necessary heat input and work input to the pump):

\[ COP = \frac{Q_o}{Q_g + W_p} \]  
(5)
3. Results and discussions
The following results are obtained when ERS is working with R134a, the condensation temperature is $t_c = 33^\circ C$, the evaporation temperature is $t_e = 3^\circ C$, the reference state temperature is $t_o = 23^\circ C$, the generating temperature is the range $82 \div 92^\circ C$, the cooling effect is 1 kW, isentropic efficiencies of the ejector are 0.90 and the isentropic efficiency of the pump is 0.75.

Figures 3 and 4 show the effect of the variation of generating temperature on work input to the pump and COP, when other temperatures are kept constant.

Together with the increase of the generating temperatures might be seen an increase of work input to the pump and COP. When keeping constant the cooling effect, COP offers best values for high values of the generating temperature; rising this temperature will lead to more consumption in the pump.

4. Conclusions
Despite of the advantages shown by ejector refrigeration systems (ERS), the performance of the basic ERS need to be improved. This paper is an attempt in this respect.

For a specific cooling effect and given condensation and evaporation temperatures, the generating temperature is varying in order to find when best COP is achieved. Thus, was found that:
- first law efficiency (COP) is increasing together with the increase of the generating temperature values;
- in the considered range for the generating temperature ($82 \div 92^\circ C$), best COP value (0.178) is obtained for the highest generating temperature: $t_g = 92^\circ C$;
- the generating temperature increase leads to the increase of work input to the pump.

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