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EXPERIMENTAL RESEARCH ON AMMONIA-BASED EJECTOR REFRIGERATION SYSTEM

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Abstract:

The demand for power for air conditioning systems in buildings has rapidly increased due to the rising need for thermal comfort. In terms of lowering energy usage, heat-driven ejector refrigeration systems look to be a potential replacement for conventional compressor-based refrigeration methods.It has been created and built for an ejector refrigeration system to run on a simulated (electric) heat source, which in real-world applications can be waste heat or renewable energy sources like solar energy, geothermal energy, etc.This paper presents experimental research on an ammonia-operated ejector refrigeration system. It is discussed how the performance of the ejector refrigeration system is affected by the temperatures of the generator, condenser, and evaporator.As the temperatures of the generator, evaporator, and condenser rise, so do the system's entrainment ratio and coefficient of performance (COP).

Keywords: Ejector refrigeration system, condenser, evaporator, COP, and generator.

1. Introduction

The fast growth in cooling system consumption caused by the rising demand for thermal comfort in turn increased the need for power for air conditioning in buildings.Utilizing thermal energy refrigeration with solar or low-grade heat would result in a large drop in energy usage[1].Due to their dependability, little maintenance requirements, and cheap initial and ongoing costs, heat-driven ejector refrigeration systems (ERSs), among other thermal refrigeration technologies, appear to be a possible replacement for conventional compressor-based technologies.Additionally, ERSs may contribute to the reduction of greenhouse gas emissions by reducing the usage of refrigerants that are hazardous to the environment and saving on primary energy[2].However, because of its low performance coefficient and substantial performance deterioration when not running under idealised design circumstances, ejector refrigeration has not been able to gain market share[3].

Various reviews of ejector technologies have been published in the available literature[4, 5, 6, 7].The objective of the current study is to offer a complete perspective of ejector refrigeration

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systems and the effect of working fluids on their performance. All of the earlier reviews concentrated on a specific feature or elements of ejector refrigeration.Both vapour absorption refrigeration systems (VARS) and ejector refrigeration systems(ERS) may utilise this renewable energy. Due to the high initial cost of VARS, ERS system is more beneficial than VARS[8, 9].

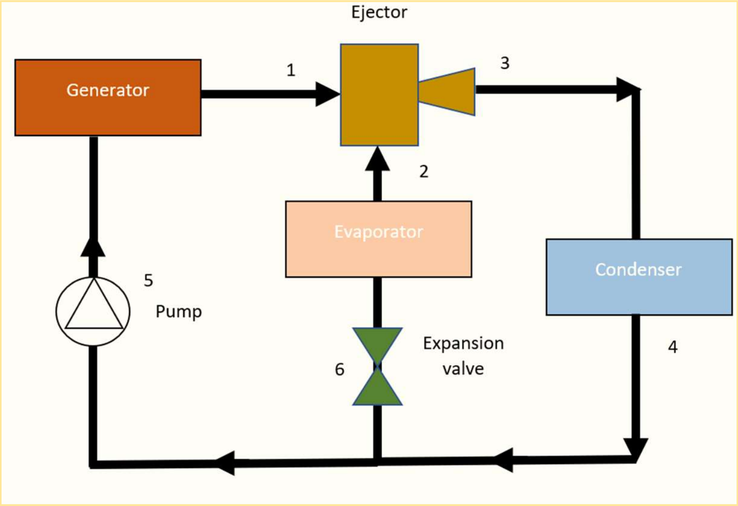


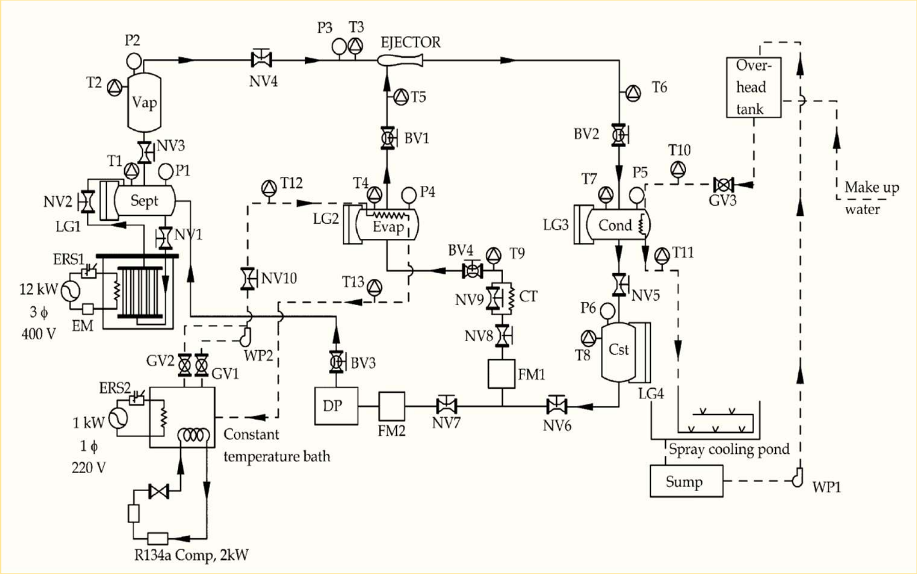
Fig.1 ESR Schematic layout

Figure 1 displays the ERS's schematic diagram. High-pressure primary vapour is produced in the generator with the aid of a simulator that runs on electrical power. In the convergent-divergent nozzle of the ejector, this vapour is permitted to expand. Secondary vapour from the evaporator is entrained by this supersonic jet. In the ejector's mixing chamber, these two streams mingle.The vapour then moves through the diffuser, where the kinetic energy of the refrigerant is changed into an increase in pressure. The condenser then condenses the vapour that was expelled by the ejector. In order to achieve the refrigerating effect, some of the refrigerant is pushed to the generator and the remaining refrigerant is expanded by an expansion device and sent to the evaporator.Using R11, Guoji et al.,[10] has experimented with an ejector refrigeration system.The surface finish of ejector components, the author has established, significantly impacts the entrainment ratio. Separately, Khetib et.al., [11] proposed an ejector hypothesis that was semi-empirical and specifically applicable to a steam jet refrigerator.Using a solar concentrating collector, Al-Khalidy[12] has tested an ejector refrigeration system. He has researched how different operational factors affect system performance and ejector efficiency. Due to their negative effects on the environment, CFCs and HCFCs are prohibited under the Montreal Protocol and subsequent International Protocols.For this reason, Manimaranet al[13] .'s theoretical assessments of ejector refrigeration systems using eco-friendly refrigerants. Ammonia is a refrigerant that is good to the environment, hence it was chosen as the working fluid in the current study. When compared to rival, now-banned halocarbon refrigerants, ammonia offers superior thermodynamic and transport characteristics. Ammonia has a number of additional benefits, including easy leak detection, limitless availability, and low cost, yet it also has drawbacks including toxicity and corrosion.

2. Ejector Refrigeration SystemsSetup

Fig. 2 depicts the experimental configuration of the ammonia ejector refrigeration system (AERS). The AERS is made up of a diaphragm pump, evaporator, condenser, liquid storage tank, and vapour generator.The three components of the vapour generator are the distributor with a riser pipe network submerged in a water tank, the vapour separation tank, and the vapour storage tank. An immersion heater rated at 12 kW is included with the vapour generator. With a PT 100 sensor, the temperature is controlled by an electric relay switch controller to within 0.1 °C. As an evaporator, a shell and tube heat exchanger is employed. The evaporator-cooling load is simulated using a different 2 kW R134a vapour compression refrigeration system. The simulator has a PT 100 sensor and an electric relay switch controller to regulate the evaporator temperatures to within 0.1 °C.A two-pass shell and tube heat exchanger, the condenser is cooled by water. A needle valve and a 0.7 m long by 0.5 mm diameter stainless steel capillary tube are arranged parallel to one another. These gadgets serve as expansion devices.

To show the liquid level in the separation tank, evaporator, condenser, and condensate tank, liquid level gauges are offered. Water was used to calibrate the liquid's volume in relation to its level in the tank fitted with level gauges to an accuracy of 2%. The metal tube rotameter FM2 is used to assess the flow rate of primary vapour. The metal tube rotameter FM1 is used to gauge the secondary vapour's flow rate.At six sites [P1-P6] in the experimental setup, calibrated Bourdon pressure gauges with an accuracy of 0.2 bar are available to monitor the pressure. For temperature measurement, the copper-constantan thermocouples with PTFE coating are inserted at the proper positions [T1-T13]. The precision of the thermocouples' calibration is 0.1 °C. To assess the performance of the AERS under various operating situations, experiments were performed at various evaporator, condenser, and generator temperatures. Fig. 3 displays the typical ejector utilised in the experimental setup and its measurements.



Needle valve (NV1- NV10)
Ball Valve (BV1-BV4Z)
Global Valve (GV1-GV3)
Thermocouple (T1-T13)
Pressure gauge (P1-P6)
Electric relay switch (ESR1,2)

Separation tank-Sept
Evaporator- Evap
Condenser-Cond
Condensate storage tank- Cst
Capillary tube- CT
Flow meter- FM

Vapour tank- Vap
Diaphragm Pump- DP
Water pump- WP
Energy meter- EM
Level gauge- LG

Fig.2 ESR Experimental layout

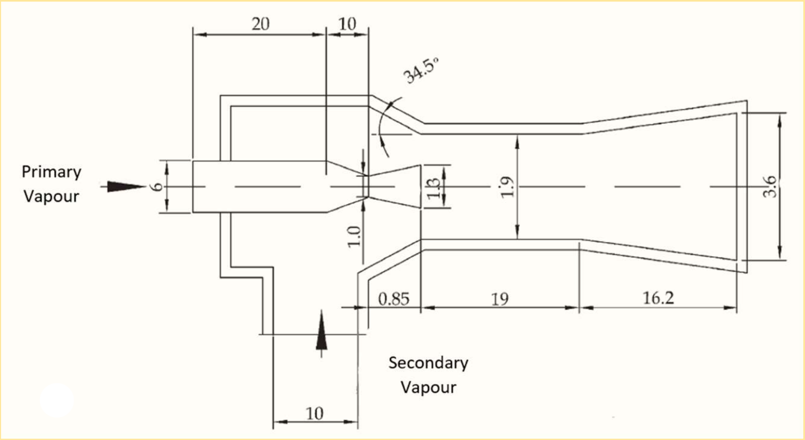


Fig.3 Ejector layout.

3. Experimental Procedure

First, the generator's electric heater is turned on. Once it reaches the required level, the electric relay switch helps to keep the temperature in the generator constant. The desired temperature in the evaporator is achieved utilising the constant temperature bath by turning on the vapour compression refrigeration system. By regulating the expansion rate, flow rate, and temperature of the cold water, the evaporator pressure is kept constant. Condenser pressure is maintained at the optimum level by recirculating cooling water from the above tank.Once there is enough generator pressure, the condenser and generator are connected via the ejector. By appropriately regulating the flow rates of the primary vapour and the circulating water, as well as the needle valve before the ejector, the condenser pressure is kept at the desired level. Following that, the evaporator and ejector are in communication. After the system has attained steady state, the readings are taken. By individually changing the temperatures in the generator from 60 °C to 72 °C, the evaporator from 5 °C to 15 °C, and the condenser from 30 °C to 36 °C, the experiment is repeated for various operational parameters.

4. Results and Discussions

The refrigerating effect to heat input ratio, as stated in Eq., is the COP of the refrigeration system (1). The ejector's entrainment ratio equals the difference between the primary and secondary vapour flow rates.

$$\text{COP} = \frac{Q_{Evaporator}}{Q_{generator} + Pump\ power} \qquad \text{Eq. (1)}$$

$$\omega = \frac{Mass\ flow\ rate_{Secondary}}{Mass\ flow\ rate_{Primary}} \qquad \text{Eq. (2)}$$

By eliminating out pump work in the equation above, the COP of the system may be rewritten.

$$\text{COP} = \omega\left(\frac{\Delta h_e}{\Delta h_q}\right) \qquad \text{Eq. (3)}$$

For various evaporator temperatures at a given condenser temperature, T_c, and a certain area ratio Φ, Fig. 4 illustrates the variation of entrainment ratio with generator temperature. The mixing chamber constant cross-section area to the primary nozzle throat area is referred to as the area ratio of the ejector. The entrainment ratio rises as the generating temperature rises. As the generator pressure, P_g, rises, ΔP across the nozzle rises as well, increasing the primary vapour velocity at the nozzle exit, which is the cause of the rising entrainment ratio. With rising evaporator temperature, the entrainment ratio rises as well.Because of the increased secondary flow velocity brought on by the rising evaporator pressure, the entrainment ratio has increased. Fig. 5 depicts how the temperature of the generator affects COP. At constant evaporator and condenser temperatures and a constant area ratio, the system's COP rises as generator temperature rises. This is due to the fact that the COP is inversely proportional to Δh_g and directly related to the entrainment ratio. The entrainment ratio rises and Δh_g falls as the generator temperature rises, which causes COP to rise. The COP rises when the evaporator temperature rises because the entrainment ratio rises with it for the same reason as previously mentioned.

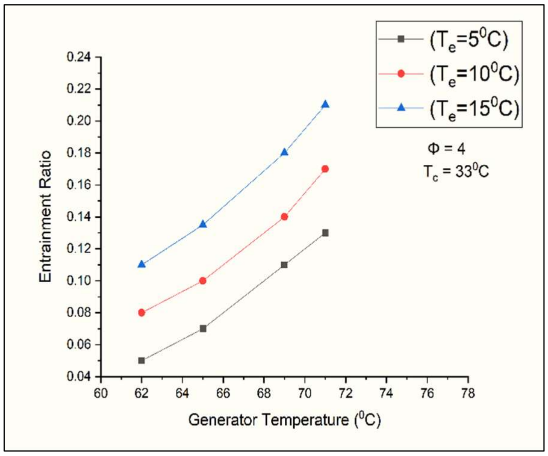
For a particular generator and evaporator temperature as well as area ratio, Fig. 6 shows how the entrainment ratio changes with condenser temperature. The entrainment ratio falls down as the condenser temperature rises. The ejector experiences increased backpressure as the condenser pressure rises, which is the cause of this. As a result, the compression ratio—the ratio of condenser pressure to evaporator pressure—rises. Decreased secondary vapour entrainment results from maintaining the original vapour's velocity.

The impact of the condenser temperature on COP is shown in Fig. 7 for various generator, evaporator, and area ratio temperatures. For the same reason as previously stated, the COP of the system drops as the condenser temperature rises.

Based on dimensional ejector theory, a computer simulation model has been created. The relation is used to compute the friction factor.

$$F = 0.079Re^{-0.25}$$

The mixing chamber velocity is used to get the Reynolds number. The software REFPROP is used to acquire the ammonia's thermodynamic characteristics. The operating parameters are changed to determine the entrainment ratio. The experimental findings are contrasted with the estimated entrainment ratio as shown in Fig. 8. With a maximum difference of 12%, the experimental and simulated performance findings are in rather good agreement.



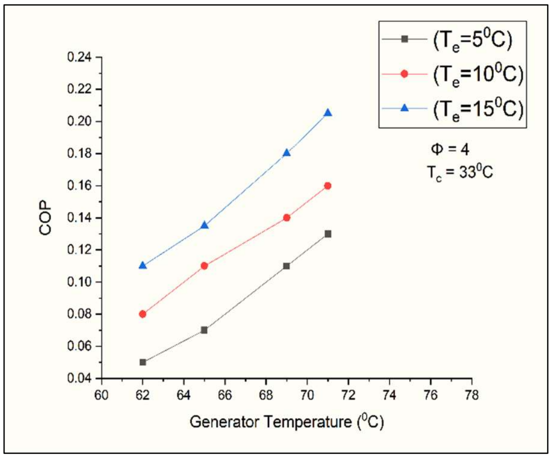
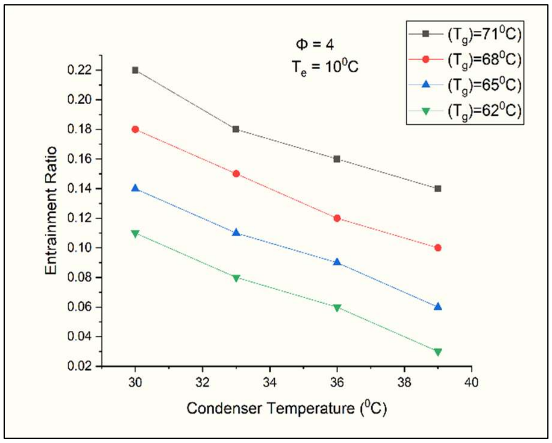


Fig. 4Variable evaporator temperatures have an impact on Fig. 5Variable evaporator temperatures have an impact on
the generator's temperature on entrainment ratio.the generator's temperature onCOP.



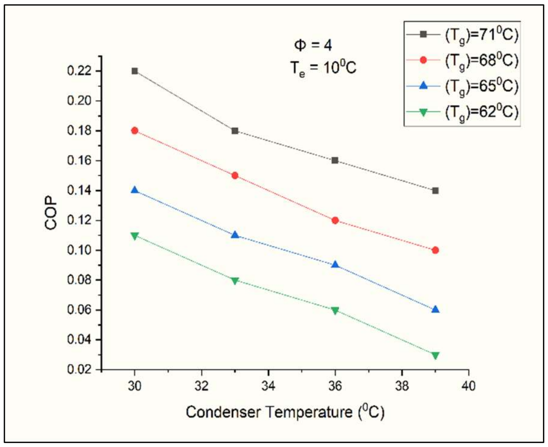


Fig. 6Variable Generator temperatures have an impact on Fig. 7Variable Generator temperatures have an impact on
the condenser temperature on entrainment ratio.the condenser temperature on COP.

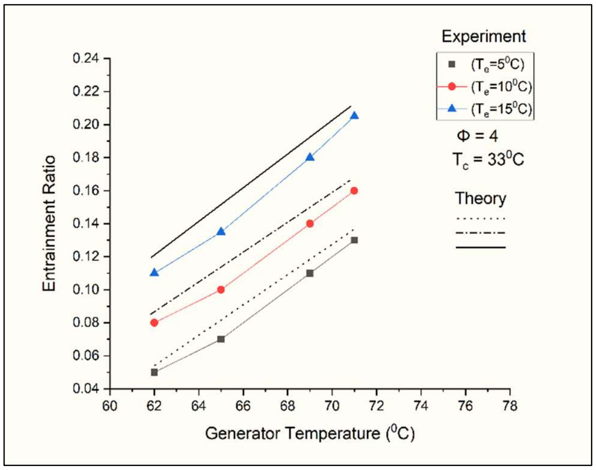


Fig. 8Variation between Experimental and Theoretical ratio.

5. Conclusion

The performance of an ERS that uses ammonia is discussed in this research in relation to operational parameters. With rising generator and evaporator temperatures, the entrainment ratio and COP of the AERS rise. As condenser temperature rises, the entrainment ratio and COP fall. Any renewable energy source, such as solar energy, geothermal energy, etc., may simply be employed in actual applications to replace the electric heater used as the simulated generator heat source in this experimental investigation.

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