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Design of Solar Powered Vapour Absorption Refrigeration System

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ABSTRACT : The continuous increase in the cost and demand for energy has led to more research and development to utilize available and renewable energy resources efficiently. The absorption refrigeration system (ARS) is becoming more important because it can produce higher cooling capacity than vapor compression systems, and it can be powered by other sources of energy (like waste heat from gas and steam turbines, sun, geothermal, biomass) other than electricity. This project presents the design and study of an environment friendly vapour absorption refrigeration system of 2 ton capacity using R-717 (NH_3) and water as the working fluids. In this project , performance of the fabricated system is outlined with respect to various operating conditions related to heat source, condenser, absorber and evaporator temperatures.

keywords – Renewable Energy, Vapour Absorption Refrigeration System, R-717(NH_3)

I. INTRODUCTION

Solar energy is a very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8 $\times 10^{11}$ MW which is much more larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, solar energy could supply all the present and future energy needs of the world on the continuing basis. This makes it one of the most promising of the unconventional energy sources. In addition to its size, solar energy has two other factors in its favour. First unlike fossil fuels and nuclear power, it is an environmental clean source of energy. Second, it is free and available in adequate quantities in almost all parts of the world where people live. However, there are many problems associated with its use. The main problem is that it is a dilute source of energy.

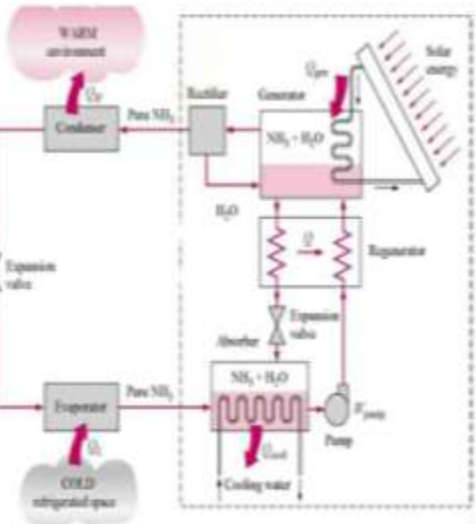
Even in the hottest regions on earth, the solar radiation flux rarely exceeds 1kWh/m^2 and the total radiation over a day is best about 6 kWh/m^2.These are low values from the point of view of technological utilization. Consequently, large collecting areas are required in many applications and this result in excessive costs.

A second problem associated with the use of solar energy is that its availability varies widely with time. The variation in availability occurs daily because of the day-night cycle and also seasonally because of the earth's orbit around the sun. In addition, variation occurs at a specific location because of local weather conditions. Consequently, the energy collected when the sun is shining must be stored for use during periods when it is not available. The need for storage significantly adds to the cost of the system. Thus, the real challenge in utilizing solar energy as an energy alternative is to address these challenges. One has to strive for the development of cheaper methods of collection and storage so that the large initial investments required at present in most applications are reduced.

II. DESIGN METHODOLOGY

- **Vapour Absorption Refrigeration (VARS) System**

The vapour absorption refrigeration is heat operated system. It is quite similar to the vapour compression system. In both the systems, there are evaporator and condenser. The process of evaporation and condensation of the refrigerant takes place at two different pressure levels to achieve refrigeration in both the cases. The method employed to create the two pressure levels in the system for evaporation and condensation of the refrigeration makes the two processes different. Circulation of refrigerant in both the cases is also different. In the absorption system the compressor of the vapour compression system is replaced by the combination of "absorber" and "generator".



- **Function of components of VARS system**

✓ **Evaporator**

The purpose of evaporator is to cool the circulating water. The evaporator contains a bundle of tubes that carry the system water to be cooled/chilled. High pressure liquid condensate (refrigerant) is throttled down to the evaporator pressure (typically around 6.5 mm Hg absolute). At this low pressure, the refrigerant absorbs heat from the circulating water and evaporates. The refrigerant vapours thus formed tend to increase the pressure in the vessel. This will in turn increase the boiling temperature and the desired cooling effect will not be obtained. So, it is necessary to remove the refrigerant vapours from the vessel into the lower pressure absorber. Physically, the evaporator and absorber are contained inside the same shell, allowing refrigerant vapours generated in the evaporator to migrate continuously to the absorber.

Evaporator pressure (P_e) : The evaporator pressure can be fixed according to the minimum temperature required to be maintained in the evaporator chamber. The minimum temperature attained is not a designing criterion in this system, as we require to cool water only for drinking purposes. The pressure maintained in the evaporator should be as close to the atmospheric pressure as possible, because maintaining a higher pressure is a difficult and costly affair. Moreover it also has leakage problems and the unit needs to be hermetically sealed. The evaporator pressure is kept equal to the atmospheric pressure (1.2 bar), to ensure design economy. The corresponding saturation temperature in the evaporator (ammonia vapours) becomes -30^{0}C.
Evaporator Temp. (T_E) = - 30˚C
Evaporator Pressure (P_E) = 1.2 bar

✓ **Condenser**

The purpose of condenser is to condense the refrigerant vapours. Inside the condenser, cooling water flows through tubes and the hot refrigerant vapour fills the surrounding space. As heat transfers from the refrigerant vapour to the water, refrigerant condenses on the tube surfaces. The condensed liquid refrigerant collects in the bottom of the condenser before traveling to the expansion device. The cooling water system is typically connected to a cooling tower. Generally, the generator and condenser are contained inside of the same shell.

Condenser Pressure (P_c) : The pressure to be maintained in the condenser for changing the phase of ammonia vapours into ammonia liquid depends on type of condensing medium used and its temperature. In this system, water is used as a condensing medium. Water is available at a temperature of 27^{0}C. i.e. condensing temperature is T_c= 27^{0}C. For condensing ammonia vapours at 27^{0}C, the corresponding pressure required can be noted from the refrigeration table of ammonia (R-717). In this way, the condenser pressure is fixed at P_c = 10.7 bar.
Condenser Temp. (T_c) = 27˚C
Condenser Pressure (P_c) = 10.7 bar

✓ **Generator**

The purpose of the generator is to deliver the refrigerant vapour to the rest of the system. It accomplishes this by separating the water (refrigerant) from the ammonia and water solution. In the generator, a high-temperature energy source, typically steam or hot water, flows through tubes that are immersed in a dilute solution of refrigerant and absorbent. The solution absorbs heat from the warmer steam or water, causing the refrigerant to boil (vaporize) and separate from the absorbent solution. As the refrigerant is boiled away, the absorbent solution becomes more concentrated. The concentrated absorbent solution returns to the absorber and the refrigerant vapour migrates to the condenser.

✓ **Absorber**

Inside the absorber, the refrigerant vapour is absorbed by the lithium bromide solution. As the refrigerant vapour is absorbed, it condenses from a vapour to a liquid, releasing the heat it acquired in the evaporator. The absorption process creates a lower pressure within the absorber. This lower pressure, along with the absorbents‟ affinity for water, induces a continuous flow of refrigerant vapour from the evaporator. In addition, the absorption process condenses the refrigerant vapours and releases the heat removed from the evaporator by the refrigerant. The heat released from the condensation of refrigerant vapours and their absorption in the solution is removed to the cooling water that is circulated through the absorber tube bundle. As the concentrated solution absorbs more and more refrigerant; its absorption ability decreases. The weak absorbent solution is then pumped to the generator where heat is used to drive off the refrigerant. The hot refrigerant vapours created in the generator migrate to the condenser. The cooling tower water circulating through the condenser turns the refrigerant vapours to a liquid state and picks up the heat of condensation, which it rejects to the cooling tower. The liquid refrigerant returns to the evaporator and completes the cycle.

✓ **Pump**

A pump is a device that moves fluids (liquids), or sometimes slurries, by mechanical action.

Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, engines, or wind power, come in many sizes, from microscopic for use in medical applications to large industrial pumps.

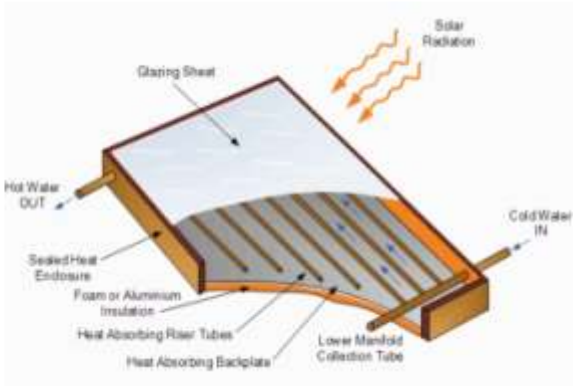
When the absorbent absorbs the refrigerant strong solution of refrigerant absorbent (ammonia water) is formed. This solution is pumped by the pump at high pressure to the generator. Thus pump increases the pressure of the solution.

✓ **Expansion Device**

From the condenser, the liquid refrigerant flows through an expansion device into the evaporator. The expansion device is used to maintain the pressure difference between the high pressure (condenser) and low-pressure (evaporator) sides of the refrigeration system by creating a liquid seal that separates the high-pressure and low pressure sides of the cycle. As the high-pressure liquid refrigerant flows through the expansion device, it causes a pressure drop that reduces the refrigerant pressure to that of the evaporator. This pressure reduction causes a small portion of the liquid refrigerant to boil off, cooling the remaining refrigerant to the desired evaporator temperature. The cooled mixture of liquid and vapour refrigerant then flows into the evaporator.

✓ **Flat-plate collectors**

The construction of a flat-plate collector is shown in Figure below. The basic parts noted are a full-aperture absorber, transparent or translucent cover sheets, and an insulated box. The absorber is usually a sheet of high-thermal-conductivity metal with tubes or ducts either integral or attached. Its surface is painted or coated to maximize radiant energy absorption and in some cases to minimize radiant emission. The cover sheets, called glazing, let sunlight pass through to the absorber but insulate the space above the absorber to prohibit cool air from flowing into this space. The insulated box provides structure and sealing and reduces heat loss from the back or sides of the collector.



Flat plate collector is an insulated weather proofed box containing a dark absorber plate under one or more transparent or translucent covers.

Parts of a Flat Plate Collector:

Cover Plate: It is made up of glass tempered with a low iron content and 3.2-6.4 mm thick. The collector has 85% transmittance when this type of glass is used.

Absorber Plate: It is made up of copper because of its high conductivity. Moreover, it is corrosion resistant. these copper plates 0.05 mm thick with 1.25 cm tubes. Tubes are spaced 15 cm apart, the efficiency is 97 %. Moreover, black paint over copper plate is used which has absorptance =0.85-0.9 and emmitance=0.08-0.12.

Enclosure/Insulation: It is made up of steel, aluminium or fibre glass. Fibre glass is widely used.

III. CALCULATIONS

The operating pressures at which the system is working needs to be determined to carry on further calculations. Once the pressure of the condenser (P_c) and the pressure of the evaporator (P_e) are determined the corresponding values can be find out.

Now :

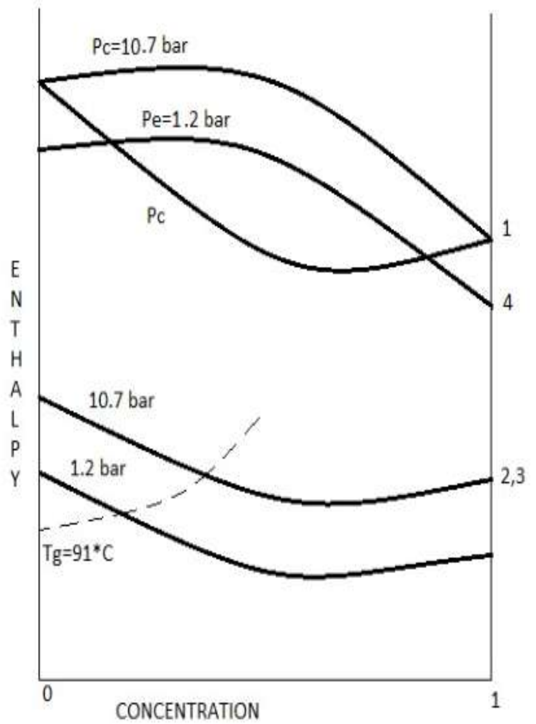
h_{gc} = 1627.7 kJ/kg

h_{fc} = 470.43 kJ/kg

h_{ge} = 1566.5 kJ/kg

h_{fe} = 206.76 kJ/kg

The points of condenser pressure and evaporator pressure can be plotted on the pressure enthalpy chart as points 1, 2, 3 and 4.
Point 1 represents pure NH_3 saturated vapour at condenser pressure P_c and concentration C=1.
Point 2 represents pure NH_3 saturated liquid at P_c and C=1. This point is marked in liquid region.
Point 3 represents the condition of pure NH_3 (wet) but at pressure P_e and C=1. Point 2 coincides with point 3 as 2-3 is a throttling process in which enthalpy remains contant.
Point 4 represents the condition of pure NH_3 at pressure P_e these are saturated vapours which absorbs heat in evaporator and converts from wet vapour to saturated vapour. This point is marked in vapour region.



The enthalpies at points 1, 2, 3 and 4 can be noted from the chart.
$\mathbf{h_1 = 1627.7}$ **kJ/kg**
$\mathbf{h_2 = h_3 = 470.43}$ **kJ/kg**
$\mathbf{h_4 = 1566.5}$ **kJ/kg**

Refrigeration Capacity of unit is 2TR
The refrigerating effect produced or the heat absorbed by ammonia refrigerant in the evaporator is
$\mathbf{Q_E = M_r(h_4 - h_3)}$ KJ/Kg of ammonia
Say the mass flow rate of ammonia in the evaporator be M_r
$Q_E = M_r (h_4 - h_3) = M_r (1566.5 - 470.43)$
$M_r \times 1096.07 = 2 \times 210$ kJ/min.
$\mathbf{M_r = 0.3831}$ **kg/min.**

Heat removed in condenser by the circulated cooling water is given by the equation :
$\mathbf{Q_C = M_r (h_1 - h_2) = 0.3831 (1627.7 - 470.43)}$
Therefore, heat removed
$\mathbf{Q_C = 443.35}$ **kJ/min.**

- **<u>For Solar Water Heater</u> :**

Useful energy (energy absorbed by the collector plate) is given by
$\mathbf{Q_u = K \times S \times A}$
Where,
K=efficiency of collector plate (assume k=0.85)
S=average solar heat falling on earth's surface=6 kwhr/m^2/day= 250 W/m^2
A=Area of collector plates
$\mathbf{Q_u = K \times S \times A}$
Assume, K = 0.85
S = 250 W/m^2
Total Area of collector plates Therefore, we can use 4 collector plates of having dimensions of 4 × 3 sq m.
Area of one plate = 4 × 3 = 12 m^2
So, Area of 4 Plates is = 4 × 12 = 48 m^2
A = 48 m^2
$\mathbf{Q_u = 0.85 \times 250 \times 48 = 10{,}200}$ **Watts = 10.2 KW**
Heat req. in the generator,$\mathbf{Q_g = 612}$ **kJ/min.**

The energy absorbed by the collector helps in heating of the water flowing in the tubes of the collector plates.
$\mathbf{Q = m \times C_p \times (T_o - T_i)}$

- **<u>For Plate Collector</u> :**

Let Rate of Water flowing through tubes
m = 0.0357 kg/s = 2.144 kg/min.
Specific heat of water C_p= 4200 J/kg/k
Inlet temp. of Water at collector plate $\mathbf{(T_i)}$**= 27˚C**
Therefore,
$0.0357 \times 4200 \times (T_o - 27) = 10{,}200$
Outlet temp.of Water at collector plate
$\mathbf{(T_o)}$ **= comes out to be 95˚C**
The temperature (T_o) should be the inlet temp.of generator, but assuming water loses heat while flowing through the tubes. Also there is certain effectiveness of the generator as a heat exchanger, less than 100 %. Hence net heating in the generator can be assumed to be taking place at 91^0C
Assuming Losses : $\mathbf{T_o = 91}$**˚C**
Temp. at generator = 91˚C

This is the net heat input to the system, which is running as a refrigeration unit of 2 TR capacity.

The work done by the pump for raising the pressure is negligible and hence neglected.

- **COP of the System :**

The cop of the refrigerating unit can be calculated by using the equation:

$$\text{COP} = \frac{\text{Refrigeratingeffect}}{\text{Heatinputingenerator}}$$

Therefore,

$$\text{COP} = \frac{2 \times 210}{612} = 0.686$$

- **COP of System as a whole (including solar water heater) :**

Now, COP of System as a whole (including solar water heater) can be used as

$$\text{COP} = \frac{\text{NetRefrigerationeffectproduced}}{\text{Heatinputatthesolarcollector}}$$

Heat input at the solar collector = Solar Constant × Area = 250 × 48 W

$$\text{COP} = \frac{2 \times 210 \times 1000}{250 \times 48 \times 60} = 0.5833$$

Hence theoretical COP of the whole system comes out to be 0.5833

IV. TECHNOLOGIES RELATED

Of the air-conditioning alternatives, the absorption system appears to be one of the most promising methods. Many arrangements or cycles are possible: solar collectors can be used to provide energy for absorption cooling, desiccant cooling, and Rankine-vapour compression cycles. Solar hybrid cooling systems are also possible.

Although a large potential market exists for this technology, existing solar cooling systems are not competitive with electricity-driven or gas-fired air-conditioning systems because of their high first costs. Lowering the cost of components and improving their performance could reduce the cost of solar cooling systems.

Improvements such as reduced collector area, because of improved system performance, and reduced collector cost will lower the cost of solar components. Several solar driven refrigeration systems have been proposed and are under development such absorption systems including liquid/vapor, solid/vapor absorption, adsorption, vapor compression and photovoltaic vapor compression systems. Most of the above mentioned systems have not been economically justified.

V. APPLICATION AREAS INCLUDING AIR CONDITIONING :

- ✓ Air conditioning machines.
- ✓ Food Processing Industries.
- ✓ Jute Industries.
- ✓ Commercial purposes.
- ✓ Industrial chemical processes such as distillation.
- ✓ Steam power plants and other heat-exchange systems

VI. ADVANTAGES OF USING VAPOR ABSORPTION REFRIGERATION SYSTEM

- ✓ As there is no moving part in the entire system, the operation is essentially quite and subjected to a very little wear.
- ✓ The load variations does not effect the performance of a vapour absorption system.
- ✓ Absorption system may be designed to use any readily available source of thermal energy such as process steam ,hot exhaust from furnaces and solar energy, therefore they can be used in places where electric power is hard to obtain or is very expensive.
- ✓ In here pump is used for pumping refrigerant absorbant solution, which consumes less power.
- ✓ Maintenance cost is low as because of absence of moving part.
- ✓ In the absorption refrigeration system no refrigerant produces the greenhouse effect, so their use won't be stopped in future.
- ✓ No moving part except pump-motor, which is comparatively smaller than compressor system.
- ✓ Quiet in operation, low maintenance cost.
- ✓ Can work only with thermal energy as an input.
- ✓ Can be built for huge working capacities.
- ✓ Can be operated at designed C.O.P's or even at part loads by varying generator temperature.
- ✓ Space and Auto. control requirements favor absorption system.
- ✓ In ammonia-water absorption refrigeration system, ammonia is used as the refrigerant, which is easily and cheaply available. In lithium bromide system, water is used as the refrigerant, which is also available cheap.

VII. DISADVANTAGES OF USING VAPOR ABSORPTION REFRIGERATION SYSTEM

- ✓ Set up is too large as it consists of three more equipment those are absorber, generator ,and pump.
- ✓ Initial cost is high.
- ✓ Corrosive in nature.
- ✓ Low working pressure.
- ✓ Due to low working pressure the cop of vapour refrigeration is low, it is about 1.1

✓ High heat rejection system is required, as heat is being rejected from condenser, analyzer, rectifier and absorber.

VIII. SCOPE FOR THE FUTURE WORK

It is obvious from the introductory part of this paper, that the basic absorption refrigeration systems can be based either on lithium bromide-water ($LiBr-H_2O$) where water vapour is the refrigerant and ammonia-water (NH_3-H_2O) systems where ammonia is the refrigerant. The future trends of research in this area would be on other refrigerants pairs which will be more effective and their main advantage is that they do not cause ozone depletion. Any change can be done that can bring an overall improvement in the system COP or material saving or more simple design procedure. The methodology described in this work can be adopted to design and develop a suitable system that can be most effectively and efficiently used maximum utilization of the solar power.

The major limiting factor at present is the availability of solar energy whenever it is required. For example at nights and extended cloudy days we cannot attain a high enough temperature and hence refrigeration is poor. Modifying the design of solar collector for wider acceptance angle and making generator tubes with material of higher thermal conductivity yield can be improved. There are many other achievements carried out by researchers. nevertheless, further improvements should be made to the solar powered refrigeration systems in order to compete with the conventional refrigeration systems.

It is hoped that these results could serve as a source of reference for designing and selecting new absorption refrigeration systems. Developing new working fluid pairs and optimizing suitable operating conditions.

Using Solar Energy as the power source of the system proved to be feasible. Solar Energy being a renewable source of energy proved to be efficient as compared to using electrical energy or steam at the same place.

With the flow of ammonia through the system, we were able to use it as an air conditioner and that too with the help of renewable and non-polluting source of energy, i.e., solar energy.

IX. RESULTS

The heat input which is given to run the 2 TR vapour refrigeration system, for the operating conditions designed, is about 612 KJ/min. This heat in the generator is supplied by the means of hot water coming from the solar flat plate water heater.

For this vapour absorption refrigeration system the coefficient of performance is also calculated. The results can be summarized as:

Mass flow rate of ammonia as refrigerant
M_r = 0.18 Kg/min

Designed operating conditions:

✓ Condenser pressure: 10.7 bar
✓ Evaporator pressure: 1.2 bar
✓ Area of the solar collectors used = 48 square meter i.e. 4 plates of 4×3 meter square can be used.
✓ Output temp of water from solar heater = 95˚C
✓ Heat input provided (at generator) = 612 KJ/min
✓ COP of refrigerating unit = 0.686
✓ COP of the whole system = 0.583

X. CONCLUSION

In light of the above results, the feasibility of the solar powered vapour refrigeration system has been reasonably proved. The COP values as calculated by us are on a little higher side than the actual COP's, but , because we have assumed ideal processes in heat exchanges etc, this obliquity can be understood.

Hence, a solar water heating unit can be usefully incorporated for water cooling purposes. In the month of summers, when the solar potential is quite high, the unit can be used for refrigeration.

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