www.arpnjournals.com

THERMODYNAMIC ANALYSIS OF AQUA-AMMONIA BASED MINIATURIZED VAPOR ABSORPTION REFRIGERATION SYSTEM UTILIZING SOLAR THERMAL ENERGY

Subi Salim[1] and Rajesh V. R.[2]

[1]Department of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham University, India
[2]Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore Amrita Vishwa Vidyapeetham University, India
E-Mail: subi6061@gmail.com

ABSTRACT

Solar Energy based refrigeration is one of the most promising technology to meet up the hiking demands for cooling applications. Among the two refrigeration cycles, Vapour Compression Refrigeration (VCR) driven by Photovoltaic (PV) system proves to be the most widely used cooling equipment, while the Vapour Absorption Refrigeration (VAR) driven by solar thermal energy is at its infant stages of development and is biased for usage in industrial applications. This work emphasize on the development of a miniaturized model of aqua-ammonia VAR system integrated with solar collector that can be used for small-scale cooling applications. The evaporator capacity is restricted to 0.5 ton of refrigeration (TR). The study is incorporated with theoretical design and evaluation of performance of the system in terms of Coefficient of Performance (COP). The COP estimated for the VAR system is 0.65. And the influence of evaporator temperature on COP is analysed.

Keywords: VCR, collector, aqua-ammonia, COP.

1. INTRODUCTION

Refrigeration is the thermodynamic process to produce cooling effect below the atmospheric temperature. Its working is governed by reverse of the second law of thermodynamics, that is, when work input is given to system heat can be transferred from a low temperature body to a high temperature body. Temperature requirement depends on the application. The performance of refrigeration system is evaluated in terms in Coefficient of Performance (COP). Most widely used refrigeration cycle across the world is VCR based, wherein the compressor in the system is energy intensive equipment that consumes a huge amount of electrical energy to perform the compression and suction of refrigerant. An alternative to this is, VAR that makes use of low grade waste heat- industrial waste heat, solar thermal energy, geothermal heat, [3] etc.

Refrigeration based on solar energy is again classified as Photo Voltaic (PV) driven VCR system and thermal energy driven VAR system. It comes under active solar cooling system, since it makes use of mechanical devices or components such as pumps, blowers, heat-exchangers, etc. to carry out the heat transfer process. PV Based systems have seen the best COP values ranging from 1.1 - 3. 3 [1], and it widely replaces the conventional VCR systems. But the challenge being highlighted for this system is the high cost of PV- panel. Thus researchers have been looking ahead to develop and commercialize thermal based VAR system for domestic applications. Thermal collectors are less expensive when compared to that of PV- Panel. Research is mainly focused to eliminate the challenges faced in this field- lower COP, system complexity and demands longer duration for cooling [6, 7].

2. SYSTEM OVERVIEW

The main objective of the compressor in the VCR system is to compress the refrigerant vapour to a high pressure, so that this vapour can reject heat in the condenser. The suction and compression of refrigerant is performed by this single unit consuming a huge amount of high- grade energy. In VAR system, the mechanical compressor is replaced by the generator- absorber unit, where in the generator performs the compression of refrigerant and absorber performs the suction of refrigerant from evaporator, utilizing waste heat.

The entire setup of VAR is shown in Figure-1.
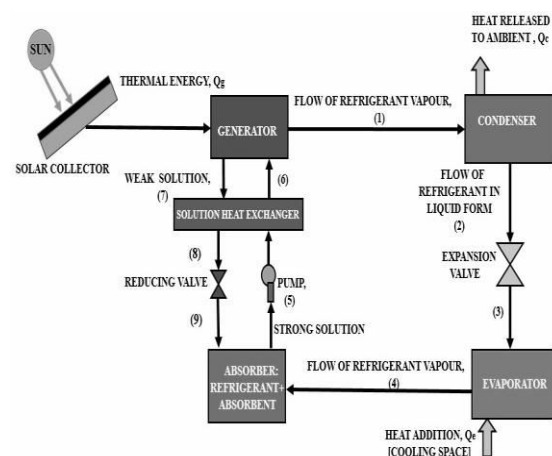
Figure-1. System overview of var based on solar thermal energy.

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,

www.arpnjournals.com

where the refrigerant circulates within the refrigeration machine and the absorbent circulation is limited within the generator and absorber unit.

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 a way 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.

For the case of aqua- ammonia system, two additional components-rectifiers and analyser, are employed to separate the water vapour leaving the generator and to send only dehydrated ammonia to the condenser.

3. THERMODYNAMIC ANALYSIS

Thermodynamic Analysis evaluates how energy is going to affect the performance of each component in the system. It is governed by:

- Principle of Mass Conservation, $\sum m_i = \sum m_o$
- Principle of Energy Conservation (First Law of Thermodynamics), $\sum E_{in} = \sum E_{out}$
- Energy Analysis (Second Law of Thermodynamics)
- Steady flow energy equation, $Q = \dot{m} \times (\Delta h)$

Where Q is the heat energy,
$\dot{m}$ is the mass flow rate and
Δ h is the change in specific enthalpy.

The first and the foremost factor to be considered before thermodynamic analysis is selection of refrigerant-absorbent mixture. Commonly used refrigerant- absorbent mixtures are Aqua- ammonia, LiBr- water, etc. One advantage with VAR system is that it makes use of eco-friendly refrigerant.

Desirable properties of refrigerant- absorbent mixture:

- Cost and availability
- Chemical stability
- Non- corrosive and non-toxic in nature
- It should not undergo crystallization
- Refrigerant should be more volatile than the absorbent
- Absorbent should have a strong affinity for the refrigerant.

Refrigerant   : Ammonia
Absorbent   : Water

Component-wise thermodynamic analysis:

Based on the steady flow equation [2], each of the components is analysed.

Evaporator

It is heat- exchanger. Liquid refrigerant undergoes evaporation and forms vapour refrigerant. Thermodynamic equation can be represented as,

$$Q_e = \dot{m}_r * (h_4 - h_3)$$

Where Q_e is heat added at the evaporator or simply the heat capacity of the evaporator;
$\dot{m}_r$ is the mass flow rate of the refrigerant and
h_4 and h_3 denotes the specific enthalpies of vapour and liquid refrigerant

Based on the designer decides the evaporator capacity, depending on the application. The specific enthalpy values are chosen from the pressure-enthalpy chart of aqua-ammonia depending on the phase of the refrigerant.

Condenser

It is also a heat-exchanger, where the heat rejection happens resulting in phase change from vapour to liquid refrigerant. Thermodynamic equation is,

$$Q_c = \dot{m}_r * (h_1 - h_2)$$

Where Q_c is heat removed or the heat capacity of the condenser.

Solution heat exchanger

It is employed to transfer heat between two fluid streams. Weak solution [absorbent alone] from the generator carries some heat which it transfers to the strong solution that is pumped from the absorber.

- Mass Balance Equation,

$$\dot{m}_{ss} = \dot{m}_r + \dot{m}_{ws}$$

- Material Balance Equation for NH_3,

$$\dot{m}_{ss} * X_{ss} = \dot{m}_r * X_r + \dot{m}_{ws} * X_{ws}$$

- Energy Balance, $Q_{in} = Q_{out}$

www.arpnjournals.com

$i.e, \dot{m}_{ss} * h_5 + \dot{m}_{ws} * h_7 = \dot{m}_{ss} * h_6 + \dot{m}_{ws} * h_8$

Where $\dot{m}_{ss}$ and X_{ss} is the mass flow rate and the concentration of the strong solution;
$\dot{m}_{ws}$ and X_{ws} is the mass flow rate and concentration of the weak solution respectively.

Absorber

It is also a heat exchanger. Refrigerant vapour from the evaporator enters into the mixing chamber which contains the absorbent and mixes well and forms a strong solution, which is pumped to the generator. Weak solution (Absorbent alone) coming from the generator enters into the absorber through a heat exchanger and reducing valve. It is maintained at temperature almost equivalent to condenser temperature. Absorber capacity is obtained from the given thermodynamic equation,

$Q_a = m_{ws} * h_9 + m_r * h_4 - m_{ss} * h_5$

Generator

It is boiler system wherein the heat energy is supplied. Heat Capacity of Generator is given as, [excluding solar collector]

$Qg = \dot{m}r * h_1 + \dot{m}ws * h_7 - \dot{m}ss * h_6$

COP

The performance of VAR system is evaluated in terms COP, which is defined as the ratio of cooling effect to the heat input.

COP =Cooling effect/ Heat Input
$= Q_e / Q_g$

4. RESULTS AND DISCUSSION

The evaporator is a chamber that has to be maintained at the lowest temperature, but the purpose of the design is not to attain low temperature at the evaporator but to provide the cooling effect. So the evaporator should be maintained at a pressure equivalent to the atmospheric pressure. The condenser and absorber are maintained to be at temperature of 25˚C. Generator is maintained at a temperature of 85˚ C.

A. COP estimation
h_1 = 1630 kJ/kg; h_2 = h_3=460 kJ/kg and h_4 =1562 kJ/kg
X_{ss} =0.42; X_{ws}= 0.38 and X_r =0.98

Based on the above analysis, heat capacity of each components and mass flow rate of the refrigerant is obtained as shown in Table-1, and COP of the VAR system alone is evaluated.

Table-1. Component-wise heat capacity of var system and mass flow rate.

| Evaporator Capacity	105 kJ/min
Condenser Capacity	111.47 kJ/min
Absorber Capacity	142.15 kJ/min
Generator Capacity	161.01 kJ/min
Mass Flow Rate of Refrigerant	0.09528 kg/min

COP estimated for VAR system,
COP= *105 / 161*
= *0.652*

B. Influence of evaporator temperature on COP

The variation in COP was analysed by varying the evaporator temperature Table-2, and it was observed that as we increase the evaporator temperature (limited to 10˚C- to provide the cooling effect and as well to prevent the growth of microbial organisms, preservation effect) the COP value gradually increased, shown in Figure-2.

Table-2. Influence of variation in T_e on cop.

Evaporator temperature [˚C]	COP
2	0.15
4	0.2345
6	0.3977
8	0.433
10	0.55
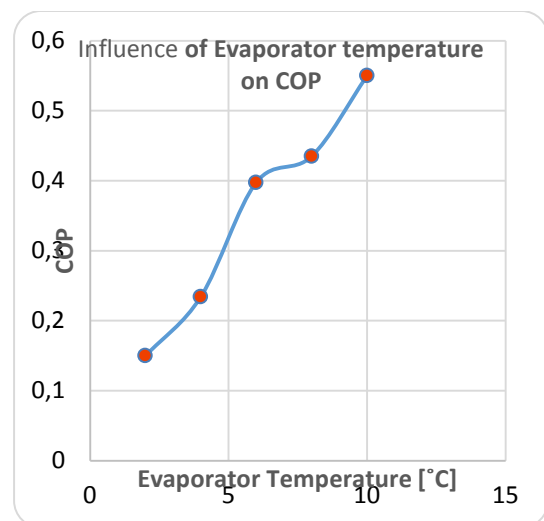
Figure-2. Plot indicating variation in COP w.r.t evaporator temperature.

The selection of solar thermal equipment is based on the heat requirement at the generator unit. A lot of experimental setups have been developed based on flat plate collector and evacuated tube type collector and

shortcoming faced by such system was that it requires a longer time to produce the cooling effect. Hence concentrating equipment can be used. The concentration ratio can be varied based on the heat requirement at the generator. Concentrating collectors with wider accepting angle can capture a huge amount of heat energy and can produce cooling in a shorter span of time.

5. CONCLUSION

The study suggests that, with a proper theoretical design and thermodynamic analysis there is scope for improvisation of the performance of vapour absorption refrigeration system utilizing low grade thermal energy source. The evaporator temperature has greater influence on performance of the system. The heat input can be provided with solar collector - flat or concentrating type (less concentration ratio). It brings into light that solar collector can not only be used for heating, it can also be used for cooling applications.

REFERENCES

[1] D. S. Kim, "Solar Refrigeration Options- a state of the art review", International Journal of Refrigeration, 2008.

[2] Ozgoren, Muammer, Mehmet Bilgili, and Osman Babayigit. "Hourly performance prediction of ammonia-water solar absorption refrigeration." Applied Thermal Engineering 40: 80-90, 2012.

[3] Satish Raghuvanshi, GovindMaheshwari, "Analysis of Ammonia- Water Vapor Absorption Refrigeration based on First Law of Thermodynamics", International Journal for Scientific and Engineering Research Volume 2, Issue 8, August- 2011.

[4] Stocker, W.F., and Jones, J.W., "Refrigeration and Air Conditioning", Mc Graw- Hill, 1985 (Book).

[5] Li, Z.F., Sumathy, K., "Technology Development in the Solar Absorption Air Conditioning Systems" Renewable and Sustainable Energy Reviews 4, 2000.

[6] Richter, L., Safarik, M., "Solar Cooling with ammonia water absorption chillers", Proceedings of International Conference on Solar Air Conditioning, 2005.

[7] Kunze, G., "Efficient Solar Cooling with an improved ammonia absorption system", Renewable Energy World 3, 2000.

[8] Robert Balmer, "Thermodynamics", Jaico Publication, 1999 (Book).

[9] Yunus A. Cengel, Micheal A. Boles, "Thermodynamics- An Engineering Approach", Mc-Graw Hill Offices, Seventh Edition, 2011 (Book).

[10] G. D. Rai, "Solar Energy Utilisation", Khanna Publishers, Second Edition, 1984 (Book).

[11] Krishnaraj, C., Mohanasundram, K. M., Devadasan, S. R. and Sivaram, N. M. 2012. Total failure mode and effect analysis: a powerful technique for overcoming failures. International Journal of Productivity and Quality Management, 10(2), 131-147.

[12] K. Ramadevi and S. Deepa Shri, "Flexural Behaviour of Hemp Fiber Reinforced Concrete Beams", ARPN Journal of Engineering and Applied Sciences, 10, (2015) - 1819-6608

[13] Pa. Ganeshwaran and S. Deepa Shri," A Solid Waste Management in Coimbatore City" , Journal of Engineering and Applied Sciences, 14, (2015) - 1819-6608

[14] W.B. Gosney, "Principles of Refrigeration", Cambridge University Press, 1982 (Book).

[15] Omer Kaynakli, R Yamankaradeniz, "Theoretical study on the effect operating conditions on performance of absorption refrigeration system", Energy conversion and management, 2007.