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Improvement of a Solar Powered Absorption Refrigeration System

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Abstract:
Background: *Over the past few decades, energy is the cornerstone of technology and economic infrastructure. Hence the costs of energy have been increasing exponentially worldwide. Conventional refrigeration is one of the most energy consuming sectors. By developing a solar power refrigeration system, we are not only cutting down the energy costs, but also maintaining our surroundings safe. A huge quantity of energy is available to us from the sunlight and all we need is efficient utilization of this energy. The objective of this paper is to design and study of an environment friendly solar powered ammonia- water absorption refrigeration system. This system does away with reliance on an electric grid, at the same time takes no batteries. Solar refrigerators can be widely used in developing countries, where the power supply is uncertain to mitigate poverty and climate change. This environmentally friendly system is an ideal paragon for vaccine storage or large-scale food preservation. Solar refrigeration system can take on an important role within a sustainable energy system of the future.*
Materials and Methods: *The solar refrigeration system described here is based on the refrigeration cycle of ammonia-water absorption system. The cycle consists of two main steps, 'Generation' and 'Refrigeration'. Generation involves generating ammonia vapor in the generator and ammonia vapor condensation in the condenser. Refrigeration includes ammonia vaporizing in the evaporator and absorbing ammonia vapor into the absorber solution. Ammonia-water (NH_3/H_2O) solution is widely used as refrigerant because the solution is extremely stable and functions smoothly at a low temperature. Flat plate solar collectors are widely used for extracting solar energy. These are capable of absorbing direct and diffused solar radiation because of their flat blackened surfaces. As an alternative to flat plate, we may use concentrating collector, a solar collector that uses reflective surfaces to concentrate sunlight onto a smaller area than the reflector. Higher energy flux can be made by this collector and thus providing a higher temperature. But it is more expensive and at the same time complex to operate. Therefore, a flat plate solar collector is our choice for this refrigeration system.*
Results: *The solar refrigerator can save the environment and energy at the same time. Trigenation, the compounding of an absorption refrigeration system with a cogeneration plant to utilize all the generated heat for the production of cooling has become a topic of wide interest in recent years. A trigeneration system can be used in supermarket and food industry to simultaneously satisfy heating, refrigeration and thereby cutting down electricity demands.*
Conclusion: *The solar refrigerator can save the environment and energy at the same time. Trigenation, the compounding of an absorption refrigeration system with a cogeneration plant to utilize all the generated heat for the production of cooling has become a topic of wide interest in recent years. A trigeneration system can be used in supermarket and food industry to simultaneously satisfy heating, refrigeration and thereby cutting down electricity demands.*
Key Word: *Solar energy; Refrigeration; Generation; Ammonia; Trigenation; Energy flux; Absorption; Climate change.*

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I. Introduction

Energy is the lifeblood of modern civilization and an indispensable condition for sustainable development [1-5]. The continued increase in world population and rapid urbanization has resulted in a gradual increase in global energy demands. Developed countries use fossil fuels like coal, oil and natural gas for various domestic and industrial purposes. In the past two decades, fossil fuel expenditure has increased dramatically. The consumption of these fuels contributes greatly to environmental degradation [6]. Fossil fuels in general are exhausting the power source and at the same time building a society without considering alternative energy sources, hence, creating a threat of adverse effect to the sustainable development in the long run. At the current rate of production, proven oil and natural gas may not last long [7]. Consumption of fossil fuels also explicitly gives rise to greenhouse gas (GHG) concentrations in the atmosphere. Among the greenhouse gases, carbon dioxide (CO_2), sulfur dioxide (SO_2) emission is thus considered an emerging problem of the world community for its ongoing effect on the environment and the ecosystem, and especially on the surrounding climate change. In most Third World developing countries, drinking water and irrigation water are scarce commodities. Even in many terrains of India, Africa and Central and South America, the water supply can be found only at a considerable depth below the surface. These sites generally do not have the substructure for electric grid to pump water to supply electricity or the infrastructure to make roads in electric generators or even have provision of fuel for these generators. So, in a grid without power or generators to produce electricity in remote areas have no water and not having to keep the cold medicine or food from spoiling. Like others Bangladesh is largely dependent on fossil fuels for her energy supply. The energy crisis has become a burning issue for the last few years, as electricity production is dominated by indigenous natural gas, which is now showing the reduced path. In recent years, rapid rental power stations have been constructed to minimize the immediate lack of power, which has also increased the price of electricity. In high season during the summer, the country faces severe energy crisis. Because of these problems, researchers are seeking for some other sources of energy that are comfortable to use, friendly to the environment, renewable and cheaper to operate and further does not necessitate long transportation distances [8-11]. The availability of these sources would create a lot of economic activity on a small scale and generally improve the quality of life of people in developing and underdeveloped countries. Renewable energy sources such as solar, wind, biomass and hydroelectric power may be now considered as sustainable alternatives to the fight against climate change. Solar energy is one of the most popular sources of renewable energy because of its low operating costs, prolonged life and available in unlimited quantities. Solar energy is a clean energy source that has less impact on the environment compared to conventional energy sources. There are several important reasons to contemplate solar energy as an energy source, to meet the needs of developing countries. First of all, most developing countries situated in or near the tropics, where plenty of sunshine is available. The second thing is that, energy is a substantial need for these countries, but not readily available from conventional energy sources. Third, the lion's share in developing countries is characterized by an arid climate and populations of difficult access and lack of capital investment and thus faces almost insurmountable obstacles to the supply of energy by conventional means. Fourth, because of the widespread nature of the solar energy all over the globe, it fits the model of the rural economy. Another important feature of this energy is that unlike conventional systems based on fossil fuels, does not produce surpluses that could affect their environment. Various numerical models have been developed to improve the performance of a solar refrigerator by using the pre-heat method [12, 13]. Improved pyrolysis system can also increase the efficiency of the solar refrigerator [14]. However, if combined heating from solar and charcoal firings is provided, it will be more efficient [15. 16]

Solar energy is a tremendous source of energy. The solar energy intercepted by the Earth is much greater than the current rate of consumption of the earth from all sources of commercial energy [3]. Therefore, in principle, solar energy could provide all the energy needs of present and future of the world on the basis of the prosecution. This makes it one of the most promising sources of non-conventional energy. Now all we have to find a very effective way to collect this huge amount of energy. The most popular method of using the solar energy is to transform it in the particular form of energy that is required in the minimum number of steps to achieve greater efficiency, as each doorstep of converting increases the value of energy losses. With that in mind, we have decided to show in this paper, the direct use of solar energy for cooling. Our primary goal is to design and study the ammonia water absorption solar refrigeration system, which is able to function only from solar radiation without the use of electrical energy. There is a demand for chilling in many parts of the world where there is no strong supply of electricity and of conventional fuels is difficult or expensive to obtain. The requisite tends to be or for medical use in which a high capital cost per kW of cooling is acceptable, or for the storage of food, where the cooling power needed is much larger, and acceptable cost per kW can be lower. This cooling system with solar energy could be able to operate in remote areas of the developing world where there is a plenty of sunshine. Producing a system of absorption cooling, we reduce not only energy costs, but also to preserve our environment. Moreover, because of the manipulation of the parts and of being cheap, it can be configured and used anywhere, with only essential component of being sunlight. This cooling system uses none of CFCs or HFCS and so our ozone layer is secure [17- 21]. It can be effectively used for the storage of essential drugs, vaccines and food for domestic use and in the backwoods, where electricity supplies are unreliable because they have little or no mains electricity at all. In urban areas, the cooling system may also contribute to the load on the power line from the national grid to facilitate the supply required. A large amount of heat is released into the environment from plants and industrial processes, thus causing both energy waste and heat stress. Therefore, recovery and use of waste heat are of great interest in energy saving and environmental protection. Refrigeration, energy production, and, of course, the direct use of the heat are the main sophisticated methods to recover waste heat. Therefore, we are able to utilize the systems of absorption refrigeration for cooling, heating and power generation using engines or combined heat of combustion of a gas turbine.

II. Material And Methods

The solar refrigeration system described here is based on the refrigeration cycle of ammonia-water absorption system. The cycle consists of two main steps, 'Generation' and 'Refrigeration'. Generation involves generating ammonia vapor in the generator and ammonia vapor condensation in the condenser. Refrigeration includes ammonia vaporizing in the evaporator and absorbing ammonia vapor into the absorber solution. Absorption is a process in which a substance is taken into another substance at different state [22]. During absorption, the molecules are completely dissolved or diffused in the absorbent resulting in a solution. After being dissolved, the molecules cannot be separated easily from the absorbent. Adsorption is a process in which a portion of the liquid or gas accumulates to the surface of another material. The absorption is not affected by the temperature while adsorption is sensitive to lower temperature. Adsorption is an intermittent system which runs at lower pressure, thus trouble to acquire air tightness [3,12]. So, we preferred absorption refrigeration system. Ammonia-water (NH_3/H_2O) solution is widely used as refrigerant because the solution is extremely stable and functions smoothly at a low temperature. Ammonia is a natural compound, cheap and does not support combustion. All the ammonia contained in an aqueous solution can be driven out by boiling. It possesses good thermodynamic properties for both power generation and refrigeration. Likewise, it is environmentally friendly as it causes no degradation of the ozone layer, thus making it an ideal refrigerant. Although the absorption refrigeration cycle can be operated by lithium bromide and water ($LiBr/H_20$), LiBr crystallizes at lower temperature and so an anti-crystallization is required [22]. Flat plate solar collectors are widely used for extracting solar energy. These are capable of absorbing direct and diffused solar radiation because of their flat blackened surfaces. They offer a required storage volume for absorbent and also provide a good thermal contact between the sunlight and the absorbent. Moreover, to reduce or control heat losses from the plate transparent covers and back insulation may be provided. As an alternative to flat plate, we may use concentrating collector, a solar collector that uses reflective surfaces to concentrate sunlight onto a smaller area than the reflector. Higher energy flux can be made by this collector and thus providing a higher temperature. But it is more expensive and at the same time complex to operate. Therefore, a flat plate solar collector is our choice for this refrigeration system.

Devices

In ammonia-water absorption cycle (Fig 2) the use of two fluids (ammonia and water) along with some quantity of heat input, rather than electrical input helps to produce the refrigeration effect. Both in vapor compression and absorption refrigeration cycle heat is gained from the environment at a low pressure through the evaporation and heat is rejected at a higher pressure through the condensation of the refrigerant. The mechanism of creating this pressure difference and way of refrigerant circulation is the primary difference between the two cycles. In conventional vapor compression cycle (Fig 1) a mechanical compressor serves the purpose of creating he pressure differences necessary to circulate the refrigerant. But in the solar absorption cycle (Fig 3) the function of the compressor is accomplished by the use of the absorber, pump and generator (dashed line region in fig 3) and a secondary fluid (water) is used to circulate the refrigerant. In generator the strong ammonia-water solution is heated by drawing heat from a solar flat plate collector. It can also be heated by some other sources such as hot water, steam, heat of exhaust waste, etc. Due to heating ammonia gets vaporized and it exits the generator. Since water has a high affinity for ammonia and its point of vaporization is quite low, some water particles are also dragged with the ammonia vapor. One of the major drawbacks of the ammonia-water absorption refrigeration system is that, some water also gets vaporized along with the vaporization of ammonia. This appreciable amount of water vapor is carried away by the ammonia refrigerant leaving the generator. The presence of water vapor in the evaporator is responsible for a reduction in the capacity of the refrigeration system. So, to get rid of this situation and to enhance the performance of the system a purification system must be used [23, 24]. Analyzer, a kind of the distillation column, withdraws water vapor from the ammonia refrigerant. It consists of a number of plates positioned horizontally at the top of the generator. Ammonia along with water vapor particles get cooled after entering the analyzer. Water having a higher saturation temperature, gets condensed into liquid water and drips down into the generator. If water vapors are not completely removed in the analyzer, Rectifier, a closed type vapor cooler is used. It is generally water-cooled heat exchange that condenses the remaining water vapor. The weak ammonia-water solution makes a motion to the generator. Pure ammonia vapor at high pressure departing the analyzer and rectifier enter into the condenser, where it condenses to the liquid state by water. Pump raises the pressure of rich ammonia-water solution to the condenser pressure by pumping. Pure liquid ammonia passes through the expansion valve situated between the condenser and generator where its temperature and pressure fall down suddenly. In the evaporator, pure liquid ammonia (NH_3) produces the cooling effect by absorbing heat from the substance to be cooled and gets evaporated. From here, the ammonia in gaseous state passes to the absorber where the weak solution of ammonia-water is already present. Water acts as the absorbent in the refrigeration cycle. The solution in the absorber being unsaturated, it has the capacity to absorb more ammonia gas. When the ammonia from evaporator enters the absorber, it is readily absorbed by water and thus forming the strong solution of ammonia- water. During the process of absorption, the heat liberated can cut down the ammonia absorption capacity of water. Hence cooling water must be supplied to cool the absorber. The heat exchanger situated between the pump and the generator cools the weak hot solution returning from the generator to the absorber. The heat taken away from the weak solution aids to raise the temperature of the strong solution while proceeds from pump to analyze. This operation lessens the heat supplied to the generator as well as the amount of cooling required for the absorber, therefore, enhancing the plant economy.

Refrigeration Cycle

Ammonium-water absorption refrigeration cycle is grounded along the principle that vapor is more readily taken up into a liquid solution as the temperature of the liquid solution is reduced. The refrigeration cycle initiates with the generation procedure. During the generation mode the ammonia-rich liquid solution, departing the absorber is pumped to a higher pressure, passed through a heat exchanger and delivered to the generator. Heat is furnished to the high concentration ammonia-water solution present in the generator. The ammonia will vaporize and the resulting vapor will cause a much higher ratio of ammonia than the original liquid solution. As a consequence, the concentration of ammonia in water will be lessened for the remaining liquid solution. Due to removal of ammonia from the solution, the pressure in the system will rise until condensation of the vapor can be accomplished in the condenser. As the concentration of liquid ammonia-water solution diminishes, the vaporizing temperature of the liquid solution at the pressure needed for condensation will rise up, tending to draw near the boiling point of water at the given pressure. Analyzer and rectifier further purify ammonia vapor. Then the pure ammonia in the vapor state and at high pressure enters the condenser where it is liquefied by air or water. Once the required amount of ammonia has been driven from the solution, the cooling process begins. The generation process being ended, the generator and condenser are terminated from the cycle and the weak solution in the generator is cooled to ambient temperature. The weak solution now plays the role of an absorber. Liquid ammonia produced in the condenser is throttled through the expansion valve to let down its temperature and pressure. Finally, in the evaporator liquid ammonia is evaporated extracting heat from the surrounding thus developing cooling effect. The ammonia vapor generated in the evaporation process is taken up by the weak solution in the absorber vessel. Enough surface contact between the ammonia vapor and the weak solution must be furnished in order to equilibrate the system. The pace of absorption of vapor in the weak solution should be equal to the rate of evaporation in the evaporator. Failure to absorb the ammonia vapor at the same pace that it is evaporated at the evaporator will result in an increase in the system pressure, which will elevate the boiling point of the ammonia in the evaporator, affecting the refrigeration cycle. As ammonia vapor is absorbed in the solution by exothermic phenomenon, the heat of solution must be taken out. Other than the temperature of ammonia-water solution will grow and therefore heighten the pressure of the system. This increase in the pressure will also result in an increment of the vaporization temperature of the ammonia in the evaporator and thus affecting the refrigeration system. During the cooling step, ammonia is being taken up in the weak solution till the concentration of the solution makes its initial concentrated condition. Then the generation process sets about again and the same round is repeated.

While designing intermittent ammonia/water absorption system, the concentrations of the strong solution and weak solution are preferred, depending upon the temperature of the heat source (solar flat plate collector), the temperature of the heat sink (cooling water) and the temperature at which the refrigeration effect is desired. In that respect are both single-stage and two-stage ammonia-water solar refrigeration systems. The two-stage system can resolve the limiting operation temperature of the single stage system. The operation of the single-stage system is hindered when the generating temperature is quite low or when the condensing temperature is too high for the given generating temperature. Hence the two-stage refrigeration system can be applied to amend the performance and enhance the efficiency of the single stage system [25].

Steady-state mass and energy balances for the components of the cycles are established in the following equations [26, 27].

Global mass balance:

$_{in}$ $_{out}$ (1)

here sym olizes the mass flow rate g s .

Mass balancing equation of ammonia:

$_{in}z_{in}$ $_{out}\, z_{out}$ (2)

Where z denotes the ammonia mass fraction (kg/kg).

Energy balancing:

$$- \quad {}_{in}h_{in} - \quad {}_{out}h_{out} \qquad (3)$$

here signifies the thermal power is the mechanical power (kW); h symbolizes the specific enthalpy (kJ/kg).

COP_R (overall Coefficient of Performance), is stated as the ratio between the desired energy output cooling effect, L to the external energy inputs to the system generator and pump inputs are gen and pump,in respectively

$$= \qquad (4)$$

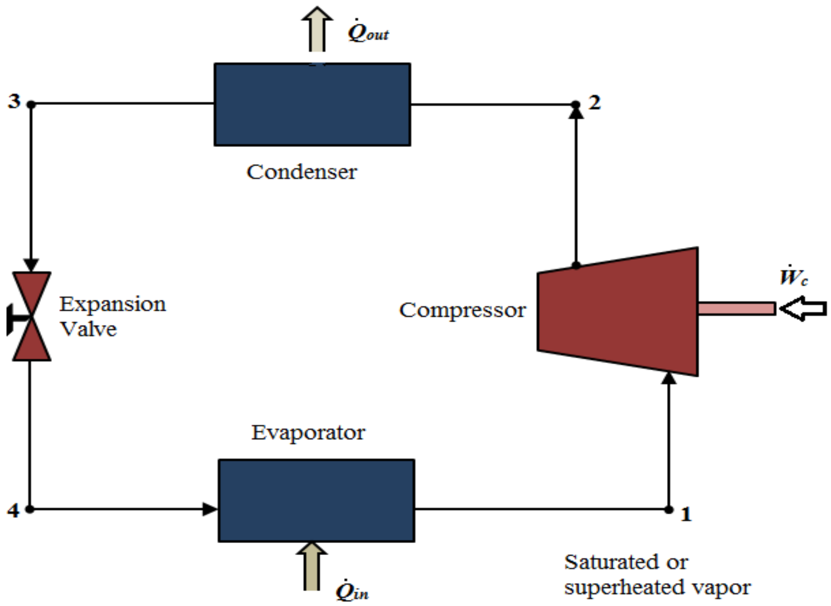

Fig 1: Conventional vapor compression cycle

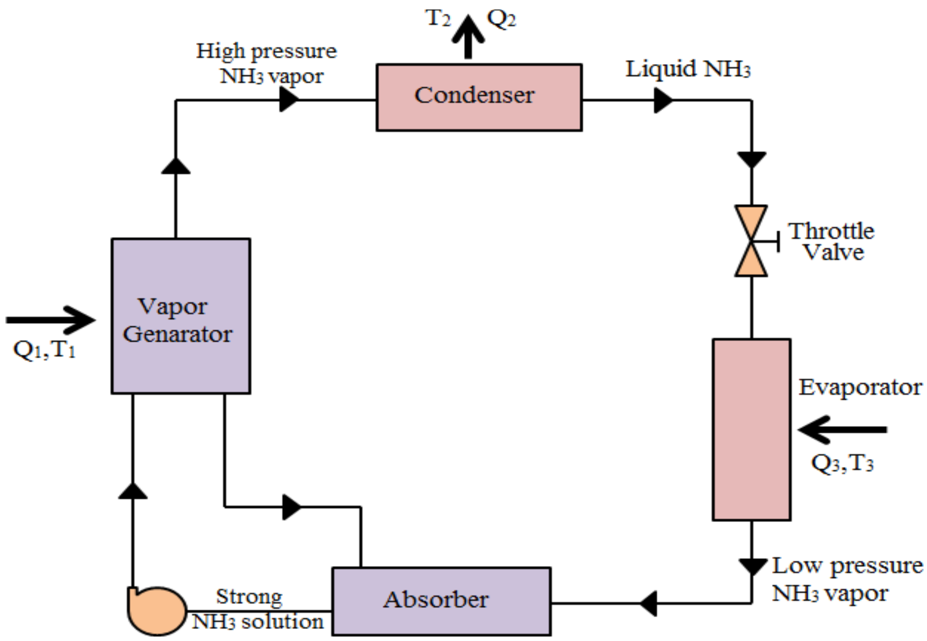

Fig 2: NH_3/ H_2O absorption cycle

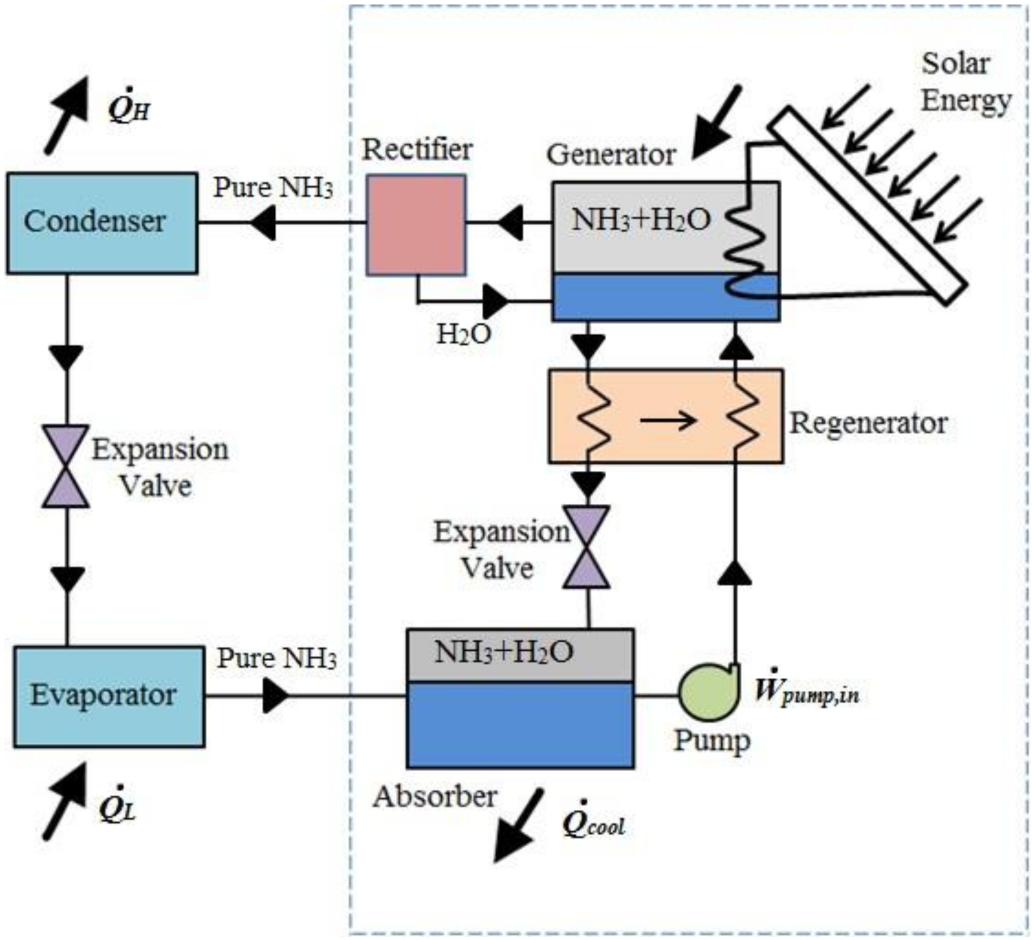

Fig 3: Solar NH_3/ H_2O absorption cycle.

III. Result & Discussion

The potential applications for the successful growth of economic solar energy conversion to satisfy demands for mechanical or electrical energy are wide. Solar cooling may have applications in developing as well as in developed countries. In developed industrial nations where there is enough grid electricity, there is no cost-effective application for solar powered refrigeration of food, medicines, etc. However, it can still have an opportunity to be profitable solar air conditioning [28]. The demand for such a system can still appreciates it if we think that millions of dollars are lost each year in developing countries due to food spoilage. The prevention of such alterations could be the economic viability of these nations, along with the fact that most famines in the universe is not only a lack of food production, but is largely due to the great food growing damage boost. Most agricultural products such as fruits, vegetables, milk, meat, fish, etc., may be stored in cold conditions for significantly long periods of time. Large amounts of these products are being lost annually due to inadequate storage facilities. Consequently, there is sharp differences in the food chain between harvesting and off harvesting seasons. Both in the developing and underdeveloped countries, preserving food in cold storage is quite costly and most of the poor farmers in the developing world are incapable of affording it. Besides the scarcity of electricity is also responsible for spoiling a lot of medicine and vaccine every year. We can solve all these problems and break this vicious circle through the application of solar refrigeration system just in an effective and intelligent way. In contrast to the conventional high electricity consuming refrigeration system, it is free, except the cost of installation and maintenance. Refrigerators containing ozone depleting and global warming substances such as chlorofluorocarbons (CFCs) as refrigerants, are harmful. After CFC were prohibited, they had been replaced by substances such as chlorofluorocarbons (CFCs), which are also substances that deplete the ozone layer. Both are environmentally destructive chemicals and have impacts on global warming. When a conventional refrigerator is used ineffectively, it will also contribute more to global warming. If we are committed to using solar powered refrigeration, we can minimize the negative impacts on the environment. Especially since it requires no electricity supply, we can reduce, in particular, the misuse of the electricity and blow some steam off our grid energy. Furthermore, the system is portable and noise levels are significantly lower than conventional refrigerators, since most of the machine operation are done without compressors. In short, the solar refrigerator can save the environment and energy at the same time. Trigenation, the compounding of an absorption refrigeration system with a cogeneration plant to utilize all the generated heat for the production of cooling has become a topic of wide interest in recent years. A trigeneration system can be used in supermarket and food industry to simultaneously satisfy heating, refrigeration and thereby cutting down electricity demands [29, 30].

Though the absorption refrigeration system is an ideal mean to combat energy consumption of refrigeration sector, it has some drawbacks. They are a lot more complex than a normal refrigerator and engage a huge place. They require much larger cooling towers to reject the waste heat owing to their low COPs. The COP of a single stage absorption refrigerator is 0.50–0.73 while that of a double stage is around 1.3 [3]. The absorption refrigeration systems are much more expensive compared to the vapor-compression refrigeration systems which are quite obvious as their price of production is high because of complex, heavy and large structure. Moreover, environmental factors such as cooling water temperature, local weather, air temperature and solar radiation influences the operation of solar refrigerator. We cannot reach a high enough temperature at nights or in extended cloudy days. We must try to make use of phase change materials, Eutectics etc., which has the potential of storing a huge amount of energy within a small space and over a prolonged period of time than water. If the cost of fossil fuels, transportation, energy conversion, electricity transmission and system maintenance are taken into account, the price of energy produced by solar thermal absorption system would be a lot more depressed than that for conventional refrigeration system. The operation of the scheme is regulated largely by the temperature deviation between the generator and the condenser and absorber units. For effective operation, it is important to keep the condenser and absorber temperatures as low as possible. We can use two-stage intermittent ammonia water, refrigeration system to amend the performance and enhance the temperature limit as well as the efficiency of the system. Although other types of mixtures (like ammonia-lithium nitrate, ammonia-sodium thiocyanate and organic fluids) can be utilized, ammonia-water mixture is the most frequently used working fluid for combined absorption cycles. The primary advantage of these non- conventional working fluids in the combined absorption cycles are that they can be utilized to overwhelm some of the drawbacks, such as the costly rectification process. In battery based solar powered refrigeration system, battery used for storing DC current should be put back at regular interval of fourth dimension. Moreover, additional space is needed for locating the battery. Ammonia-water solar absorption refrigeration includes many interesting features and can be a means to a more sustainable energy system, if designed ideally and used effectively.

IV. Conclusion

In the prevailing situation of the power crisis, the utilization of the Ammonia-water Solar Refrigeration System might play a greater role, to minimize the use of electricity and thus to conserve the energy obtained by burning of fossil fuels. On the contrary, it has got some drawbacks. It takes comparatively more time for cooling, has got a low COP, and the initial cost is high as mentioned earlier. The design is relatively complicated as we have to think of replacing the compressor with some more complicated functioning parts. Still, mass-scale production may result into the solution of the availability and high costing of the components. The rest of the drawbacks might be reduced by adopting more efficient technology. Thus, it might become a better alternative of the prevailing conventional refrigeration cycles. Using this methodology may result in a significant alteration of the scenario of the prevailing power crisis. In other words, the scarcity and hike for the energy may be considerably reduced, side by side, the wastage of food, medicine and drugs may be declined significantly, and hence it can lay aside our money and resources from being abused. It might play the part of the best solution to the refrigeration problems where it is impossible to transmit electricity through the lines like the hilly regions, marsh lands and mostly the little islands. This concept might take an overall solution to the emission of GHGs, noise and other means of environment pollution and most importantly, make the refrigeration system easily available all over the globe.

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