Theoretical and Experimental Evaluation of Vapour Absorption Refrigeration System

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ABSTRACT

The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression system, in order to change the condition of the refrigerant required for the operation of the refrigeration cycle. In this system, the compressor is replaced by an absorber, a pump, a generator, and a pressure reducing valve. This complete papers discuss about the theoretical calculations are made of different components of the systems like evaporator, absorber, condenser and pump of vapour absorption system for a capacity of 0.25TR and experimentally developed and run system to validated for reducing the temperature for the free of cost of operation.

Keywords: Absorption, absorber, NH_3, VAR, VCR.

I. INTRODUCTION

In the vapour absorption refrigeration (VAR) system, a physicochemical process replaces the mechanical pro-cess of the vapour compression refrigeration (VCR) sys-tem by using energy in the form of heat rather than mechanical work. The main advantage of this system lies in the possibility of utilizing waste heat energy from industrial plants or other sources and solar energy as the energy input.

The VAR systems have many favourable characteristics. Typically a much smaller electrical input is required to drive the solution pump, compared to the power requirements of the compressor in the VCR systems, also, fewer moving parts means lower noise levels, higher reliability, and improved durability in the VAR systems [1–5].

A Robur Servel ACD-3600 gas-fired system was originally obtained for a study of the suitability of VAR systems of road transport refrigeration. However, an early approach to the manufacturer for comprehensive details of the system characteristics received a negative response. It was therefore decided to conduct a detailed experimental analysis of the system. This work forms the basis of this paper. A vapour absorption refrigeration system is a heat operated unit which uses refrigerant (NH_3) that is alternately absorbed by and liberated from the absorbent (water). The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression system, in order to change the condition of the refrigerant required for the operation of the refrigeration cycle. In this system, the compressor is replaced by an absorber, a pump, a generator, and a pressure reducing valve. These components in the system perform the same function as that of compressor in vapour compression system. The vapour refrigerant from evaporator is drawn into an absorber where it is absorbed by the weak solution of refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by utilizing solar energy. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquefied**.** The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

The papers discuss about the complete theoretical calculations and design the system as per the theoretical calculations and experimentally validate the system with reducing the temperature.

II. METHODOLOGY

Fig.1 shows the schematic diagram of a vapour absorption system. Ammonia vapour is produced in the generator at high pressure from the strong solution of NH_3 by an external heating source. A solar cooker will produce the heat and generate ammonia gas. Ammonia gas then enters into the condenser. High pressure NH_3 vapour is condensed in the condenser. The cooled NH_3 solution is passed through a throttle valve and the pressure and temperature of the refrigerant are reduced below the temperature to be maintained in the evaporator. The low temperature refrigerant enters the evaporator and absorbs the required heat from the evaporator and leaves the evaporator as saturated vapour. Slightly superheated, low pressure NH_3 vapour is absorbed by the weak solution of NH_3 which is sprayed in the absorber.

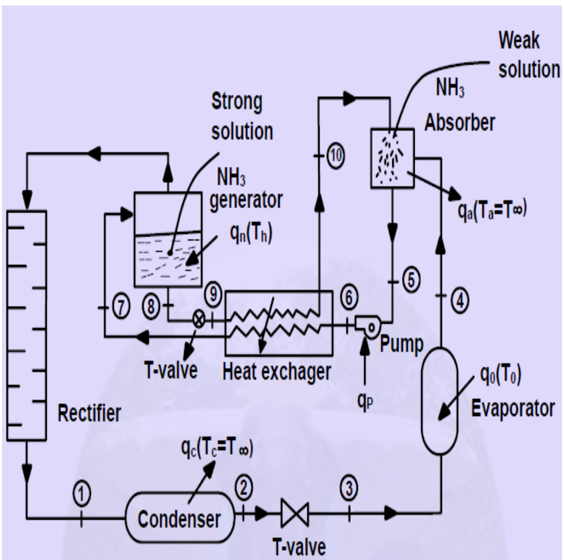

Fig.1 Schematic diagram of vapour absorption refrigeration system.

Table1
Properties of Ammonia (R717).

Properties of Ammonia(R717)	Values
Molecular weight	17.031
Normal boiling point	33.35°C
Critical temperature	132.4°C
Critical pressure	112.97bar
Critical volume	$4.13m^3$
Freezing point	-77.7°C
Cp/Cv (γ)	Cp/Cv (γ): 1.31
Latent heat of vaporization	1315.5 kJ/kg
Specific volume of NH_3	15°C
Quantity of vapour per ton of refrigeration per hr	15°C
Mass of refrigerant circulated per ton	0.19kg/min (standard)
Volume of liquid refrigerant circulated per ton	0.32lit/min at 30°C(standard)

The above table 1 shows the properties of Ammonia (R717) for the used in the system.

III. THEORETICAL CALCULATION OF THE SYSTEM

The following specific parameters are assumed for theoretical calculation of the complete system design:

Condenser pressure: 5 bar,
Evaporator pressure: 2 bar,
Capacity of refrigeration: 0.25 TR,
Degasification factor: 0.1.

i) Heat removed in condenser (Q_c):

The amount of heat removed in the condenser is given by:

$Q_c = (h_2 - h_1)$ kJ/kg of NH_3. (1)

Where h is enthalpy at different points on chart. As NH_3 saturated vapour enters in and NH_3 saturated liquid comes out.

ii) Heat absorbed in the evaporator (Q_e):

The amount of heat absorbed in the evaporator is given by:

$Q_e = (h_4 - h_3)$ kJ/kg of NH_3. (2)

where h_4 is the heat of saturated vapour at P_c and h_3 is the heat of mixture of NH_3 liquid and vapour at P_e or heat of NH_3 liquid at points '2' as 2-3 is constant enthalpy throttling process.

iii) Heat removed from the absorber (Q_a):

When NH_3 vapour at point 4 and aqua at point 10 are mixed, the resulting condition of the mixture in the absorber is represented by 7'' and after losing the heat in the absorber (as it is cooled), the aqua comes out at condition 5. Therefore, the heat removed in the absorber is given by:

$Q_a = (h_7 - h_5)$ kJ/kg of aqua. (3)

iv) Heat given in the generator (Q_g):

Q_g is the heat supplied in the generator and Q_d is the heat removed from the water vapour, then the heat removed per kg of aqua is given by:

$(Q_g - Q_d) = (h_7' - h_7)$ kJ/kg of aqua. (4)

As the aqua goes in at point 7 and comes out at condition 8 and 1 which can be considered a combined condition at 7'. By extending the triangle 8-7-7' towards right till 8-7' cuts at 1 and 8-7 cuts at 'a' on y-axis then, the heat removed per kg of NH_3 is given by:

$(Q_g - Q_d) = h_1 - h_a$ kJ/kg of NH_3. (5)

For finding out Q_d separately, extend the vertical line 7-7' till it cuts the auxillary P_c line and mark the point 'b'. Then draw horizontal line through 'b' which cuts the P_c line in (in vapour region) at point 11. Then join the points 7 and 11 and extend that line till it cuts y-axis at 12. Therefore, Q_d is given by:

$Q_d = (h_{12} - h_1)$ kJ/kg of NH_3. (6)

The table 2 shows the values obtained on enthalpies based on enthalpy concentration chart of Ammonia (R717).

Table 2

Enthalpy values on different points on enthalpy entropy chart of Ammonia (R717).

Point	Enthalpy(kJ/kg)
h_1	1632.462
h_2	376.722
h_3	376.722
h_4	1632.462
h_5	41.858
h_6	41.858
h_7	133.9456
h_8	209.29
h_9	92.0876

Based on above enthalpies calculation values the following results are obtained for the design load of different component of the system.

i) Mass flow rate of NH_3 through evaporator (m_f):

m_f = Cooling load/ $h_4 - h_3$

= (0.25x0.35)/(1632.462-376.722)

$m_f = 6.968\times10^{-4}$kg/s=2.51kg/h.

ii) Heat rejected in absorber (Q_a):

$Q_a = m_r \times x \times (h_4 - h_a)$

$= 6.968 \text{ x } 10^{-4} \text{ x } (1632.462-(-334.864))$

Q_a =1.371kW.

iii) Heat removed in condenser (Q_C):

$Q_C = m_r \times x \times (h_1 - h_2)$

= 6.968 x 10^-4 x (1632.462-376.722)

Q_C = 0.875kW.

iv) Mass of strong solution handled by pump per second (m_s):

Enthalpy balance across heat exchanger is,

Heat lost by weak solution = heat gained by strong solution,

$m_w \times (h_8 - h_9) = (m_w + 1) \times (h_7 - h_6)$

$m_w \times (209.92-92.0876) = (m_w+1) \times (133.9456-41.858)$

m_W = 3.6667kg/kg of NH_3.

Hence, mass of strong solution handled by pump (ms),

$m_s = m_r \times (m_w + 1) = 6.968 \text{ x } 10^{-4} \times (3.6667+1)$

Therefore, $m_s = 3.2517\times10^{-3}$ kg/s.

v) Heat supplied to generator temperature = 75°C.

$Q_g = m_r \text{ x } (h_{12} - h_a)$

$= 6.968 \text{ x } 10^{-4} \text{ x } (1820.823-(-334.864))$

Therefore, Q_g = 1.502kW.

vi) Design of pressure vessel for generator:

At pressure 5bar, with diameter (d) =200mm, and assuming 33% overload, the design pressure,(*Pd*) obtained 6.65bar.Design pressure *(Pd)* =1.33 x_P = 6.65bar. Therefore, thickness of pressure vessel as thin cylinder, [(Pd x d)/2 x_t] =330N/mm^2 (330N/mm^2 assuming C40 as a material for pressure vessel from PSG data book).

Therefore, t=8mm.

vii) Design of air cooled condenser:

Calculations are made and obtained LMTD (Log Mean Temperature Difference) = 42.45°C, and length of coil=1.87m.

IV. EXPERIMENTAL SETUP

Based on above theoretical value calculations the all the components of system are assemble for the vapour absorption refrigeration system as shown in Fig.2.

Fig.2 Complete view of vapour absorption refrigeration system.

V. RESULTS AND CALCULATION

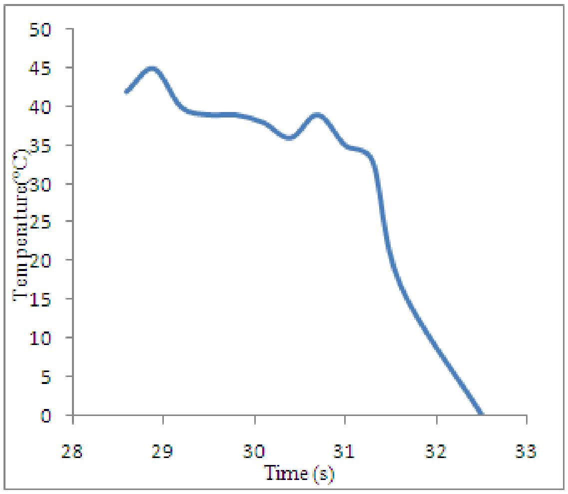

Fig.3 Time–Temperature curve for vapour absorption refrigeration system.

VI. CONCLUSIONS

After designing, manufacturing and run the system the achieved temperature drop of 3.5°C below ambient temperature with the time period of 32.5s as shown in Fig.3. Although the system was designed for a capacity of 0.25TR the desired capacity was not completely achieved. This was due to fact that certain parameters could not be achieved during the practical design as compared to the theoretical design as stated below.

1 Less number of turns of condenser& tube length resulted in inefficient heat rejection. This caused the hot vapour from the generator to enter the evaporator coil without changing its phase completely and thus reduced the cooling effect.

2 The system couldn't sustain desired pressure range. The pressure capacity of the flexible hoses used in the system limited the system pressure and thus the design pressure could not be achieved due to fear of failure.

3 Concentration of ammonia in the system design was for 50% concentration of ammonia but in the ammonia commercially available is of 25% concentration. This was also a limitation.

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