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Experimental Investigation of Hot water Fired R134A-DMAC VARS System at Various Heat Source Temperatures

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Abstract: **The objective of this paper is to present the experimental results of Vapour Absorption Refrigeration System of 1kW capacity using R134a–DMAC as the working fluids. The system is designed using hot water as heat source for a heat input of 4 kW at various generator temperatures and tested at sink temperature of 25^{o}C. An average COP of 0.34 was obtained under the above test conditions. The study reveals the feasibility of using environmental friendly R134a-DMAC as working fluids in the absorption system using low potential heat sources for the Heating, Ventilation, Air Conditioning and Refrigeration applications. The hot water source can be replaced with solar panel heater to harness solar energy.**

1. INTRODUCTION

The demand for air-conditioning and refrigeration is increasing year after year due to increasing desire for comfort, necessity of food storage and medical applications in hot climates especially in developing countries like India. The normal cooling unit used for the above purpose is an electrically powered vapour compression system, which often uses Chloro Fluoro Carbons (CFC's) or Hydro Chloro Fluoro Carbons (HCFC's) as refrigerants. The Montreal Protocol marked a turning point in refrigeration industry and has a focus on international commitment to end the use of CFC and HCFC refrigerants aimed to protect the environment. One of the alternatives to overcome these draw backs is to use vapour absorption refrigeration systems using non CFC / HCFC working fluids. The normal vapour compression refrigeration system used for domestic and commercial refrigeration purposes uses high-grade electrical energy for the vapour compressor. The absorption system is observed to be a viable alternative to the vapor compression system which results in environmental problems like global warming and ozone layer depletion. In the vapour absorption system solar energy, engine exhaust heat and waste heat in industries can be used as a heating source instead of high-grade electrical energy. The only mechanical input in to the VAR system is the pump work which is also comparatively low as only liquid is pressurized in the system. The hot water source can be replaced by solar heating or engine exhaust gas.

Use of solar energy in VARS will not add to the global warming and ozone layer depletion. Other prominent benefits include reducing local air pollution levels, as well as using power that doesn't emit carbon dioxide, methane or other harmful gasses that hurt the atmosphere. I.C. engines convert only 25 to 35% of the heat supplied into shaft output and nearly an equal amount of heat is exhausted into the atmosphere in the form of hot exhaust gases from the engine. The heat carried by the engine exhaust gases can be used in the generator of the absorption refrigeration system and can be converted to useful refrigeration. This makes the vapour absorption refrigeration system an attractive alternative to the vapor compression refrigeration system in automobiles. Badarinarayana et al [1] presented the concentration-enthalpy chart for R21-DMF refrigerant-absorbent combination for solar-driven cooling applications. Their analysis of the vapour absorption refrigeration system (VARS) working with R21-DMF is observed to be advantageous over R22-DMF systems at lower evaporator temperatures as they are able to operate at lower generator temperatures. They also reported that R 21-DMF systems perform better than R22-DMETEG systems. Borde et al [2] presented the possibilities of using R134a with absorbent solutions as DMETEG, MCL, DMEU. The investigation showed that of the three combinations tested as potential working fluids in absorption units, R134a – DMETEG was the best because of its better overall performance compared to R134a – MCL or R134a – DMEU. Abdullah Keçeciler et al [3] presented the design of an absorption refrigeration system using geothermal energy in the hot Spring which is alternative to the ordinary mechanical refrigeration system. The change in the coefficient of performance of the ARS was investigated with the various parameters and it was observed that geothermal energy in the hot Spring can be used especially for refrigeration and it will provide a considerable economic gain, taking into account the need of storing at 4–10°C. Horuza and Callander [4] presented their experimental investigation of the performance of commercially available vapor absorption refrigeration (VAR) system. They used modified natural gas-fired VAR system with aqua-ammonia solution and ammonia as the refrigerant and water as the absorbent with a rated cooling capacity of 10 kW. Variations in chilled water inlet temperature, chilled water level in the evaporator drum, chilled water flow rate, and variable heat input were investigated.

Crepinsek et al [5] compared the performance of working fluids for absorption refrigeration systems that are used for refrigeration temperatures below 0°C. The performances of the ammonia-water and possible alternative cycles as ammonia-lithium nitrate, ammonia-sodium thiocyanate, monomethylamine-water, R22-DMEU, R32-DMEU, R124-DMEU, R152a-DMEU, R125-DMEU, R134a-DMEU, trifluoroethanol (TFE)-tetraethylenglycol dimethylether (TEGDME), methanol-TEGDME and R134a-DMAC are compared in respect of the coefficient of performance (COP). Manzela et al [6] presented an experimental study of an ammonia–water absorption refrigeration system using the exhaust of a production automotive engine as energy source when the refrigeration system was installed in the engine exhaust. It was observed that the refrigerator reached a steady state temperature between 4 and 13 °C about 3 h after system start up, depending on engine throttle valve opening. When the refrigeration system was installed in the engine exhaust, unburned hydrocarbon emissions were found to be higher but carbon monoxide emissions were less while carbon dioxide concentration remained practically unaltered.

Subhadip Roy and Maiya [7] investigated the use of liquid vapour heat exchanger (LVHX) for the recovery of cooling loss by the residual liquid in the evaporator. They observed that for fixed cooling temperature, the system COP enhances with evaporator pressure and that the enhancement rate is more when efficiencies of rectifier and LVHX are high. Suresh and Mani [8] carried out experimental investigation to study heat and mass transfer characteristics of R134a - DMF in a compact bubble absorber of vapour absorption refrigeration system of 1 TR capacity using plate heat exchangers as system components. Bubble absorption principle is employed in the absorber and hot water supplies heat to the generator. They investigated the effect of various parameters such as circulation ratio, absorber and generator temperatures on heat and mass transfer effectiveness, overall heat transfer coefficient and volumetric mass transfer coefficient. The results showed that heat and mass transfer effectiveness of absorber are better at lower circulation ratios and higher generator temperatures. Balamurugan and Mani [9] investigated heat and mass transfer during desortion of R134a-DMF absorption refrigeration system desorption of R134a from R134a and DMF solution in a tubular generator. Effects of various parameters such as solution two phase Reynolds number, driving temperature and pressure ratios, solution initial concentration on generator performance are analyzed. It was observed that desorption ratio, Sherwood number and Nusselt number increase as the solution Reynolds number, solution initial concentration, driving temperature ratio increase But as the driving pressure ratio increased, these parameters are found to decrease. Based on the experimental investigations, a correlation for Nusselt number and Sherwood number are proposed. Paurine et al [10] presented the modeling, design, manufacture and testing of a packed bed regenerative solution heat exchanger (R-SHX) for improved effectiveness of a vapour absorption refrigeration (VAR) system. The system made use of an efficient regenerative heat exchanger with reduced risks of crystallization and low maintenance costs.

They determined the optimum value of the low-pressure generator temperature exists at which all the vapour generated at the high-pressure generator is condensed in a double-effect series flow vapour absorption refrigeration system (VARS). A comparative study of the performance of VARS using refrigerants such as, R32, R134a, and R124 with DMAC as the absorbent is made. The system with R32-DMAC was observed to give the best performance at high evaporator temperatures. It was found that R124-DMAC may be suitable at extreme operating conditions like low evaporator and high heat rejection temperatures. Influence of operating temperatures (high-pressure generator, evaporator, condenser and absorber) and the effectiveness of heat exchangers on the optimum low-pressure generator temperature, cut-off temperature, circulation ratio and coefficient of performance were studied.

2. EXPERIMENTAL SETUP

The schematic diagram of continuous VARS used is shown in Fig. 1 and Fig. 2 shows the flow diagram and the location of the various measuring instruments. This system generates and condenses refrigerant vapour continuously to meet the refrigeration load. As can be seen from the figure, its major components are evaporator, absorber, generator, condenser, and solution pump and expansion valve. It allows the possibility of incorporating a regenerative heat exchange process between the strong and weak solutions that can lead to higher COPs. However, a continuous system needs a solution pump to pump the strong solution from absorber pressure to generator pressure. This absorber-solution pump-generator combination essentially performs the same task as the compressor in the vapour compression refrigeration system. However, the high-grade energy requirement in a vapour absorption refrigeration system (in the form of pump work) is much lower compared to the compression system as only liquid is pressurized in the pump.

Since the VARS is essentially a heat system, it is suitable for operation with different types of heat sources. This fact has been mainly responsible for the recent revival of interest in large scale on VARS with a view to harness solar radiation or use waste heat in industries for the purpose of producing refrigeration.

The unit consists of an absorber, evaporator, condenser, generator, solution heat exchanger, solution pump, expansion valves with suitable insulated copper piping. In the generator heat is supplied by an electrical heat source and the high pressure refrigerant vapour separated from the strong solution passes on to the condenser next where it is condensed by circulating cold water. The high pressure liquid refrigerant passes through a filter-drier to remove moisture that may be present in it and a flow meter is incorporated in the circuit measures the flow rate of the refrigerant. It is then expanded in a capillary tube and the low temperature wet vapour flows through the evaporator where it gets evaporated at a lower temperature absorbing heat from the refrigeration load simulator. Then the refrigerant vapour enters the bottom of the absorber where it is absorbed by the weak solution and the heat released during the absorption process and also during the mixing process is rejected to the cooling water circuit. A solution pump is provided to enable its entry into the generator through the solution heat exchanger. The strong solution-entering generator is heated by hot water circulated separating the refrigerant in the solution. The weak solution at high pressure and temperature flows through the solution heat exchanger before entering the absorber for improvement of system performance .Each component of the system is provided with gate valves at inlet and outlet to control the water flow rate and also to isolate it at the time of repair.

Experimental investigations have been carried out in the fabricated vapour adsorption system using R134a–DMAC with heat input of 4kW at 80˚C. Evaporator temperature is varied from 0 to 10 °C while sink temperature of 25°C is used. Temperatures of refrigerant and absorbent solution at various points in the system and temperature of cooling water and the ambient temperature are measured using copper-constantan thermocouples. The flow rates of the liquid refrigerant and the strong solution are measured using suitable flow meters. Hot water and cooling water flow rates are measured using water flow meters.

3. RESULTS AND DISCUSSIONS

Experiments are carried out with R134a-DMAC as working fluid in the Single Stage Vapor Absorption Refrigeration System. The following ranges of operating conditions could be achieved with the fabricated experimental setup.

Hot water at a temperature upto 80°C was used as the low potential heat energy source. Higher temperature was not attempted, as water at atmospheric pressure is used as fluid for the heat transfer.

Sink temperature was maintained at 25°C.

Evaporator temperature is varied from 0 to 10°C. It could be lowered up to -10°C.

Actual heat loads at various components are calculated from the measured flow rate and temperature rise (or drop) of water passing through each component with the Specific heat capacities of fluids calculated at the average of inlet and outlet temperatures. The various heat loads are listed below:

Generator heat input :
$$Q_g = m_{hs}\, cp_{hs}\, (T_1\text{-}T_2)\ \text{kW} \quad (1)$$

Heat rejected at the condenser:
$$Q_c = m_{cw}\, cp_{cw}\, (T_3\text{-}T_4)\ \text{kW} \quad (2)$$

Heat supplied at evaporator:
$$Q_e = m_{rw}\, cp_{rw}\, (T_6\text{-}T_5)\ \text{kW} \quad (3)$$

Heat rejected at absorber:
$$Q_a = m_{cw}\, cp_{cw}\, (T_8\text{-}T_7)\ \text{kW} \quad (4)$$

Two important performance characteristics of VARS are circulation ratio (CR) and coefficient of performance (COP).

CR is defined as the ratio of the mass flow of the strong solution to that of the refrigerant, i.e.

$$CR = m_{ss} / m_r \quad (5)$$

Coefficient of performance (COP) is defined as the ratio of the cooling load at evaporator (Q_e) to the heat energy input at generator (Q_g). Solution pump work is very small and hence neglected in the calculation of the COP.

$$COP = Q_e / Q_g \quad (6)$$

Where

m_{hs}	kg s^{-1}	:	Mass flow rate of water through generator
m_{cw}	kg s^{-1}	:	Mass flow rate of water through condenser and absorber
m_{rw}	kg s^{-1}	:	Mass flow rate of water through chiller
m_{ss}	kg s^{-1}	:	mass flow rate of the strong solution
m_r	kg s^{-1}	:	mass flow rate of the refrigerant
cp_{hs}	kJ/kg K	:	specific heat capacity of heat source
cp_{cw}	kJ/kg K	:	specific heat capacity of cooling water
cp_{rw}	kJ/kg K	:	specific heat capacity of chilled water
T_1 & T_2	K	:	Inlet and outlet temperatures of

			water at generator
T_3 & T_4	K	:	Inlet and outlet temperatures of water at condenser
T_6 & T_5	K	:	Inlet and outlet temperatures of water at evaporator
T_8 & T_7	K	:	Inlet and outlet temperatures of water at absorber

Fig. 3 shows the temperature variation of the various components-generator absorber, condenser and evaporator with time. The generator temperature is observed to increase initially and stabilizes at 75°C after 3 hours. The temperatures of condenser and absorber follow the same pattern as that of the generator. There is a higher heat loading in the absorber due to large heat of formation of solution in the absorption process and these results in higher absorber temperature compared to that of condenser. Only the temperature of the evaporator is seen to decrease with time due to the cooling effect of the refrigerant. As the system is a heat operated one, there is a heat carrying capacity for all the components of the system which results in a delay in the evaporator temperature stabilization.

Fig. 4 shows the variation of component temperatures with heat source temperature with sink maintained at constant temperature of 25°C. The mass flow rate of cooling water 'm_{cw}' is also held constant. It is seen that the temperatures of all components increase with heat source temperature. This is due to the increase in temperatures of both weak solution and refrigerant vapor at the respective outlet of generator. The cooling water flow rate through the absorber and condenser is maintained constant. Therefore when the temperature of the refrigerant vapor leaving the generator and entering the condenser increases, the condenser pressure and hence condenser temperature increases. Due to the increase of weak solution temperature at the outlet of the generator, weak solution temperature at the inlet of the absorber increases and therefore strong solution temperature at absorber outlet also increases. This causes the evaporator pressure and evaporator temperature to increase.

Fig. 5 shows the variations in various component heat loads with heat source temperature. It can be observed that with increase in heat source temperature all component heat loads increase marginally. However the generator heat input increases more rapidly than all other heat quantities. It is also seen that the variation in generator heat load (Qg) follows the same trend as absorber heat load (Qa) mainly because both of them depend on the variation in circulation ratio (CR).

The variation of COP with heat source temperature is shown in Fig. 6. The COP is observed to decrease with increase in heat source temperature due to the large increase in the heat input at the generator while the cooling at the evaporator only increases marginally. Because of the heat losses in the system the actual COP is also found to be less than the theoretical COP.

Fig. 7 shows the variation of circulation (CR) with heat source temperature at the sink temperature of 25°C. It is observed that the circulation ratio decreases with increase in heat source temperature. This is attributed to the higher rate of increase of the concentration of the weak solution compared to that of the strong solution with increase in heat source temperature. At the same time the amount of DMAC escaping to the condenser along with R134a vapour increases resulting in an increase in degassing width (difference between concentrations of strong and weak solutions). This also leads to a decrease in the circulation ratio with increase in heat source temperature.

4. CONCLUSION

A vapour absorption refrigeration system is fabricated with R134a as the working fluid and Dimethyl acetamide (DMAC) is chosen as the suitable absorbent.

- As the heat source temperature increases, heat quantities at generator, absorber, condenser and evaporator are observed to increase, while the Circulation ratio decreases.
- For the designed system the COP was observed to vary from 0.36 to 0.32 when the heat source temperature was increased from 65 to 80 °C.
- The Circulation ratio is seen to decrease with increase in heat source temperature.

The study reveals the feasibility of using environmental friendly working fluids R134a-DMAC in future absorption machines using low potential heat sources.

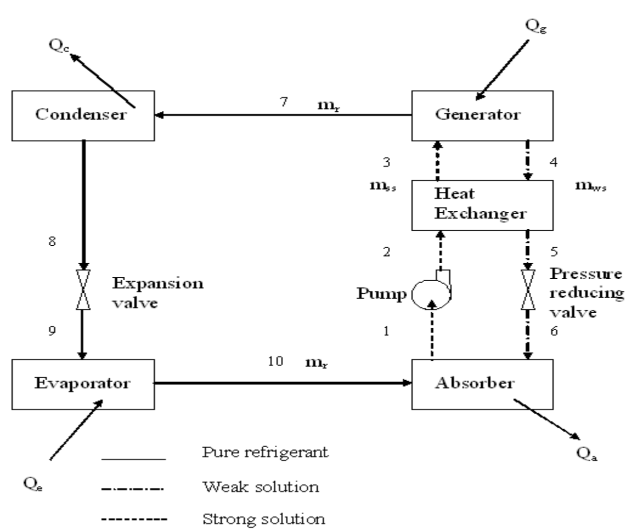

Fig. 1. Schematic diagram of continuous VARS

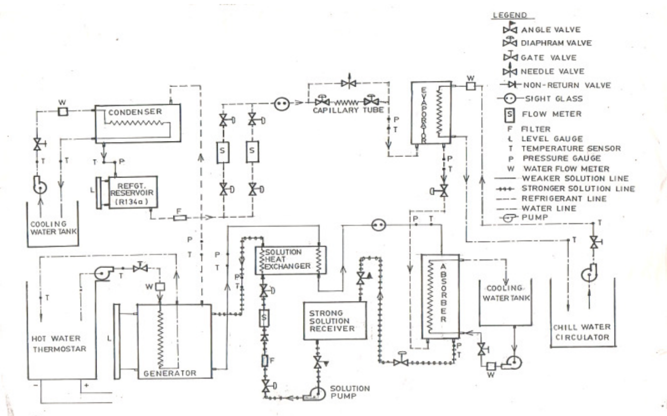

Fig. 2. Schematic diagram of Experimental Set-up

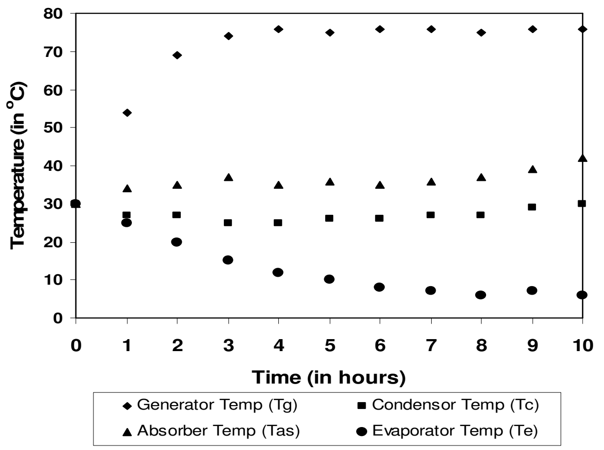

Fig. 3. Variation of Component Temperatures with Time

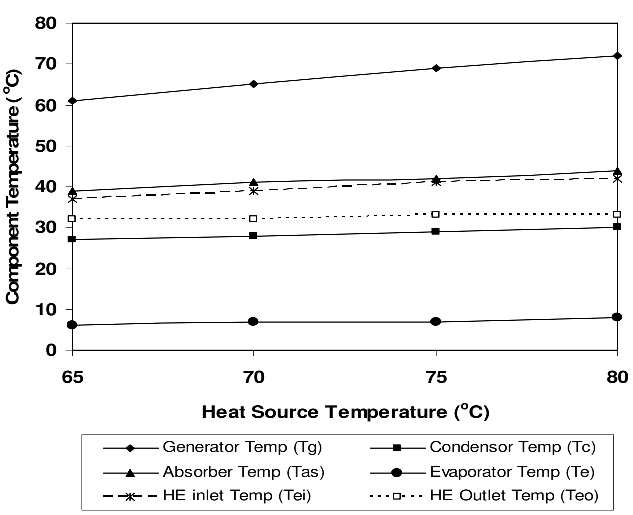

Fig. 4 Variation of Component Temperatures with Heat Source Temperature

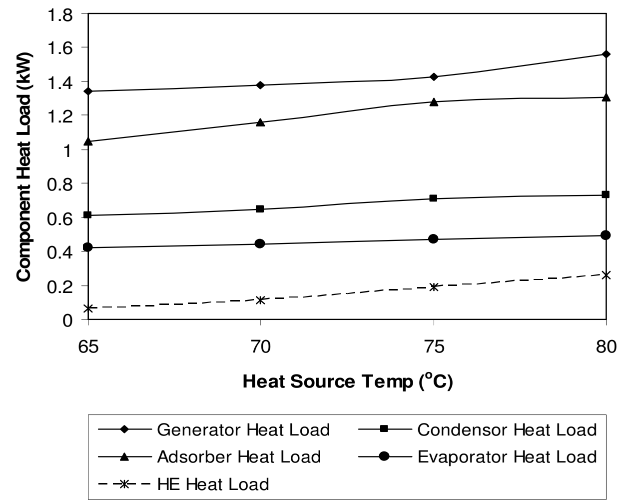

Fig. 5 Variation of Component Heat Loads with Heat Source Temperature

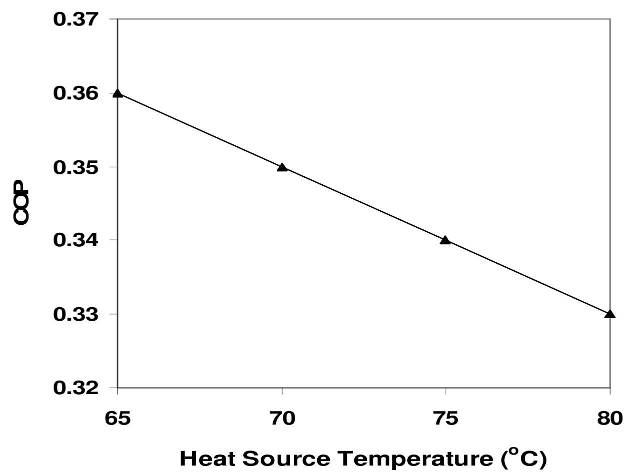

Fig. 6 Variation of COP with Heat Source Temperature

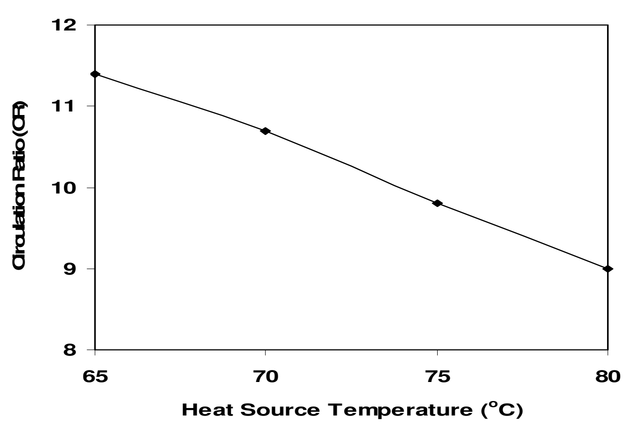

Fig. 7 Variation of Circulation Ratio with Heat Source Temperature

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