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Investigation of a Novel Solar Powered Absorption Refrigeration System with Solar Point Collector

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Abstract

The design of energy systems becomes more important due to limitations of fossil fuels and the environmental impact during their use. Energy systems are complex as they involve in economic, technical and environmental factors. There are no thermally driven absorption refrigeration machines available on the market which could provide small-capacity cooling for domestic housing applications as well as hotel rooms of less than 10 kW at present. This paper presents a detailed description of a new solar-based refrigeration system using three fluid ammonia-hydrogen/water (NH3-H_2/H_2O) vapour absorption systems. This technique uses solar energy to produce cold air and does not pollute the environment.

Key words: Solar, waste energy, diffusion-absorption cooling, ammonia, water.

Introduction

Solar cooling is an attractive idea because cooling loads and availability of solar radiation are approximately in phase. As the refrigeration system operates – pump work neglected - without the need for mechanical or electrical power, it is independent of electrical grids and thus may prevent in remote rural regions the spoiling of agricultural products in storage due to the lack of refrigeration. That is why there is a high demand for application of solar cooling for decentralised cold storage of food in the countries of the sun belt of the earth[1].

Solar cooling uses solar thermal energy to power a refrigerator, which in order to preserve food has to maintain temperatures lower than 5°C in the storage room. Heat operated cooling systems are well known. Ammonia-water absorption refrigeration systems are normally preferred for low temperature applications.

The heat input for this system is required at temperatures higher than 90°C. Therefore high performance solar collectors are needed to supply a sufficient solar energy input[2].

At present there are no thermally driven absorption cooling machines available on the market which could provide small-capacity cooling for domestic housing applications as well as offices and hotel rooms of less than 10 kW. This paper investigates the development and testing of single-stage solar or waste energy heated ammonia/water (NH_3-H_2/H_2O) absorption cooling machines (ACM). The designed cooling capacity of the cooling machine is 2.5 kW at evaporator temperatures between -10°C and +15°C with indirect heating through novel solar collectors. Here are two main types of refrigeration system: Mechanical vapour compression and absorption refrigeration system. The mechanical vapour compression system is outstanding due to its higher coefficient of performance, flexibility and compactness in manufacturing and operation. However, the fact that it is generally powered by electricity results in the emission of a large amount of CO_2, which, in turn, causes the greenhouse effect. In addition, CFCs used as the working medium seriously affect the ozone layer around the globe. The absorption system, powered by either electric or wasted heat, is mainly used in large air conditioning and refrigeration systems. Owing to the environmental problem caused by CFCs and the huge energy consumption of conventional cooling system, this novel solar powered absorption refrigeration system has been developed[3-5].

Novel solar powered absorption refrigeration system has many advantages in refrigeration or heat pumping application such as: Materials are environmentally friendly, chemically stable and the system can be powered by either solar energy or wasted heat.

Air-conditioning is one of the major consumers of electrical energy in many parts of the world today and already today air-conditioning causes energy shortage. The demand can be expected to increase because of changing working times, increased comfort expectations and global warming. Air-conditioning systems in use are most often built around a vapor compression system driven by grid-electricity.

However, most ways of generating the electricity today, as well as the refrigerants being used in traditional vapour compression systems, have negative impact on the environment.

Solar air-conditioning might be a way to reduce the demand for electricity. In addition many solar air-conditioning systems are constructed in ways that eliminate the need for CFC, HCFC or HFC refrigerants[6].

Alternatives to using solar energy are to use waste heat from different industrial processes such as refineries, garbage treatment facilities etc. Even driving the air-conditioning systems directly with fossil fuels might in some cases is a more environmental friendly alternative than using electricity[6].

This report deals with a wide range of components, from room air-conditioners to solar collectors; this can be used as subcomponents in a solar air-conditioning system.

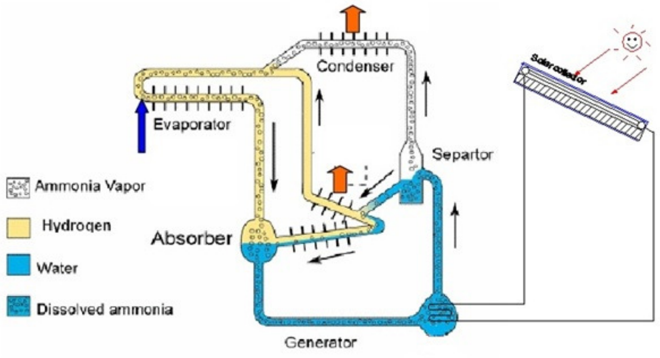

Figure-1
Typical solar powered absorption refrigeration system

Material and Methods

The core components of a SARS are the solar collector, generator, condenser, evaporator and absorber figure1. A fluid heat exchanger (FHX) in the fluid circuit and a gas heat exchanger in the auxiliary gas circuit are also components of the SARS as well as a separator for the condensation of the evaporated solvent.

At low partial pressure in the evaporator the cooling agent evaporates and is absorbed again in the absorber by the weak ammonia/water fluid from the generator. In the indirectly solar powered generator with high heating temperatures the cooling agent is driven out of the rich ammonia/water fluid and so a high cooling agent vapour pressure is generated which is enough for the condensation of the cooling agent in the condenser. The usual mechanical fluid pump of absorption cooling machines is replaced in a SARS by a thermal gas bubble pump. The circulation of the fluid between the generator and absorber is maintained by vapour bubbles which are generated at nucleation cells at the lower part of the lifting pipes and forms at best a slug flow regime to push up a liquid column. So the processes of desorption of the cooling agent and lifting the fluid are combined in one component. The pressure compensation between high and low pressure level is achieved by the inert auxiliary gas hydrogen. The auxiliary gas circulates between the evaporator and absorber because of the temperature and density differences. There are no mechanical moving components inside the cooling unit and total pressure is constant at all points inside the cooling unit [8-13].

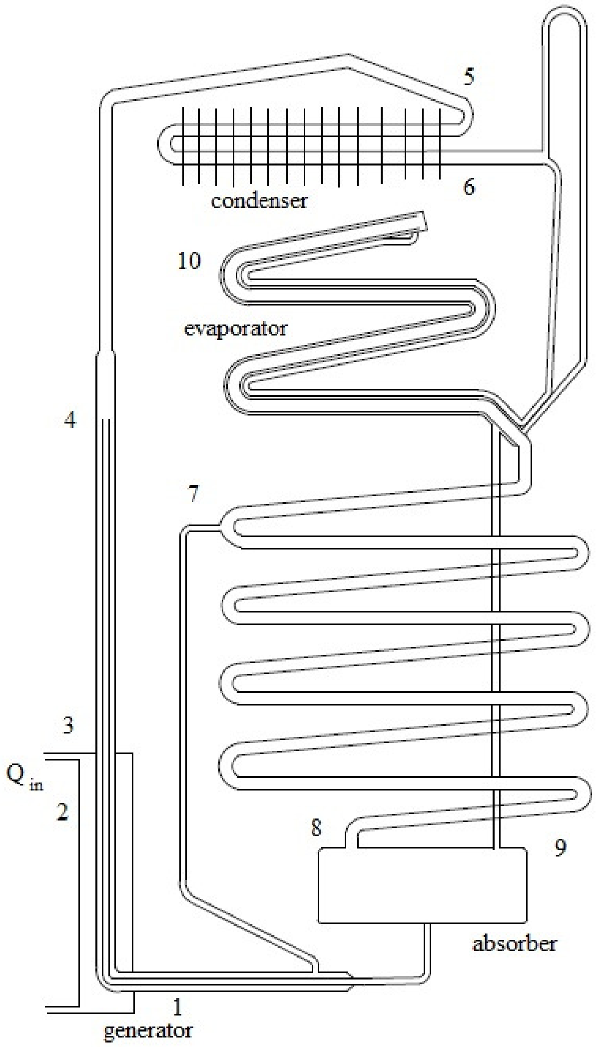

Figure-2
Schematic view of experimental refrigerator

A mathematical model was developed to analyze the performance of the experimental refrigerator. It was used to determine the maximum performance for given operating conditions. When calculated results are compared with actual values, this should show how losses for different devices occur and how the system could be modified. Temperatures and pressures of working fluid are obtained based on actual values obtained from the experimental refrigerator. Working fluid (water and ammonia) properties were obtained from standard properties of pure substances table. Solution properties were obtained from ASHRAE[9].

Generator, bubble-pump and separator: All state numberings correspond to those in figure 2. Heat input to the generator is used for two purposes: to vaporize and separate ammonia from the liquid, and to stimulate the pumping effect through the pump-tube. By applying the energy and continuity equations[7-10]

$$Q_{gen} = m_4h_4 + m_3h_3 - m_1h_1 \qquad (1)$$

$$m_1 = m_3 + m_4 \qquad (2)$$

$$m_1X_1 = m_3X_3 + m_4X_4 \qquad (3)$$

The relation between liquid and vapour flows leaving the separator can be determined based on the pump-tube characteristics [8]. The bubble-pump correlation is given as

$$V3 = -0.00014\ V_4{}^{4} + 0.00625\ V_4{}^{3} - 0.09706\ V_4{}^{0} + 0.63772V_4 - 0.46802 \qquad (4)$$

As the bubble-pump correlation is presented in terms of volumetric flow rate, the mass flow rate of both vaporized and liquid solution must be transformed into volumetric flow rate. The specific volume of the liquid solution and the vapour can be obtained [10] as

$$v_3 = (1 - X_3)v_{water\text{–}liquid} + 0.85X_3v_{ammonia\text{–}liquid} \qquad (5)$$

$$v_4 = (1 - X_4)v_{water\text{–}vapour} + X_4v_{ammonia\text{–}vapour} \qquad (6)$$

To calculate mass flow through the pump-tube when the heat input is specified, X1 must be first assumed. Then eqs. (1)-(6) must be solved using trial and error.

Evaporator and absorber: In an evaporator of a diffusion absorption system, liquid ammonia evaporates in an environment of inert gas. There are many factors affect the evaporation rate such as ammonia mass flow, helium partial pressure, wetted surface area, and absorption rate. In the absorber, the absorption rate depends upon the solution mass flow rate, concentration temperature, and wetted surface area. The mass flow of solution entering the absorber is also affected by the bubble-pump performance. Thus, it is likely that liquid ammonia cannot completely evaporate in the evaporator. The unevaporated liquid just returns to the absorber without producing any cooling effect. An index named ‘‘combined evaporator–absorber effectiveness (ε)’’ is presented. It specifies the capability of the evaporator and absorber. It is defined as a ratio of evaporated ammonia mass rate to the total ammonia available in the evaporator[8-10].

$$\varepsilon = \frac{m_9X_9 - m_7X_7}{m_6X_6} \qquad (7)$$

The refrigerating capacity when the effectiveness is included into the calculation is given by

$$Q_{evap} = (m_9X_9 - m_7X_7)(h_{8\text{–}vapor} - h_6) \qquad (8)$$

The unevaporated liquid accumulated at the bottom of the evaporator returns back to the absorber with mass flow and concentration of

$$m_{8\_liquid} = m_6 - (m_9X_9 - m_7X_7) \qquad (9)$$

$$X_{8\_liquid} = \frac{m_6X_6 - (m_9X_9 - m_7X_7)}{m_6 - (m_9X_9 - m_7X_7)} \qquad (10)$$

The calculated results must be verified by calculating the solution concentration of ammonia in the solution where

$$X_{13} = \frac{m_9X_9 + m_{8\text{-liquid}}X_{8\text{-liquid}}}{m_9 + m_{8\text{-liquid}}} \qquad (11)$$

This figure must correspond to the concentration of compressed liquid solution entering the generator (X_1).

Coefficient of performance: Since DAR is a refrigeration system that uses only heat as input power to drive the system, its coefficient of performance is

$$COP = \frac{Qevap}{Qgen} \qquad (12)$$

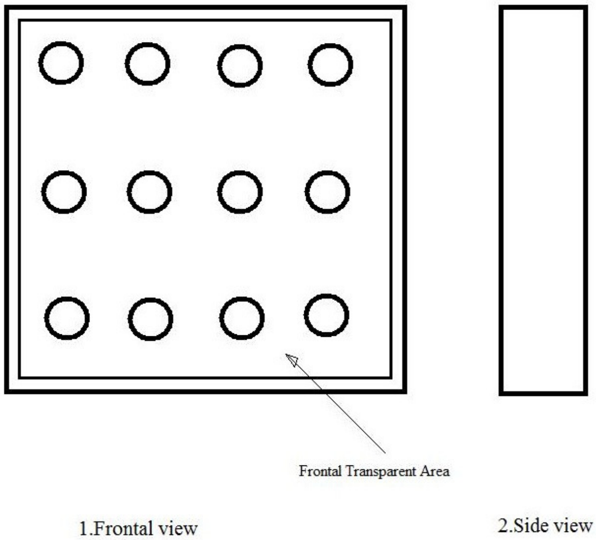

Figure-3
Solar point collector

A solar collector whose glass cover is provided with equally spaced lens is shown in the figure.3. Focus point of the lenses are made to fall directly onto copper tubes which is conducting the thermic fluid, water. The temperature at the focusing point is twice that of the ambient temperature. Thus the maximum temperature that can be gained by the thermic fluid and rate of rise in temperature is high for the same size when compared to the flat plate collectors.

Results and Discussion

From the performance curve, it is obvious that comparing to flat plate collector, solar point collector has significantly high outlet fluid temperature.

Table-1
Comparison of Perfomance between suncube collector and flat plate collector

Local time	Solar radiation intensity (W/m^2)	Ambient temperature (°C)	Wind speed (m/s)	Collector fluid temperature (°C)		
				Inlet	Outlet fpc	Outlet spc
10:00	858.3	29.8	2.6	29.5	45.8	60.8
11:00	894.2	32.3	2.8	29.5	46.5	62.0
12:00	858.1	32.3	1.6	29.5	48.9	65.9
13:00	968.5	34.5	0.85	29.5	51.0	68.0
14:00	846.2	35.6	2.4	29.5	52.4	69.4
15:00	723.2	35.6	2.9	29.5	53.8	70.3

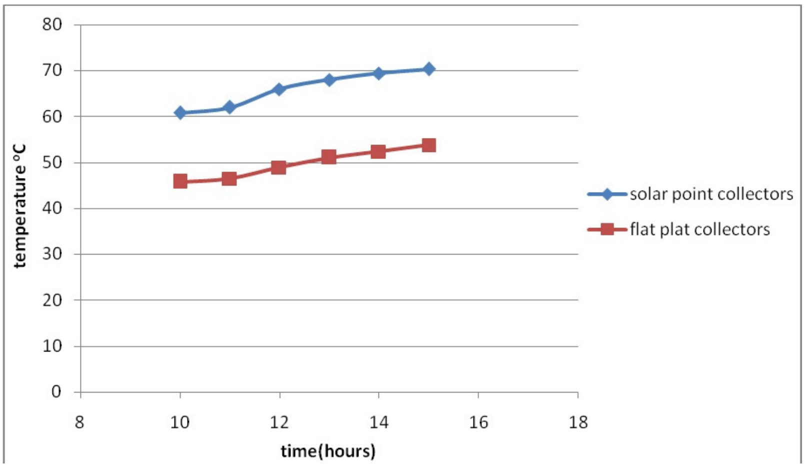

Figure-4
Comparison of Perfomance between suncube collector and flat plate collector

Table-2
Variation of COP with generator temperature

T (°C)	T_e (°C)	T_c (°C)	Q_{load} (W)	COP
60	10	35	400	0.025
62	10	35	400	0.07
65	10	35	400	0.13
67	10	35	400	0.16
70	10	35	400	0.21

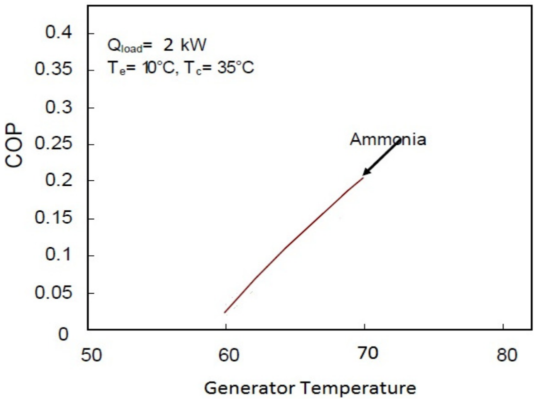

Figure-5
Variation of COP with generator temperature

It was discovered that to operate the experimental refrigerator there was a minimum generator input below which the system could not produce any cooling effect. When the heat input was lower than the minimum value, the system was not able to produce any cooling effect. This is due to the bubble-pump characteristics. To obtain a pumping effect, a minimum vapour generated is required. When the heat input is too low, there is not enough vapour to drive the pump. This means that only the vapour refrigerant is produced. This refrigerant liquefies and enters the evaporator. However, it cannot evaporate and produce any cooling effect since there is no liquid pumped to the absorber to absorb the vapour refrigerant

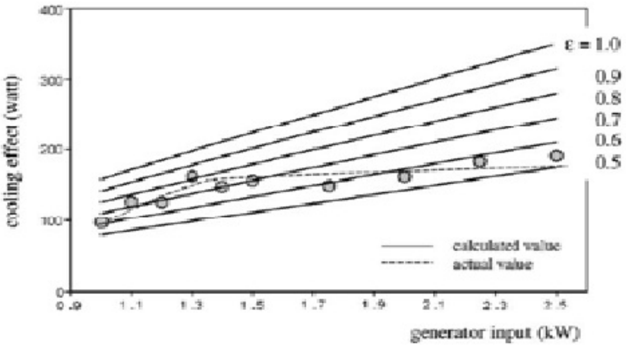

Figure-6
Comparisons between calculated and actual cooling capacity

When the heat input increases beyond the minimum value, the bubble-pump begins to operate. The liquid then circulates to the absorber and absorbs the vapour refrigerant. Thus, a cooling effect is produced. Further increase in heat input produces a higher cooling effect as more refrigerant vapour is generated and more liquid is pumped to the absorber. This also causes the COP to increase. From the figure, it can be seen that when the heat input continues to increase beyond a certain point (around 1300 W), the cooling capacity increases with a lower rate.

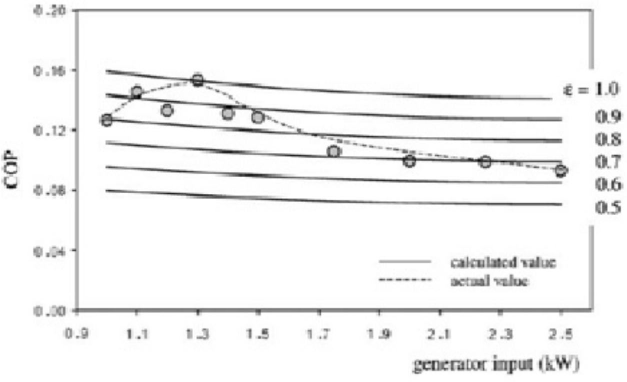

Figure-7
Comparisons between calculated and actual COP

This implies that the cooling capacity is limited by the evaporator or absorber mass transfer performance. As the increasing rate of cooling capacity does not match with the rate of heat input, this result in a drop of COP. Cooling capacity is dependent upon the evaporation and absorption rates, which are dependent upon the wetted surface area. To evaporate all refrigerant, there must be enough wetted surface (an evaporator coil on which the liquid evaporated to vapour and an absorber column on which the vapour ammonia is absorbed into solution). When there is an increase in the generator heat input the mass flow of ammonia is increased. However, the evaporator and absorber surface are fixed. This may not be enough for all the ammonia to evaporate or to be absorbed. It must be noted during the tests that it was observed through the sight glass that the absorber column and evaporator coil were not completely covered with liquid.

Conclusions

Ammonia absorption refrigeration technology has great potential to offer economical and innovative solutions to various refrigeration requirements. Absorption machine theory has existed for many years, however just recently this technology has reached a stage where it is also a commercially viable option.

The system was tested with heat input values between 1000 and 2500 W for a helium pressure of 6.1 bar. The system cooling capacities were found to be between 100 and 180 W with a COP between 0.09 and 0.15. A simple mathematical was developed to analyze the experimental refrigerator. Comparisons between actual and calculated values show that the evaporator and absorber mass transfer have a strong effect on the system performance. The system produces maximum performance when all refrigerant is completely evaporated in the evaporator. This requires sufficient mass transfer surface in the absorber and evaporator. The bubble-pump is also an important part of the system.

The small capacity application potential of ammonia absorption refrigeration technology makes it a strong candidate for the refrigeration technology of the millennium.

Nomenclature

M	mass flow rate ($kg\ s^{-1}$)
H	specific enthalpy ($kJ\ kg^{-1}$)
X	mass concentration
V	volume (m^3)
ν	specific volume ($m^3\ s^{-1}$)
Q	heat transfer ($kJ\ s^{-1}$)
ε	combined evaporator–absorber effectiveness

Subscripts1,2,3,. . . see Figure.2

abs	absorber
evap	evaporator
con	condenser
gen	generator
rec	rectifier

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