A Comprehensive Solar Powered Absorption Refrigeration System

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Abstract: Consistently increasing CO2 emission and ozone depletion from CFC’s are serious environmental issues challenging scientific community. The dependence on fossil fuels has to be reduced and alternative environmental friendly options need to be explored. In this aspect, vapor absorption system gives scope of utilizing low grade energy source i.e. solar energy for generating cooling effect which is dominated by high grade energy driven compression technology. The NH₃-H₂O aqueous solution based absorption cycle consists of four stages: generation, condensation, evaporation and absorption with ideally no moving part. Absorption refrigeration system provides large potential for reducing heat pollution of the environment. This paper describes simple solar powered absorption refrigeration system using NH₃-H₂O as a working pair.

Key-words: performance; absorption; solar energy; NH₃-H₂O; refrigeration; generator

1. INTRODUCTION

Energy is vital for progress and development of a nation’s economy. The economic growth and technological advancement of every country depends on it and the amount of available energy reflects that country’s quality of life. Economy, population and per capita energy consumption have caused the increase in demand for energy during the last few decades. Fossil fuels continue to supply much of the energy used worldwide, and oil remains the primary energy sources. Therefore, fossil fuels are the major contributor to global warming. Along with the global warming impacts and climate changes, the demands for air conditioning and refrigeration have increased. Encouraged by the successful worldwide effort to protect the ozone layer, scientists and engineers have been committed to minimize and reverse the harming environmental effects of global warming. Global warming occurs when carbon dioxide, released mostly from the burning of fossil fuels (oil, natural gas, and coal) and other gases, such as methane, nitrous oxide, ozone, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and water vapor, accumulate in the lower atmosphere. The awareness of global warming has been intensified in recent times and has reinvigorated the search for energy sources that are independent of fossil fuels and contribute less to global warming. The Vienna Convention for the Protection of the Ozone Layer (1985), the Kyoto Protocol on Global Warming (1998) and the five amendments of the Montreal Protocol (1987) all discussed the reduction of CFCs to protect the ozonosphere, but the situation continues to decline.

1.1. Solar energy

The nuclear fusion reactions in the sun yield a huge amount of energy, which is estimated at 3.47 × 10²⁴ kJ per unit time. Only a small part of about 5 × 10⁻¹¹ of this huge energy is irradiated onto the earth's surface. Solar energy is both clean, inexhaustive and harmless to living organisms on the earth because the harmful short wavelength ultra-violet rays are absorbed before reaching the troposphere by the stratospheric ozone layers and weakened by the air composition and moisture in the troposphere. Solar energy activates the atmosphere thus generates climatic phenomena, but the balance of the energy is absorbed by molecules of the materials on the earth and converted into heat at low temperatures. This is an example of the entropy increasing process of nature. It is, therefore, necessary to plan actively to utilize sun’s photon and high temperature heat-energies before they decay to produce entropy. In recent years, scientists have increasingly paid more attention to solar energy. There is a sudden demand in the utilization of solar energy for various applications such as water heating, building heating/cooling, cooking, power generation and refrigeration. Solar energy is the result of electromagnetic radiation released from the Sun by the thermonuclear reactions occurring
inside its core. All of the energy resources on earth originate from the sun (directly or indirectly), except for nuclear, tidal and geothermal energy. The sun actually transmits a vast amount of solar energy to the surface of the earth. The term “solar constant” signifies the radiation influx of solar energy. The mean value of solar constant is equal to 1368 W/m². Most countries are now accepting that solar energy has enormous potential because of its cleanliness, low price and natural availability. For example, it is being used commercially in solar power plants. In recent years, many countries have been facing difficulties with the issue of refrigeration systems. Specifically, the demand of air conditioning for both commercial and residential buildings during the summer is ever-increasing. There is a lack of electricity and storage in developing countries to accommodate high energy consumptive systems such as refrigeration and cooling. The solar cooling techniques can reduce the environmental impact and the energy consumption issues raised by conventional refrigeration and air-conditioning systems.

2. SYSTEM DESCRIPTION

Fig. 1 shows a schematic of the basic ammonia–water absorption refrigeration cycle. The cycle starts at the absorber. The absorber receives the vapor-refrigerant from the refrigerator and creates a rich-mixture. The pump forwards this mixture to the generator or the high-pressure zone. In the generator, the refrigerant is then separated from the absorbent by the heat provided by the solar collector. Using a pressure-relief valve, the weak-solution then returns to the absorber. A HX (heat-exchanger) is in place to recover the internal heat. It is also responsible for pre heating the outgoing rich-solution from the absorber, improving the system efficiency and resisting the irreversibility of the cycle. A 60% higher COP can be achieved by using the HX.

The refrigerant then follows the conventional cycle through the condenser, expansion valve and evaporator. High pressure ammonia vapor enters the condenser, where it transfers heat to the neighborhood. Liquid ammonia leaves the condenser and passes through an expansion valve, reaching the evaporator pressure. The refrigerant then enters the evaporator, where it receives heat from the cold source, turning into low pressure vapor. In the sequence, ammonia vapor enters the absorber and cycle is completed. The absorption refrigeration system instantaneous coefficient of performance (COP) is given by: a ratio of the instantaneous cooling capacity \( Q_c \) and the instantaneous heat transfer rate from the energy source \( Q_s \) to the absorption refrigeration system, both given in W:

![Diagram of the absorption refrigeration cycle](image-url)
Performance of absorption refrigeration systems is critically dependent on the Chemical and thermodynamic properties of the working fluid. A fundamental requirement of absorbent/refrigerant combination is that, in liquid phase, they must have a margin of miscibility within the operating temperature range of the cycle. The mixture should also be chemically stable, non-toxic, and non-explosive. In addition to these requirements, the following are desirable.

1. The elevation of boiling (the difference in boiling point between the pure refrigerant and the mixture at the same pressure) should be as large as possible.
2. Refrigerant should have high heat of vaporization and high concentration within the absorbent in order to maintain low circulation rate between the generator and the absorber per unit of cooling capacity.
3. Transport properties that influence heat and mass transfer, e.g., viscosity, thermal conductivity, and diffusion coefficient should be favorable.
4. Both refrigerant and absorbent should be non-corrosive, environmentally friendly, and low-cost.

Since the invention of an absorption refrigeration system, water NH3 has been widely used for both cooling and heating purposes. Both NH3 (refrigerant) and water (absorbent) are highly stable for a wide range of operating temperature and pressure. NH3 has a high latent heat of vaporization, which is necessary for efficient performance of the system. It can be used for low temperature applications, as the freezing point of NH3 is −77°C. Since both NH3 and water are volatility, the cycle requires a rectifier to strip away water that normally evaporates with NH3. Without a rectifier, the water would accumulate in the evaporator and offset the system performance. There are other disadvantages such as its high pressure, toxicity, and corrosive action to copper and copper alloy. However, water/NH3 is environmentally friendly and low cost.

The use of LiBr/water for absorption refrigeration systems began around 1930. Two outstanding features of LiBr/water are non-volatility absorbent of LiBr (the need of a rectifier is eliminated) and extremely high heat of vaporization of Water (refrigerant). However, using water as a refrigerant limits the low temperature application to that above 0°C. As water is the refrigerant, the system must be operated under vacuum conditions. At high concentrations, the solution is prone to crystallization. It is also corrosive to some metal and expensive. Some additive may be added to LiBr/water as a corrosion inhibitor or to improve heat-mass transfer performance.

Although LiBr/water and water/NH3 have been widely used for many years and their properties are well known, much extensive research has been carried out to investigate new working fluids. Fluorocarbon refrigerant-based working fluids have been studied. R22 and R21 have been widely suggested because of their favorable solubility with number of organic solvents. The two solvents, which have stood out are Dimethyl Ether of Tetraethylene Glycol (DMETEG) and Dimethyl Formamide (DMF).
3.2 Condenser
Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser.

Based on the external fluid, condensers can be classified as:
1. Air cooled condensers
2. Water cooled condensers, and
3. Evaporative condensers

3.2.1 Shell-and-tube type condenser
This is the most common type of condenser used in solar vapor absorption refrigeration systems. In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes. The condensed refrigerant collects at the bottom of the shell. The coldest water contacts the liquid refrigerant so that some sub-cooling can also be obtained. The liquid refrigerant is drained from the bottom to the receiver. There might be a vent connecting the receiver to the condenser for smooth drainage of liquid refrigerant. The shell also acts as a receiver. Further the refrigerant also rejects heat to the surroundings from the shell. The most common type is horizontal shell type. A schematic diagram of horizontal shell-and-tube type condenser is shown in Fig.3.
3.2.2 Analysis of condensers

The total heat rejected in the condenser, $Q_c$ is given by:

$$Q_c = \dot{m}(h_1 - h_2) = m_{\text{ext}} c_{p,\text{ext}} (T_{\text{ext,o}} - T_{\text{ext,i}})$$

Where $\dot{m}$ is the mass flow rate of refrigerant, $h_1, h_2$ are the inlet and exit enthalpies of refrigerant, $m_{\text{ext}}$ is the mass flow rate of the external fluid, $c_{p,\text{ext}}$ is an average specific heat of the external fluid, and $T_{\text{ext,i}}$ and $T_{\text{ext,o}}$ are the inlets and exit temperatures of the external fluid.

The required condenser area is then given by the equation:

$$Q_c = U A \Delta T_m$$

Where $U$ is the overall heat transfer coefficient, $A$ is the heat transfer area of the condenser, and $\Delta T_m$ is mean temperature difference between refrigerant and external fluid.

3.3 Evaporators

The process of heat removal from the substance to be cooled or refrigerated is done in the evaporator. The liquid refrigerant is vaporized inside the evaporator (coil or shell) in order to remove heat from a fluid such as air, water etc. Evaporators are manufactured in different shapes, types and designs to suit a diverse nature of cooling requirements. Thus, we have a variety of types of evaporators, such as prime surface types, finned tube or extended surface type, shell and tube liquid chillers, etc.

Evaporators are classified into two general categories-

1. Dry expansion evaporator
2. Flooded evaporator

3.3.1 Dry expansion evaporator

In the dry-expansion evaporator, the liquid refrigerant is generally fed by an expansion valve. The expansion valve controls the rate of flow of refrigerant to the evaporator in such a way that all the liquid is vaporized and the vapor is also superheated to a limited extent by the time it reaches the outlet end.
As the refrigerant passes through the evaporator, more and more liquid is vaporized by the load. The refrigerant, by the time it reaches the end of the evaporator, is purely in the vapor state and that too superheated. Thus the evaporator in its length is filled with a varying proportion of liquid and vapors.

3.4 Expansion devices
There are different types of expansion or throttling devices. The most commonly used are:

1. Capillary tube
2. Float valves
3. Thermostatic expansion valve

3.4.1 Capillary Tube
This is the most common type of expansion device used in solar vapor absorption refrigeration systems. Instead of an orifice, a length of a small diameter tube can offer the same restrictive effect. Small diameter tubing is called ‘capillary tube’, meaning ‘hair-like’. The inside diameter of the capillary used in refrigeration is generally about 0.5 to 2.28 mm. The longer the capillary tube and/or the smaller the inside diameter of the tube, greater is the pressure drop it can create in the refrigerant flow; or in other words, greater will be the pressure difference needed between the high side and low side to establish a given flow rate of the refrigerant. The length of the capillary tube of a particular diameter required for an application is first roughly determined by empirical calculations. It is then further correctly established by experiments. The capillary tube is not self-adjusting. If the conditions change, such as an increase in the discharge/condenser pressure due to a rise in the ambient temperature, reduction in evaporator pressure, etc. the refrigerant flow-rate will also change. Therefore a capillary tube, selected for a particular set of conditions and load will operate somewhat less efficiently at other conditions. However if properly selected, the capillary tube can work satisfactorily over a reasonable range of conditions. The capillary tube is quite a simple device and is also not costly. The capillary tube is used in small hermetic units, such as domestic refrigerators, freezers and room air conditioners.

3.4.2 Thermostatic Expansion Valve
TEV is a throttling device which works automatically, maintaining proper and correct liquid flow as per the dictates of the load on the evaporator. Because of its adaptability to any type of dry expansion application, automatic operation, high efficiency and ability to prevent liquid flood backs, this valve is extensively used.

The functions of the thermostatic-expansion valve are:
1. To reduce the pressure of the liquid from the condenser pressure to evaporator pressure,
2. To keep the evaporator fully active and
3. To modulate the flow of liquid to the evaporator according to the load requirements of the evaporator so as to prevent flood back of liquid refrigerant to the compressor.

3.5 Absorber
The absorber is a sort of vessel consisting of water that acts as the absorbent, and the previous absorbed refrigerant. Thus the absorber consists of the weak solution of the refrigerant (ammonia in this case) and absorbent (water in this case). When ammonia from the evaporator enters the absorber, it is absorbed by the absorbent due to which the pressure inside the absorber reduces further leading to more flow of the refrigerant from the evaporator to the absorber. At high temperature water absorbs lesser ammonia, hence it is cooled by the external coolant to increase it ammonia absorption capacity. The strong solution of refrigerant-absorbent enters the generator with the help of the pump. The refrigerant then enters the condenser while the remaining weak solution enters back to the absorber and the cycle is repeated.

3.6 Generator
The refrigerant-ammonia solution in the generator is heated by the external source of heat. This can be steam, hot water or any other suitable source. Due to heating the temperature of the solution increases. The refrigerant in the solution gets vaporized and it leaves the solution at high pressure. The high pressure and the high temperature refrigerant then enters the condenser, where it is cooled by the coolant, and it then enters the expansion valve and then finally into the evaporator where it produces the cooling effect. This refrigerant is then again absorbed by the weak solution in the absorber. When the vaporized refrigerant leaves the generator weak solution is left in it. This solution enters the pressure reducing valve and then back to the absorber, where it is ready to absorb fresh refrigerant. In this way, the refrigerant keeps on repeating the cycle.

3.7 Pump
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.

4. CONCLUSION
Solar refrigeration can be expected to play vital role in meeting the need of people in the rural area of developing country for refrigeration. Many solar cooling technologies have proved to be technically feasible and have scope for further improvements. The improvements required are mainly in area of increasing system performance and lowering cost. With probable increase in the cost of conventional energy sources, it is expected that solar technology will become competitive with the conventional system in future.

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