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Performance analysis of ejector refrigeration system with environment friendly refrigerant driven by exhaust emission of automobile

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ABSTRACT

Ejector refrigeration is a thermally driven technology which utilizes low grade thermal energy for its operation. This paper experimentally investigates the performance analysis of ejector refrigeration system with R404A as refrigerant. The ejector refrigeration system used exhaust emission of automobile as thermal energy for providing heat to refrigerant in the generator. Effect of different operating parameters on the performance of system has been investigated. The result shows that system using R404A as refrigerant can be used in the ejector refrigeration system for area ratio 7.84. Cooling capacity of the system increases with increase in evaporator temperature and generator temperature.

Keywords: Generator, Ejector, Ejector refrigeration system, and R404A

Nomenclature

T_e Evaporator temperature, ^oC
T_g Generator temperature, ^oC
A Area ratio=A_m/A_t
T_c Condenser temperature, ^oC
W_p Mechanical pump input energy, kW
m_e Mass flow rate given to evaporator,$kg.s^{-1}$
m_g Mass flow rate given to generator,$kg.s^{-1}$
Δh_e Enthalpy difference between exit and inlet side of evaporator, $kJ.kg^{-1}$
Q_e Cooling capacity, kW $=m_e.\Delta h_e$
Q_g Total heat input to the generator, kW
μ Entrainment ratio=m_e/m_g

Subscripts

c Condenser
e Evaporator
g Generator
m Mixing chamber
t Throat

INTRODUCTION

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[3] 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. Alexis G.K. and Rogdakis E.D. in 2003[4] presents a paper on a verification study of steam- ejector refrigeration model. The model takes into account the shocking phenomena and assumes that the mixing process of the two streams, motive and secondary stream, takes place with constant pressure and the conservation of fluid momentum in effect. Selvaraju A. and Mani A. in 2004[5] did the analysis of an ejector with environment friendly refrigerants. 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 R134a gives better performance. Sankarlal T. and Mani A. in 2006[6] conducted experimental studies on an ammonia ejector refrigeration system. The results showed that entrainment ratio and coefficient of performance of the system increase with increasing generator and evaporator temperatures and decrease with increasing condenser temperature.

Alam S. in 2006[7] proposed a model for utilizing exhaust heat to run automobile air-conditioner. The analysis shows that the maximum amount of useful heat available in the exhaust gas is about 6 KJ/sec and the amount of heat required for generator is 3.02 KJ/sec. Butterworth M.D. and Sheer T.J. in 2007[8] studied high-pressure water as the driving fluid in an ejector refrigeration system, the purpose of which was to chill water. Elbel S. and Hrnjak P. in 2008[9] presented a review paper which gives an overview of historical and recent developments regarding air-conditioning and refrigeration systems that use ejectors. Kashyap S. in 2011[10] conducted a simulation program on the basis of one dimensional mathematical model to analysis 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. Jain A., Agrawal S. K. and Pachorkar P. in 2012[11] described the exergy analysis of the solar-driven ejector refrigeration system. The largest portion of the exergy is lost in the solar collector followed by the ejector, the generator, the condenser, the evaporator and the expansion valve.

Jaruwongwittaya T. and Chen G. in 2012[12] presents a paper on application of two stage ejector cooling system in a bus. The aim was to investigate the feasibility of implementing a two stage ejector cooling system in a bus. The results indicate that the application of a two stage ejector cooling system to replace the vapour compression system in a bus is a suitable alternative. Conventional refrigeration system in automobile can run with the help of engine power but gives extra load to engine. The addition of refrigeration system in automobile cause higher fuel consumption and increases the impact on the environment due to the increasing amounts of exhaust emission from the internal combustion engines. Mostly researchers has done a lot of work on improving the performance of vapour compression systems(VCS) by reducing the fuel consumption or installing system which does not include a compressor, such as the absorption system, adsorption system and ejector cooling system. Although these systems have drawback of low coefficient of performance but their advantages are that they do not need any power from the engine. Consequently, not only the fuel consumption is reduced but also the exhaust emissions are reduced which are the main cause for global warming. Such systems can help to improve the global warming situation which at present is a leading environmental problem. The ejector structure is characterised by the area ratio (A) which is defined as the cross-section area of the constant area section of mixing chamber of ejector (A_m) divided by that of the primary nozzle throat (A_t).

Singh K. [13] has described that all the heat produced by the combustion of fuel in engine cylinder is not converted into useful power at the crankshaft. The heat which is converted into useful work at the crankshaft is 25 percent, loss to the cylinder walls is 30 percent, loss in exhaust gases is 35 percent and loss in friction is 10 percent.

Exhaust emission is emitted as a result of the combustion of fuels such as natural gas, petrol, diesel fuel, fuel oil or coal. According to the type of engine, it is discharged into the atmosphere through a pipe. Performance of ejector refrigeration system driven by exhaust emission of automobile with refrigerant R404A is analysed in this paper. The performance of the refrigerant R404A is investigated at evaporator temperature (6.9^{o}C to18.9^{o}C), condenser temperature (42.4^{o}C to 47.6^{o}C) and generator temperature (58^{o}C to 64^{o}C).

MATERIALS AND METHODS

The schematic diagram of experimental set-up has been shown in fig.1 and the ejector used in the system is shown in fig. 2.

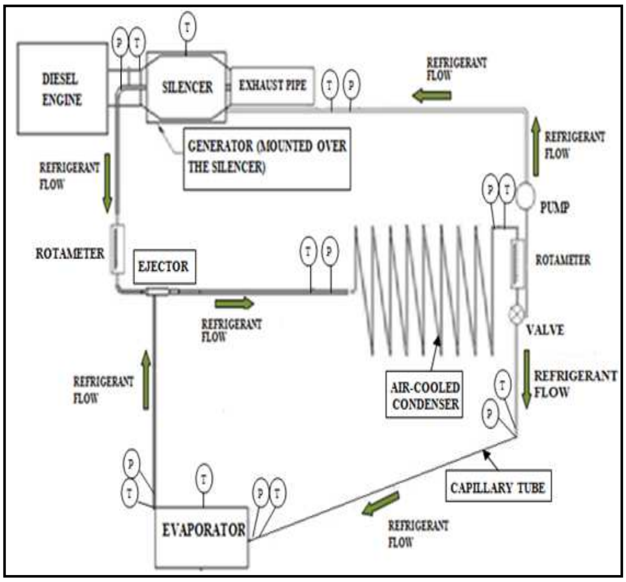

Fig.1 Experimental setup of the ejector refrigeration system

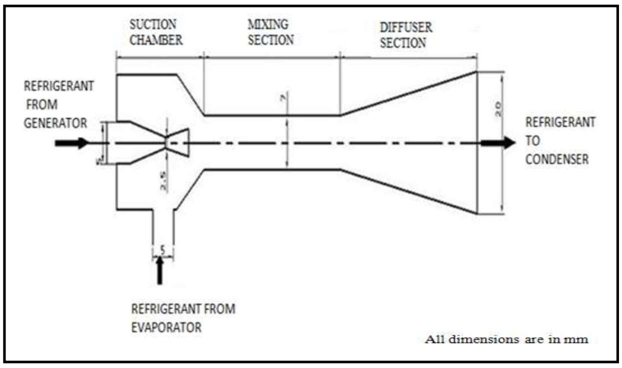

Fig.2 Ejector diagram

2.1 Description of Experimental Setup

The experimental set up consists of a generator, evaporator, condenser, ejector, capillary tube, a circulating pump, and measuring devices. The thermal energy (Q_g) required for vaporising the refrigerant in the generator is taken from the exhaust emission of automobile. The quantity of refrigerant entering into ejector from the generator and evaporator is measured with the help of Rotameter. Quantities of refrigerant from generator and evaporator are used for determining entrainment ratio. Pump used in the system gets power (W_p) the battery of automobile. The Bourdon tube pressure gauges within ±0.3 bar accuracy are used in the experimental setup to measure the pressure. Temperature indicator with ±0.1 °C accuracy is used to measure the temperature at the outlet and inlet of components.

2.2 Description of Experimental procedure

The refrigerant enters into the generator which is mounted over the silencer. Diesel engine exhaust is connected via exhaust pipe to the silencer which is also called muffler. The normal operating temperature range of exhaust gases is from 200°C to 500°C in diesel engine. To attain temperature in the generator required for vaporising the refrigerant, it is mounted over the silencer. Engine is made to run for half an hour, exhaust gases coming from the silencer provide thermal energy to the generator for attaining the required temperature. Refrigerant is made to flow through the Rota meter and then goes to condenser via ejector. Entrainment ratio (μ) is the ratio of mass flow rate given to evaporator (m_e) to the mass flow rate given to generator (m_g) and it is one of the important parameters of ejector refrigeration system. Refrigerant is divided on the basis of entrainment ratio by adjusting the needle valve from where one part of the refrigerant goes to the generator with the help of pump and the other part goes to the evaporator. Refrigerant from evaporator is sucked into the ejector and then two streams one coming from the generator and other from the evaporator mix in the constant area section(mixing chamber) of the ejector and then through the diffuser of ejector to recover the pressure. The refrigerant goes to the condenser where refrigerant condenses and again same procedure is repeated by changing the entrainment ratio.

RESULTS AND DISCUSSION

The performance of the ejector refrigeration system with R404A as refrigerant using the thermal energy of exhaust emission of the automobile is studied in this paper. The effect of different operating parameters on the system performance was studied. In the experiments, the ranges of the operation conditions were as follows: evaporator temperature from 6.9°C to 18.9°C, condenser temperature from 42.4°C to 47.6°C and generator temperature from 58°C to 64°C.

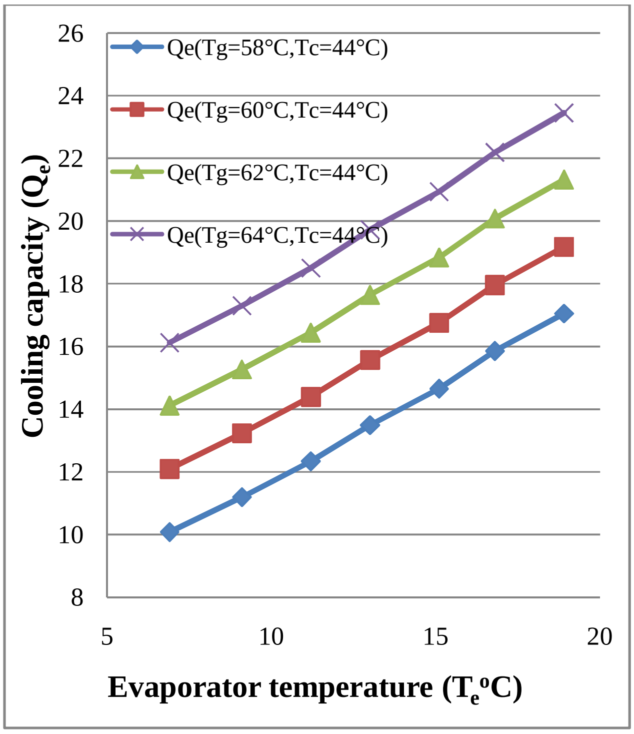

Fig .3 Effect of evaporator temperature on cooling capacity

3.1. Effect of evaporator temperature (T_e)

The graph shown in the Fig. 3 shows the effect of evaporator temperature (T_e) on the cooling capacity of refrigerant for different generator temperatures and fixed condenser temperature. The result shows that the cooling capacity of refrigerant increases with increasing evaporating temperature because irreversibility decreases with increase in evaporator temperature. The performance of the ejector increases with increased evaporator temperatures because with the decrease in evaporator temperature, pressure of refrigerant coming from the generator decreases more in the nozzle of ejector below the evaporator pressure to suck the refrigerant from the evaporator. With the increase in evaporator temperature at fixed generator temperature and condenser temperature, the heat given to the refrigerant in the generator decreases and pump work required to deliver the refrigerant from exit of condenser to inlet of generator decreases. Increased entrainment ratio is one of the main causes of increased cooling capacity of the system with increase in the evaporator temperature for fixed generator and condenser temperature.

3.2. Effect of generator temperature (T_g)

Fig.4 depicts the effect of generator temperature (T_g) on entrainment ratio for different evaporator temperatures and fixed condenser temperature. The entrainment ratio of the system with the refrigerant R404A increases with the increasing generator temperature at given evaporator and condenser temperatures because as generator temperature increases temperature pressure of the refrigerant also increases and when high pressure refrigerant goes into nozzle section of ejector pressure energy is converted into kinetic energy which leads to the increase of entrainment ratio.

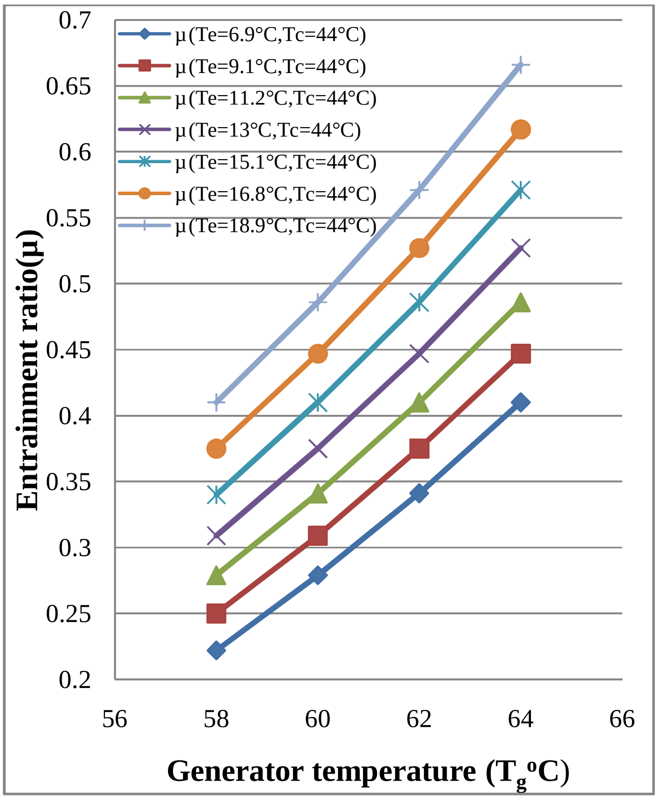

Fig.4 Effect of generator temperature on entrainment ratio

3.3. Effect of entrainment ratio (μ)

The variation of cooling capacity with change in entrainment ratio at given generator temperature and condenser temperature is shown by the Fig.5.Cooling capacity of the refrigerant increases with increase in entrainment ratio because entrainment ratio is directly proportional to mass flow rate given to evaporator. With the increase in generator temperature, entrainment ratio also increases.

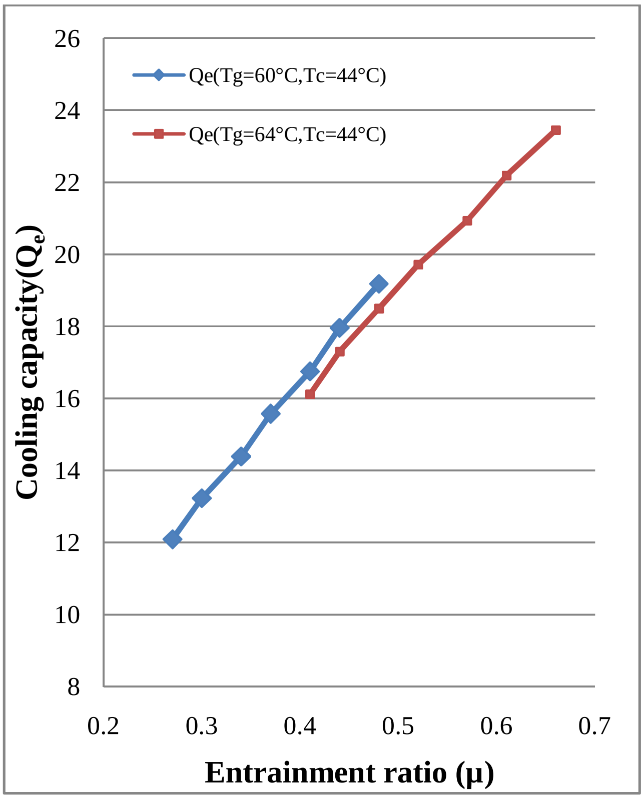

Fig. 5 Effect of entrainment ratio on cooling capacity

CONCLUSION

The performance of ejector refrigeration system driven by exhaust emission of automobile with refrigerant R404A was experimentally investigated. The results of the experimental investigation show that cooling capacity of the system increases with increase in evaporator temperature and entrainment ratio. On the basis of result obtained it can be concluded that entrainment ratio increases with the increase in generator temperature. Ejector refrigeration system has used low grade thermal energy in the form of exhaust emission of automobile which saves costly fuel used for running automobile.

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