ASSESSMENT OF THE USE OF SOLAR FLAT PLATE COLLECTORS FOR SOLAR THERMAL REFRIGERATION

Dinesh Khanna[1], Aneesh Jose[2]

[1]*P.G student Department of Mechanical Engineering NMAM Institute of Technology, Nitte, Udupi, Karnataka, India*
[2]*Asst.Professor, Department of Mechanical Engineering NMAM Institute of Technology, Nitte, Udupi, Karnataka, India*

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Abstract - *The report aims to provide a comprehensive overview of technologies relating to solar cooling and to analyse trends in the solar cooling field. The present study was carried out on solar thermal Vapor Absorption system. This project is based upon previous research and prototyping in the field of solar thermal refrigeration. Generally, research is being done on different principles to harvest solar thermal energy for cooling purposes.*
The use of solar energy to power refrigeration with replacing the compression cycle with vapor absorption cycle strives to minimize the negative impacts refrigerators have on the environment and energy. Replacing the electrical energy with solar energy will reduce the consumption of high grade electrical energy. Ammonia being an environmentally friendly gas reduces the effect of ozone layer depletion and global warming by artificial refrigerants. This project deals with a model solar thermal refrigeration system using NH_3-H_2O vapour absorption system.

***Key Words*: Solar Cooling, Refrigeration, NH_3-H_2O**

1.INTRODUCTION

Refrigeration is the thermodynamic process to produce cooling effect below the atmospheric temperature. The working is conducted by reversing the second law of thermodynamics that is, when a work input is given to system heat can be moved from a low temperature body to a high temperature body. Temperature requirement depends on the application .The performance of refrigeration system is calculated in terms of Coefficient of Performance (COP) [1].

A refrigeration system is a system which can reduce the temperature or heat of a substance under a controlled condition. Refrigeration might make characterized likewise the transform from claiming accomplishing furthermore looking after an temperature that of the surroundings, those point constantly with cool a few result or space of the required temperature. Those fill in of high temperature transport will be customarily determined toward mechanical work and additionally run by perusing heat energy, motion of electric charge, electricity, laser, alternately other implies. Refrigeration has many different applications, including unit refrigerators, streamlined freezers furthermore ventilating [2].

Those liable from claiming refrigeration and ventilating need developed out about human requirement to nourishment and comfort, what's more its historical backdrop dates go will hundreds of years. Those historical backdrop of refrigeration may be thick, as fascinating since each part of it, the accessibility from claiming refrigerants, those prime movers and the developments for compressors and the strategies of refrigeration every last bit would an and only it. Over past times refrigeration might have been attained by regular implies for example, such that the utilization about ice alternately evaporative cooling. Currently refrigeration is prepared by fake methods. However, refrigeration engineering need quickly developed in the keep going century [2].

1.1 Different types of Vapour Refrigeration Cycle

There are two types of Vapour Refrigeration cycle

1. Vapor Compression Refrigeration Cycle.
2. Vapor Absorption Refrigeration Cycle.

Vapor Compression Refrigeration Cycle

The vapor compression refrigeration system is by far the most popular and widely used system in refrigeration air conditioning and refrigeration both for industrial and household applications. The schematic diagram of a vapor compression refrigeration system is shown in below Fig. 1.1

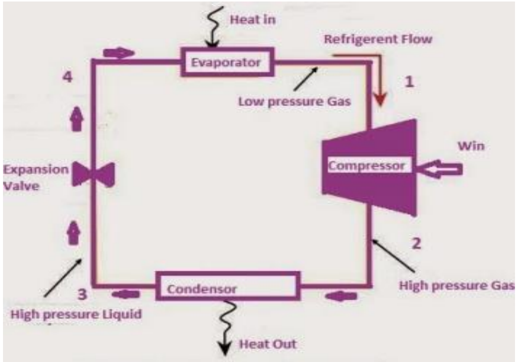

Fig 1.1 Compression refrigeration system

Vapour Absorption Refrigeration Cycle

Fig-1.2 shows the schematic diagram of vapour absorption system. In this system, low pressure refrigerant vapour leaves the evaporator and enters the absorber. Here the development of "arrangement combine" happens i.e. mix of refrigerant and spongy (absorbent) and the combined solution is strong in nature. Presently this strong solution is then pumped to the generator where pressure increases. In generator this strong solution is heated by some outer heat source. After heating procedure is proficient strong solution at high pressure moves to the condenser leaving back the feeble arrangement which is sent to expansion valve and then to absorber. Presently the high pressure refrigerant moves from generator to the condenser where the refrigerant vapour is dense to high pressure fluid refrigerant. This fluid refrigerant is passed to the throttle valve and where it is sent to the evaporator, where the refrigeration impact is accomplished and along these lines finishes the total vapour absorption cycle [5].

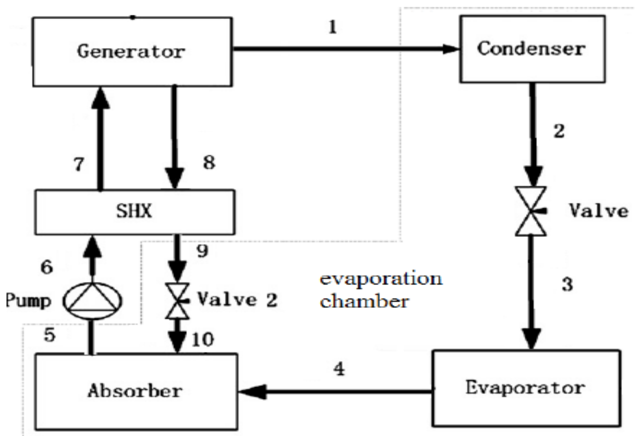

Fig. 1.2 Vapour absorption cycle

Photovoltaic Operated Refrigeration Cycle

Photovoltaic's (PV) include the immediate transformation of sun powered radiation to coordinate current (DC) power utilizing semiconducting materials. In idea, the operation of a PV-powered sun oriented refrigeration cycle is basic. Sun based photovoltaic boards create DC electrical power that can be either used to work a dc motor, which is coupled to the compressor or an inverter can be utilized to change over this DC current to AC current for running the compressor of a vapor compression refrigeration system. The real contemplations in outlining a PV-refrigeration cycle include properly coordinating the electrical attributes of the motor driving the compressor with the accessible current and voltage being created by the PV panel [3].

The PV system can execute as a Stand Alone system, a cross breed framework (working with an oil/hydro/gas control plant) or as a lattice or utility inter tied frameworks. In spite of the fact that the proficiency of PV modules can be expanded by utilizing inverters, their COP and productivity are as yet not alluring. Consideration should then be given to Solar Thermal Refrigeration frameworks for cooling purposes [4]

Solar Thermal Refrigeration

Thermal cooling innovation is wanted to PV-based cooling system since it can use more episode daylight than a PV system. A large portion of the aggregate solar energy changes over into heat, and a little segment produces power in a PV framework, with 65% of the occurrence beams changed over into warm vitality and just 35% valuable for creating power in a silicon-based PV framework. Along these lines, warm sun based cooling is ending up more well-known on the grounds that a thermal sun oriented authority specifically changes over light into heat [4].

In a Solar thermal VAR system, the mechanical compressor is replaced by the generator- absorber unit, where in the generator performs the heating of refrigerant and absorber performs the suction of refrigerant from evaporator. The essential parts of VAR in include- generator, absorber, condenser, evaporator, solution-heat exchanger, an expansion valve, reducing valve and a pump. VAR systems comprises of refrigerant- absorbent mixture, where the refrigerant circulates within the refrigeration machine and the absorbent circulation is limited within the generator and absorber unit [5].

The thermal component of solar energy is taken up the working fluids in solar collector and this heat energy will be supplied to generator unit that has a strong solution of refrigerant- absorbent mixture, wherein the concentration of refrigerant is high. This heat energy heats up the mixture and the mixture should be chosen in such that, the refrigerant has a lower boiling point than the absorbent, so the refrigerant boils and gets converted to vapour phase. The pressure and temperature of the refrigerant

vapour will be high. These vapours will be fed to condenser unit for heat rejection. The heated absorbent alone will be present in the generator unit as weak solution is fed to the absorber through a solution heat-exchanger that will take up the heat from the weak solution and leaves the weak solution to the absorber unit. The refrigerant vapour at the condenser rejects heat to the ambient and condenses to liquid phase. The liquid refrigerant is subjected to expansion where it undergoes a pressure drop and is fed to the evaporator, which is the space of actual cooling process. Heat will be added from the ambient object placed in the cabinet to the evaporator that will convert the liquid refrigerant to vapour phase. The vapour refrigerant moves to the absorber unit that contains the weak solution of absorbent. The absorbent should be chosen in such a way that it has strong affinity for the refrigerant. The absorbent solution will absorb the refrigerant vapour and thus forms a strong solution. This strong solution is pumped to solution heat exchanger, that will regenerate the heat that was absorbed from the weak solution, and heat will be added to the strong solution which is pumped to the generator unit and thus the excess heat is utilized properly, continuing the VAR cycle [5].
For the case of aqua- ammonia system, two additional components-rectifiers and analyzer, are employed to separate the water vapour leaving the generator and to send only dehydrated ammonia to the condenser [5].

2. COP Calculations

The Coefficient of performance (COP) of the system as theoretically known is given by COP= Heat Absorbed in the Evaporator /(Work done by pump +Heat Supplied in the evacuated tube) or COP =Qe/(Qg+Wp). Figure 2.1 shows a circuit of solar vapour absorption system.
Neglecting pump work, Theoretical COP = Qe/Qg

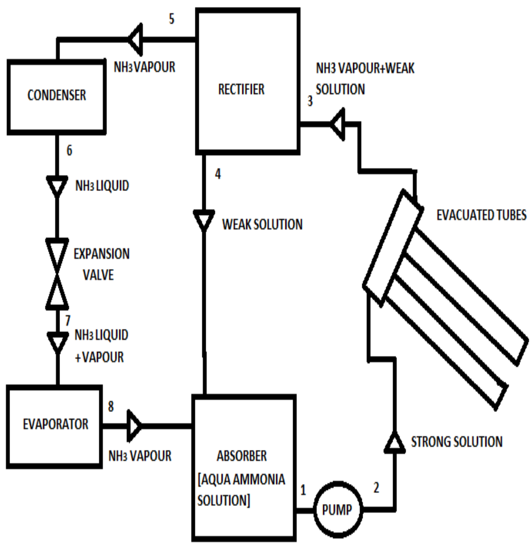

Figure 2.1 Block diagram of Solar vapour absorption system

Assumed values are as follows.
High pressure = 7 bar
Generator temperature = 110°C
Evaporator temperature = -5°C
Qe= 1TR = 3.516 KW (Theoretical valve)
Let m = mass flow rate of refrigerant, kg/s
Q=Heat
Heat absorbed at generator Qg= m (h3-h2)
COP=3.516/m (h3-h2)
Mass Concentrations: X1 = X2 = 0.55
X3=X5 = X6 = X7= X8 = 1
X4 = 0.42
At Pump (Aqua ammonia liquid state), Pressure = 7 bar, X2= 0.55
Temperature = 40°C, h2= 130 kj/kg
At Evacuated tube (Ammonia vapour state), X3=1 and temperature =110°C.
Pressure =7 bar, h3= 1716.4 kj/kg.
At Evaporator, X7=1 and temperature = -5°C, Pressure =3 bar
Applying the Energy balance
Qe = Refrigerating effect =3.516kW = m (h8 – h7)
= m× (1461.56-176.9)
m=3.788/ (1461.56-176.9) = 2.94×10^-3 kg/s
m =2.94×10^-3 kg/s = mass flow rate of refrigerant.
Now circulation ratio, λ= X4/(X1-X4)= 3.23
Strong solution, m1=m2= λ× m= 9.49×10^-3 kg/s
Weak solution, m4=(1+ λ)m= 12.43×10^-3 kg/s
So, Qg= m(h3-h2)= 2.94×10^-3 (1716.4-130) =4.66 kj/sec = 4.66 KW
Theoretical COP=3.516/4.66 = 0.75

Statement: For such a design circuit the refrigeration system produce a cooling capacity of COP 0.75 which a good value for applications such as air conditioning where the temperature is not much of concern.

3. Design of STVARS

The design of solar thermal refrigeration designed considering various criteria and assumptions. The design is done to get the refrigeration capacity of 1 ton with required COP. The calculated COP of the system is 0.75.Design depends on the individual components used in the system. Figure 3.1 shows 3D model of solar thermal refrigeration system.

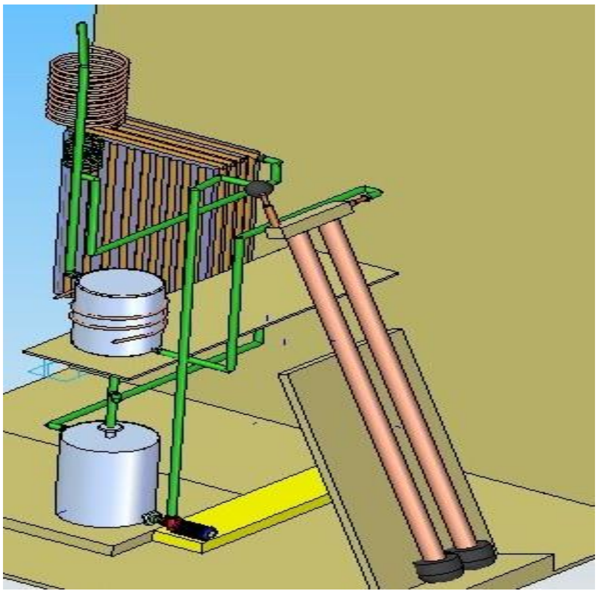

Fig. 3.1 3D Model of solar thermal refrigeration

Following are the individual components used in STVARS are as follows.

3.1 Absorber Tank

Absorber tank is used to store Ammonia hydroxide solution. It is kept at the lowest position in the system. The vapor ammonia returns from Evaporator is absorbed by the Strong solution. Also the weak solution returns from Rectifier is mixed with strong solution. Water is used as absorbent and Ammonia as refrigerant.

Absorber tank is designed according the volume of evacuated tube collectors (6ltrs) and specification of the pump (5ltrs/min).
Specifications:

- Type: cylindrical tank
- Material used: Mild Steel
- Refrigerant= R717 (Ammonia)
- Absorber = Water
- Inner diameter of the tank = 260mm
- Outer diameter of the tank = 263mm
- Length of the tank = 370mm
- Total volume of the tank = $V = \pi r^2 h = \pi\times(0.153m)^2\times0.4m = 0.02m^3 = 20.10$ litres

Volume of ammonia water solution used= $V = \pi r^2 h = \pi\times(0.13m)^2\times0.3m = 16$ litres

3.2 Pump

Pump is used to pump the ammonia hydroxide from the absorber to the generator tank attached to the evacuated tube. It is used according to the maximum pressure rate required and also maintain adequate discharge flow rate at the refrigerant.

Specifications:

- Type: Auto Diaphragm DC pump
- 0.08 Hp = 60 W
- Pump flow rate = 5 ltrs/min
- Rated pressure = max 8bar
- Dimensions: 165×95×60mm

3.3 PV Panel

PV panel is used with respect to the power rated capacity of the pump. A 100W PV panel is used.

3.4 Generator tank

Generator tank is designed to maintain steady statelevel for continuous discharge and act as accumulator above the evacuated tube.

Specifications:

- Type: Cylindrical tank
- Inner Diameter= 100mm
- Thickness = 2mm
- Length = 300mm
- Volume=$\pi r^2 h = \pi\times(50)^2\times300 = 2.3$litres

3.5 Evacuated Tubes

To get higher temperature to vaporize ammonia refrigerant, Evacuated tube collectors are used instead of solar flat collectors.

Specifications:

- No. of Tubes = 2
- Length of the Tube = 1500mm
- Outer diameter of the tube = 58mm
- Inner diameter of the Tube = 48mm
- Volume of one tube = = $V = \pi r^2 h = \pi\times(23.5)^2\times1500 = 2.6$ litres

3.6 Rectifier tank

Rectifier tank is used to separate ammonia vapour from the water (weak solution) and also provides cooling required converting water vapour to liquid state.The weak solution, after the separation of ammonia vapour is then transferred to the absorber.

Rectifier tank is designed according to the volume of absorber, evacuated tube collectors and cooling required converting water vapour to liquid state.
Specifications:

- Type: Water cooled tank
- Material used = Mild steel
- Inner diameter of tank one = 200mm
- Outer diameter of the tank= 203mm
- Length of the tank = 200mm
- Thickness of inner tank = 3mm
- Capacity of the tank = V = π r^2 h = π ×(0.115m)^2×0.3m= 6.28 litres
- Copper coil length= 3m
- Copper tube diameter= 9mm

3.7 Condenser

Condenser is selected to withstand the temperature and pressure and that amount of heat to be removed from ammonia vapour and convert it into liquid state.

Specification:

- Type: Wire and tube coil
- Material: Mild steel
- No. of turns = 26
- Outer diameter of condenser pipe= 6mm
- Thickness = 1mm
- Area of the condenser = 0.95m × 0.4 m = 0.38 m^2

3.8 Capillary tube

Capillary tube has very small internal diameter and it is of very long in length. It is coiled to several turns, so that it would occupy less space. This device connects between condenser and evaporator to reduce the pressure. The refrigerant comes out of capillary tube to evaporator this change in diameter drops the refrigerant pressure there by reducing its temperature.

Specifications

- Material: Copper
- Inner diameter = 0.3mm
- Thickness = 0.1mm
- Capillary tube length = 3m

3.9 Evaporator

In evaporator low temperature, low pressure refrigerant extract the heat from the cabin or system which we have to cool. Evaporator should be designed to get capacity of 1 ton as the heat input is of 4.65 KW (from COP calculations).

Specifications:

- Material : Mild steel
- Cylinder inner diameter = 200mm
- Cylinder length = 300mm
- Cylinder thickness= 3mm
- Volume of the thank V = π r^2 h = π×(100)^2×2= 9.42 litres
- Coil material= Copper
- Coil length = 3m
- Coil outer diameter = 6mm

4. Fabrication

Table4.1 Specification of Model

Sl. No	Components	Specifications	Operations performed
1	Absorber tank	20 litres	Arc welding and Brazing
2	Pump	60W	Threading
3	Generator tank	3 litres	Arc welding
4	Rectifier tank	6.28 litres	Arc welding and Brazing
5	Condenser	0.48 m^2	Soldering
6	Capillary tube	3m	Brazing
7	Evaporator tank	9.42 litres	Arc welding and Brazing
8	Pressure Gauge	150 psi	Threading
9	Thermometer	-30°C to 300°C	Sealing

4.1 Modification

The fabricated assembly is then tested with water to check any leakage in the system, there by pump is made to run with 12V DC adapter. There by we find out that when the pump is in high pressure there is a leakage in outlet of coupling part that attached to pump. After many attempts of sealing and trials of testing the leakage didn't reduced at the outlet, so decided to modify the assembly by removing the pump from the system and replacing it with a valve (opening and closing) and changing the position of absorber tank by keeping above level of generator tank height, which is similar arrangement of vapour absorption refrigeration system with absence of pump. The modified assembly is then tested with water and resulted in leak proof on absorber and the generator tank setup. The modified assembly is shown in the figure 4.1

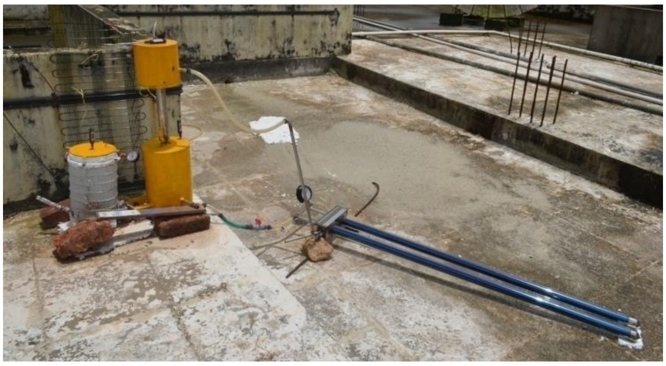

Figure.4.1 Modified assembly of STVARS

5. Optimization of Design

The fabricated solar thermal vapour absorption refrigeration system was found to be not holding the system pressure and the evacuated tubes had moved out of generator tank due to excess system pressure. As the system pressure had more than the designed value, it was the reason that tube may fail or break causing overall damage to the system and living things around the area.
The whole vapour absorption system has been decided to re-modify both in terms of design and fabrication. The following are the areas where new modification is put in the place due to the above reasons.

- Design of solar collector area.
- Connective areas of generator tank.
- Identification of valves
- Proper insulation in the system.
- Better instrumentations in the system.

Therefore all the problems it has been decided to optimizing the design of the solar thermal vapour absorption refrigeration system. The new design should overcome the problems related to evacuated tubes and its vacuum chamber to avoid over heating problems and have a better circulation. There by improving the existing design.

5.1 Optimized Instrumentations

For calculating COP of the system, temperature and pressure of refrigerant flow is required to be noted at each point. Pressure gauges and digital thermometers will be installed in the system. It is required to install 150psi pressure gauges available in market which is suitable for the measurements. To measure max and min pressure, pressure gauges are installed one after pump and one after expansion valve. Thermometer rated temperature if from -50°C to +300°C are used on generator tank, condenser, absorber tank, rectifier tank and evaporator tank. Installing four stainless steel ball valves in the system will improve the system safety, whenever there is a leakage or damage in the parts, there by closing the valves will help saving ammonia solution and vapour which can be vaporised to atmosphere. Figure 5.1 Circuit diagram 0f STVARS for instrumentations.

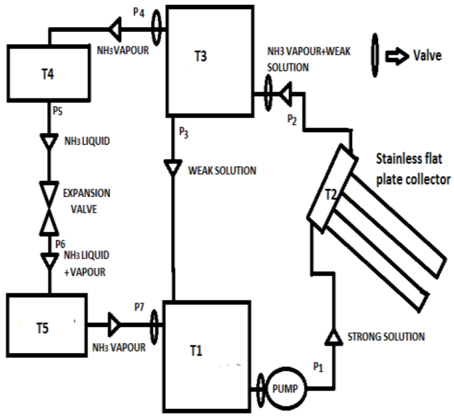

Figure 5.1 Circuit diagram of STVARS for instrumentations

High pressure =P2=P3=P5=P6
Low pressure=P1=P7=P8
T1=Absorber temperature
T2=Generator temperature
T3=Rectifier temperature
T4=Condenser temperature
T5= Evaporator temperature

6. Result and Discussion

- Literature review is done on different type refrigeration system mostly based on solar thermal refrigeration.
- Solar thermal refrigeration is designed and fabricated with reference to the COP calculation.
- System fabrication components had drilling, welding, brazing and other operations.
- Fabrication model is tested, and find out that there is leakage in pump outlet coupling part due to pressure as the pump in working condition.
- Modification is done by removing pump from the system and changing the position of absorber and generator setup, also replacing the stainless steel pipes to flexible pipe.
- Ammonia solution is filled successfully as per the procedure of handling ammonium hydroxide.
- As the absorber tank valve is opened the solution entering evacuated tubes by generator is failed to hold up the pressure developed by ammonia vapour and there was gas leakage in bush to that connects generator tank and evacuated tubes.
- Design has optimized on the system by replacing evacuated tube collector by stainless steel flat plate collectors and some minor modifications in piping and insulations.

- Optimized design is better to the system's new design which can deal with pressure and leakage problems and quantity of ammonia ammonium hydroxide is used is 6 litres.

Instrumentations like new pressure gauges and ball valve has been introduced to be used in the system as per the requirements.

7. CONCLUSIONS

1. The new solar thermal refrigeration has been introduced with ammonia as working fluid Evacuated tubes mainly to replace the high grade electricity
2. Reviews of different area of solar thermal refrigeration system have been carried out; designed components used in solar thermal refrigeration system are shown in detailed with its pictures
3. To find the performance parameter of refrigeration system instrumentation studies has been carried out and different types of gauges and exact locations have been represented
4. The designed refrigeration system is fabricated, tested and modified as per the requirement.
5. The fabricated system when tested it was found incapable of holding the system pressure and the evacuated tubes could not keep itself in place. The evacuated tubes lost its vacuum pressure not suitable for ammonia solution for present design.
6. Considering the factor a new design has been introduced after optimization which takes care of problems encountered in the earlier design.

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