Business Model for Non-Conventional Energy Source: Absorption Refrigeration System Using Solar Evacuated Tube Collectors

Suhaib Jawed, Yakub Mogul, Muhammad Azeem, Asma Begum, Ibtisam Mogul, Ayesha Adeel.

University of Bolton RAK Academic Center, Ras Al Khaimah, UAE

ABSTRACT

The clean source of energy such as solar power has great potential which has not been tapped yet, in a country where heat is highly affecting the environment the electrical load due to the functioning of air conditioning is quite high, the cooling load can be reduce by single effect vapor absorption which has a huge potential and very promising in summer months in the tropical countries. The use of evacuated tubes with Lithium Bromide-Water as a refrigerant is a very collaboration in our current stud and by reducing the CO_2 emissions to study for 5.25 KW system.

Keywords: Solar, Vapor Absorption Refrigeration Cycle, LiBr-Water refrigerant, CO_2 Emissions.

INTRODUCTION

Environmental conditions have a significant impact on humans as some specific environmental conditions are more comfortable to humans than others. The main aim of the refrigeration is to achieve and sustain a specific temperature than the surrounding temperature. It is attainted by transferring of heat from the place to be cooled.

Absorption system requires thermal energy for generating cooling, which can be solar energy, waste heat or other forms of energy. These systems are environmental friendly as there are no CFCs used. Absorption is basically a process which holds and attracts moisture by substances called desiccants. Absorption air conditioning systems and vapor compression systems are similar to each other but the pressurization stages are different. The basic common mixtures of chemicals fluids are Lithium Bromide-Water (LiBr-H_2O) in which water is used as a refrigerant and lithium bromide is used as an absorbent, Ammonia-Water (NH_3-H_2O) where ammonia is used as refrigerant and water is used as an absorbent.

Window Air Conditioner

A window air conditioner is a machine which consists of all the basic elements of an air conditioning system in a common casing. Due to its compact size, it is conveniently installed in a window or on the wall of the room to be cooled. There are different units of air conditioner available depending on the cooling capacity such as 1 ton, 1.5 ton and 2 ton required for a room, house or building etc.

An air conditioner uses a chemical called refrigerant which is easily converted from a liquid to a gas and back again. This is the law of physics where a liquid converts into a gas by absorbing heat. This process is known as phase conversion.

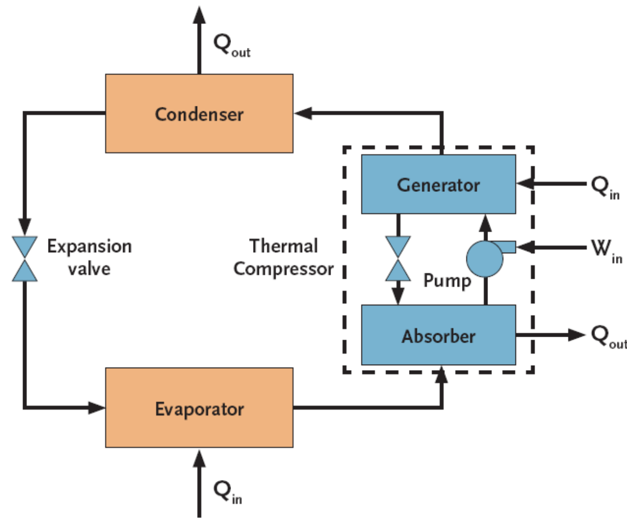
Vapor Absorption Refrigeration System

In refrigeration cycle the method of compression and suction of refrigerant is the main difference between the vapor compression and vapor absorption systems. The process of compression and suction is carried out by a compressor in a vapor compression system. The compressor sucks the low-pressure gas refrigerant from evaporator and compresses it to the high pressure. Compressor also performs the task of pumping and moving the refrigerant through the whole refrigeration cycle. Whereas in vapor absorption system generator and an absorber are used for the process of suction and compression. These two devices are replaced instead of a compressor in a vapor absorption refrigeration system. The most common combinations of fluids which are used as refrigerant for vapor absorption system are ammonia-water (NH_3-H_2O) where ammonia is used as refrigerant, lithium bromide-water ($LiBr$-H_2O) where water is used as refrigerant.

Electric motor run by electricity produces input energy for vapor compression system in the form of mechanical work. In vapor absorption system, the input energy is taken in the form of heat.

Components of the Vapor Absorption System

Vapor absorption system consists of all the similar components which a vapor compression system consists off except compressor which is replaced by an absorber, pump, heat exchanger, expansion valve and a generator. Working mechanism of all the components remains same. Lithium bromide-water ($LiBr$-H_2O) is used as the refrigerant for the system.



1. Condenser

The function of the condenser is to condense the refrigerant. The refrigerant enters the condenser at high temperature and pressure and gets condensed. The heat is thrown outside in the atmosphere.

Q_C = Condenser Heat, (KJ/s)

$Q_C = m\ (h_7 - h_8)$ ………….. Equation (1)

2. Expansion Valve

Expansion valve reduces the pressure of the refrigerant once it passes through it. It is situated between condenser and evaporator. High pressure liquid coming from condenser enters the expansion valve which is quite hot and while leaving the expansion valve it becomes low pressure liquid.

3. Evaporator

The function and working mechanism of the evaporator remains same, as the refrigerant which is at low pressure enters the evaporator and it generates cooling effect. The refrigerant in vapor compression system then passes into compressor and gets compressed while in vapor absorption system the refrigerant flows into the absorbed where the refrigerant gets absorbed. This absorber acts as a suction part of the refrigeration cycle.

Q_e = Evaporator Heat, (KJ/s)

$Q_e = m\ (h_9 - h_8)$ ………….. Equation (2)

4. Absorber

Absorber is used instead of a compressor in vapor absorption system. Absorbers acts as an absorbent, it is kind of vessel consisting of Lithium Bromide (LiBr) which is an absorbent. The weak solution of the refrigerant (water) and absorbent (LiBr) is present in the absorber. When water flows from the evaporator and enter the absorber, it is absorbed by a desiccant (LiBr), due to this the pressure inside the absorber drops and more refrigerant flows from the evaporator into the absorber.

5. Pump

The function of the pump is to move and pump the refrigerant through the complete refrigeration cycle. The absorbent present inside the absorber absorbs the refrigerant, a strong solution of refrigerant absorbent (lithium bromide- water) is produced. Pump is the only mechanical device which is used in the complete vapor absorption system.

$w_p=(1+\lambda)\ mV\ sol(p_C-p_E)$ kJ/s …...Equation (3)

6. Heat Exchanger

Heat exchanger is fixed between the generator and the pump. Once the vaporized refrigerant exists the generator a weak solution is left in it which then flows back to the absorber passing through the heat exchanger (pressure reducing valve). The function of the heat exchanger is to cool the weak hot solution coming from generator to the absorber. And the strong solution coming from pump also passes through this heat exchanger and flows into the generator. It heats the refrigerant coming from pump so that it reduces the heat supplied at generator.

$Q_{HX} = (1+\lambda)\ m(h_3-h_2) = \lambda m\ (h_4-h_5)$, kJ/s …... Equation (4)

7. Generator

The generator consists of a refrigerant water solution which is heated through an external source of heat. The external source of heat can be by hot steam, renewable energy (solar), or any other appropriate source. The heating causes the temperature of the solution to rise due to which the refrigerant in the solution gets vaporized and it exists the solution at high pressure. This refrigerant at high pressure and temperature enters the condenser, where it is cooled by the coolant. The refrigerant then passes through expansion valve and then into evaporator where the cooling effect is produced. Now the refrigerant flows into the absorber where it is again absorbed by the weak solution present. The generator increases the pressure of the refrigerant, so it is equivalent to the compression part of the compressor. The cycle keeps on repeating until the system is working.

Q_g = Generator Heat, (KJ/s)

$Q_g = mh_7 + \lambda mh_4 - (1+\lambda)\ m_3$ ……Equation (5)

System Description

Water is used as a refrigerant and lithium bromide is used as an absorber. The system consists of generator, condenser, expansion valve, evaporator absorber, pump, heat exchanger and solar evacuated tubes. Solar evacuated tube collectors receive energy from sunlight. This energy is converted into heat and transferred to the fluid (water) which is flowing through the manifold box of evacuated tubes. This heat is supplied to the generator. The heat is taken from evaporator which evaporates the refrigerant as water vapor. This water vapor now passes into an absorber where it is absorbed by an absorbent (LiBr) to form a weak solution. This weak solution is then pumped into the generator via heat exchanger. The heat supplied to the generator from solar evacuated tubes is used for separating the solution into water vapor and strong lithium bromide solution. The water vapors formed are at high pressure and temperature. These water vapor flows into the condenser where heat is removed and rejected to the outside atmosphere and the water vapors cools down to form a liquid. This liquid water (refrigerant) at high pressure passes through an expansion valve which reduces the pressure of the refrigerant and then it passes to the low-pressure area in the evaporator. This water liquid turns back into vapor by taking out the heat from the entering water in the tube heat exchanger. Now again these water vapor passes to the absorber and the cycle is repeats. The strong solution produced in the generator is pumped back into the absorber through a heat exchanger and the weak solution present in the absorber passes through the heat exchanger to the generator.

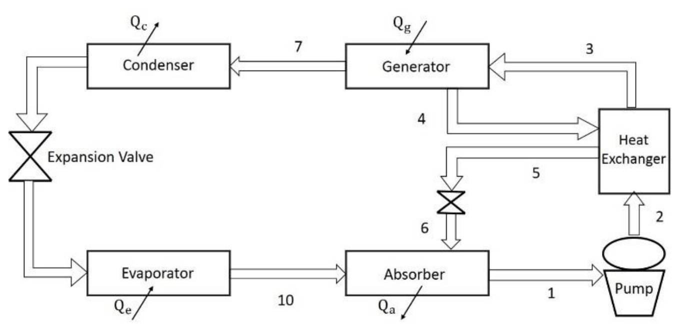
Solar Evacuated Tubes

The technology of evacuated tube collectors beats flat plate panels for nearly all water heating applications and the advantages are dramatic when used for solar air conditioning, heating and commercial processes. This is because the evacuated tube collectors are able to achieve high temperature needed more easily. These collectors also collect and retains heat even when the ambient temperate outside is low.

THERMODYNAMIC ANALYSIS OF THE SYSTEM

Thermodynamic analysis of the vapor absorption refrigeration system includes finding some significant parameters like mass flow rate, flow ratio, enthalpy, heat and mass transfer for the whole system which then finally includes calculating the Coefficient of Performance (COP) of the system. All the parameters taken are measured for designing of the system.

By applying mass and energy balance for each component set of thermodynamic equations have been derived in terms of enthalpy and mass flow rate. Then the actual system conditions like temperature, pressures, enthalpies are substituted in the equations to finally calculate the COP value for the system.



The followed nomenclature is:

m = Mass Flow Rate of Refrigerant (Kg/s)

m_{ws} = Mass Flow Rate of Weak Solution (kg/s)

m_{ss} = Mass Flow Rate of Strong Solution (Kg/s)

Mass and Heat Balance for Each Component

(FORMULAS)

M = Mass (KJ/s)

Q = Heat

h = Enthalpy

CONDENSER

Q_C = Condenser Heat, (KJ/s)

$m_7 = m_8 = m$

$Q_C = m (h_7 – h_8)$

EXPANSION VALVE

$m_8 = m_9 = m$

$h_8 = h_9$, (KJ/Kg)

EVAPORATOR

Q_e = Evaporator Heat, (KJ/s)

$m_9 = m_8 = m$

$Q_e = m (h_9 – h_8)$

ABSORBER

From Total Mass Balance

$m + m_{ss} = m_{ws}$

CIRCULATION RATIO

The circulation ratio (λ) is defined as "the ratio of strong solution flow rate to refrigerant flow rate".

$\lambda = m_{ss} / m$

Therefore, $m_{ws} = (1+\lambda) m$

From Mass balance of pure water

$m+(1+\xi_{ss}) m_{ss} = (1+\xi_{ws}) m_{ws}$

Solving for λ,

$\lambda= \xi_{ws}/ (\xi_{ss}- \xi_{ws})$

and $Q_a = mh_{10} + \lambda mh_6 - (1+\lambda) mh_1$, (KJ/s)

PUMP SOLUTION

$m_1 = m_2 = m_{ws}$

$w_p=(1+\lambda) mV sol(p_C-p_E)$ kJ/s

where V_{sol}. is specific volume of solution which can be taken as approximately 0.00055 m^3/kg.

HEAT EXCHANGER SOLUTION

$m_2= m_3 = m_{ws}$

$m_4 = m_4 = m_{ss}$

$Q_{HX} = (1+\lambda) m(h_3-h_2) = \lambda m (h_4-h_5)$, kJ/s

GENERATOR

Q_g = Generator Heat, (KJ/s)

$m_3 = m_4 + m_7$

Heat input to the Generator

$Q_g = mh_7 +\lambda mh_4 - (1+\lambda) m_3$

COEFFICIENT OF PERFORMANCE (COP)

$$\text{COP} = \frac{\text{Heat Absorbed in the Evaporator}}{(\text{Work Done by Pump} + \text{Heat Supplied in the Generator})}$$

0r

$$\text{COP} = \frac{Q_e}{(Q_g + W_p)}$$

Neglecting the work done by the pump as it is very small. The equation becomes:

$$\text{COP} = \frac{Q_e}{Q_g}$$

The above equation is the expression for coefficient of performance (COP) of the system.

CALCULATING HEAT TRANSFER RATE FOR EACH COMPONENT

Operating Temperatures

The most suitable working temperatures for a single effect lithium-bromide and water refrigeration system **for a COP value between 0.7 and 0.9** are:

Condenser Temperature (Tc) = 24 - 46 ℃

Evaporator Temperature (Te) = 2.5 -10 ℃

Absorber Temperature (Ta) = 16 - 32 ℃

Generator Temperature (Tg) = 55 - 90 ℃

The operating temperatures selected for the system are;

Condenser Temperature (Tc) = 34℃

Evaporator Temperature (Te) = 7℃

Absorber Temperature (Ta) = 24℃

Generator Temperature (Tg) = 70℃

Operating Pressures

(From Steam Table)

Condenser Pressure (P_c) = 40 mm of H_g

Generator Pressure (P_g) = 40 mm of H_g

Evaporator Pressure (P_e) = 7 mm of H_g

Absorber Pressure (P_a) = 7 mm of H_g

At any temperature, the enthalpy of superheated water vapors and of pure water can be determined from steam stables. And from LiBr-Water Pressure-Temperature-Concentration-Enthalpy Chart the enthalpies of solutions are calculated.

Table (1) LiBr-Water Enthalpy-Pressure-Temperature-Concentration

State Points	Temperature (°C)	Pressure (mm of Hg)	Enthalpy (h, kj/kg)	Concentration (ξ)
7	70	40	2626.8	-
8	34	40	142.4	-
9	34	7	142.4	-
10	6	7	2512.6	-
1	24	7	-180	0.47
2	24	40	-180	0.47
3	52	40	-114.4	0.47
4	70	40	-98	0.59
5	24	40	-180	0.59
6	24	7	-180	0.59

Table (2) Heat Transfer Rate of Components

Sr. No	COMPONENETS	HEAT TRANSFER RATE	VALUE (kW)
1	Evaporator	Q_e	5.25
2	Absorber	Q_a	5.964
3	Condenser	Q_c	5.503
4	Generator	Q_g	6.217

COEFFICIENT OF PERFORMANCE (COP)

$$\mathrm{COP} = \frac{Q_e}{Q_g}$$

$$\mathrm{COP} = \frac{5250}{6217} = 0.844$$

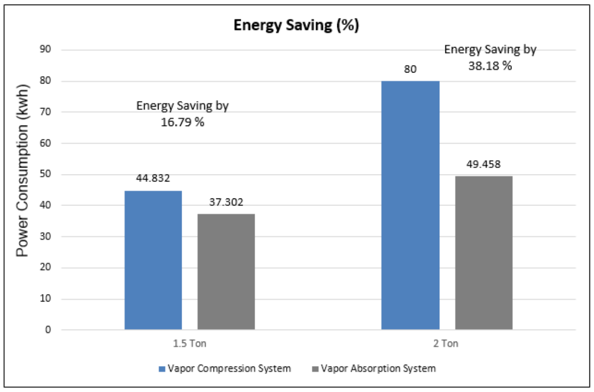
COP = 0.84

Therefore, the COP obtained for the system lies within the range i.e. from 0.7 – 0.9.

ANALYSIS

ENERGY SAVING ANALYSIS

1.5 Tonnage: Vapor compression system consumes more power i.e. 44.832 kwh /day as compared to vapor absorption system which consumes 37.302 kwh /day. By using vapor absorption refrigeration system 16.79% of electricity consumption can be saved.



Graph (1) Energy Saving Analysis

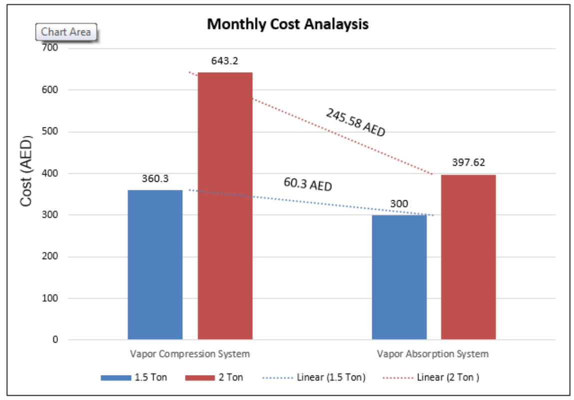
2 Tonnage: Vapor compression consumes more power i.e. 80 kWh /day and vapor absorption refrigeration system consume 49.46 kWh /day. By using vapor absorption refrigeration system 38.18% of electricity consumption can be saved.

It is observed that the energy saving percentage increase as the tonnage of the air conditioner increases. When the tonnage of air conditioner increases the power consumed by the unit increases as well. So, more electricity can be saved from larger a/c units.

MONTHLY COST ANALYSIS

The power consumed by vapor compression system of 1.5-ton costs 360.3 AED /month whereas vapor absorption system costs 300 AED / month. So, on monthly basis 60.3 AED is saved for 1.5-ton air conditioner.

The power consumed by vapor compression system of 2-ton costs 643.2 AED /month whereas vapor absorption system costs 397.62 AED / month. So, on monthly basis 245.58 AED is saved for 2-ton air conditioner.

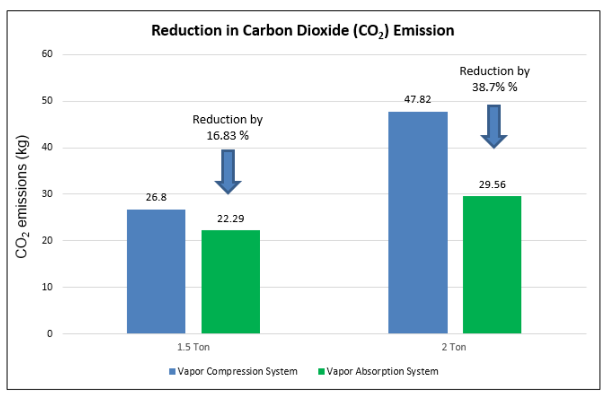


Graph (2) Monthly Cost Analysis

More billing cost can be reduced as the tonnage of the air conditioner increases. When the tonnage of air conditioner increases the power consumed by the unit increases. So, more cost can be saved from larger a/c units.

CARBON DIOXIDE EMISSION ANALYSIS

The graph shows the reduction in carbon dioxide emission. Vapor compression system of 1.5 tonnage which runs on electricity releases 26.8 kg of carbon dioxide and vapor absorption system of 1.5 tonnage which runs on solar energy releases 22.29 kg of carbon dioxide. So, by using solar energy as source of heat CO_2 emissions is reduced by 16.83%.



Graph (3) Reduction in Carbon Dioxide (CO2) Emission

Vapor compression system of 2 tonnage which runs on electricity releases 47.82 kg of carbon dioxide and vapor absorption system of 2 tonnage which runs on solar energy releases 29.56 kg of carbon dioxide. So, by using solar energy as source of heat CO_2 emissions can be reduced up to 38.7%.

So, the vapor absorption refrigeration system is an environment friendly option as compared to vapor compression system. Electricity is produced from fossil fuels which releases carbon dioxide, affects the environment by depleting the ozone layer and is the prime cause for global warming. By using solar energy as source of heat, the system tends to reduce the emission of carbon dioxide there by being environmental friendly.

CONCLUSION

Environmental conditions have a significant impact on humans as some certain environmental conditions are more comfortable to humans than others. The main aim of the refrigeration system is to achieve and sustain a specific temperature and moisture content than the surrounding temperature. It is attainted by extracting heat from the place to be cooled. Vapor absorption refrigeration system uses solar evacuated tubes with working fluid lithium bromide-water (LiBr-H_2O) where water is used as refrigerant and lithium bromide is used as absorbent.

Vapor absorption refrigeration system gives a sustainable alternative with financial and environmental benefits. The system uses solar energy as a source of heat which reduces the billing cost by up to 17743.618 AED annually and indirectly it reduces the emission of carbon dioxide by 38.7% for a two-ton air conditioner. The initial setup cost of the vapor absorption system is high as compared to conventional vapor compression system, however it is compensated by total annual cost saving and significant decrease of the CO_2 emissions which cause the greenhouse effect. So, this technology is environmental friendly also it saves electricity and fossil fuels.

REFERENCES

B.Babu and G. Maruthi Prasad Yadav. (2015) Performance Analysis of Lithium-Bromide Water Absorption Refrigeration System. International Journal of Engineering Research and Management, [Online] 2 (2), Available From: https://www.ijerm.com/download_data/IJERM0202013.pdf.

D.P. Kothari and Rakesh Ranjan. (2008) Renewable Energy Sources and Emerging Technologies. New Delhi: Asoke K. Ghosh.

K Sumathy. (2000) Technology Development in the Solar Absorption Air Conditioning Systems. Renewable and Sustainable Energy Journal, [Online] 4 (3), pp. 267-293. Available From:http://www.sciencedirect.com/science/article/pii/S1364032199000167.

Manohar Prasad. (2003) Refrigeration and Air Conditioning. 2nd Edition. [Online]. Available From: https://books.google.ae/books?id=ZiDbFhFk-AYC&pg=PA17&dq=COP+and+EER&hl=en&sa=X&ved=0ahUKEwif3eHEloDSAhXDWhQKHdIiB88Q6AEIHjAB#v=onepage&q&f=true.

M. David Burghaedt and James A. Harbach. (1993). Engineering Thermodynamics. United States: HarperCollins College Publishers.

Minh, Nguyen Q.; Hewitt, Neil James; And Eames, Philip Charles, *"Improved Vapour Absorption Refrigeration Cycles: Literature Review And Their Application To Heat Pumps"* International Refrigeration And Air Conditioning Conference

Roger A. Hinrichs and Merlin Kleinbach. (2006) Energy Its Use and the Environment. Thomas Corporation, Canada: David Harris.

Sachin Kaushik, Prof.S.Singh,“ Thermodynamic analysis of Vapour Absorption Refrigeration System and Calculation of COP” International journal for Research in Applied Science and Engineering Technology, Vol No.2, Issue No.II