SOLUTIONS FOR SOLAR-ASSISTED AIR CONDITIONING SYSTEMS IN CONDITIONS OF VIETNAM

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ABSTRACT *: Vietnam is one of countries where solar radiation is available in most areas. Over the past few years, the economy of the country has continuously developed, which leads to the increase of many kinds of demand, among which the demand on air conditioning is considered quite considerable. However, due to the unbalance between the electricity supply and the demand , due to the need of energy savings and due to the prohibition of CFC-containing refrigerants, the use of conventional vapour-compression refrigeration machine should be limited.*
Dealing with this problem, the paper discusses the ability of application of solar energy for air conditioning systems and presents some schematic diagrams proposed for conditions of Vietnam.

(Keywords: air conditioning and refrigeration, absorption, solar energy, water/lithium bromide, desiccant and evaporative cooling)

1. INTRODUCTION

Technologies using solar energy for operating air conditioning and refrigeration systems, are :

-Continuous absorption,

- Intermittent absorption,
- Solid/gas adsorption,
- Diffusion,
- Evaporative cooling and desiccant systems,
- Photovoltaic/vapour-compression systems,
- Photovoltaic/thermoelectric systems.

Focusing on the field of air conditioning engineering in scale of low and medium cooling capacity, researches of R.Best.[1], M.R.Yeung [2], A.Y.Alkhamis [3] and M.Izquierdo Millan [4] show that water/lithium bromide absorption cooling systems have been considered as the most suitable and practical solution. Besides these, studies of F.Steimle [5], S.Biel [6] and

L.M.Lazzarin [10] present the alternative method for dehumidifying and cooling the air, which is considered as the promising solution in the near future .

Based on this brief review, in this paper some experimental data and the calculation on the solar-assisted water/lithium bromide absorption air conditioning system are presented, and the feasibility study of the application of the proposed system as well as of the system with sorptive dehumidification and evaporative cooling in conditions of Vietnam is discussed.

2. PROPOSED SCHEMATIC DIAGRAMS OF THE SOLAR-ASSISTED WATER/LITHIUM BROMIDE ABSORPTION AIR CONDITIONING SYSTEM

2.1. Schematic diagrams

In almost countries, especially in developing countries like Vietnam, it is clear that lowering first cost of the system is still the main target to pursue in order to allow this technology to enter the market [1]. Based on this idea, figure 1 presents schematic diagram of the solar-assisted water/LiBr absorption air conditioning system with flat plate collector and figure 2-with tubular collector.

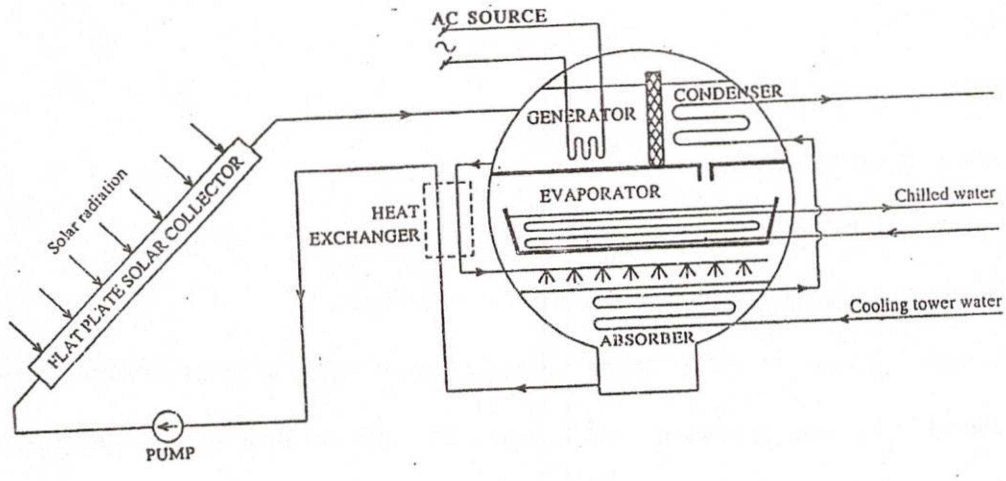

Fig.1. Water/LiBr absorption air conditioning system with flat plate solar collector

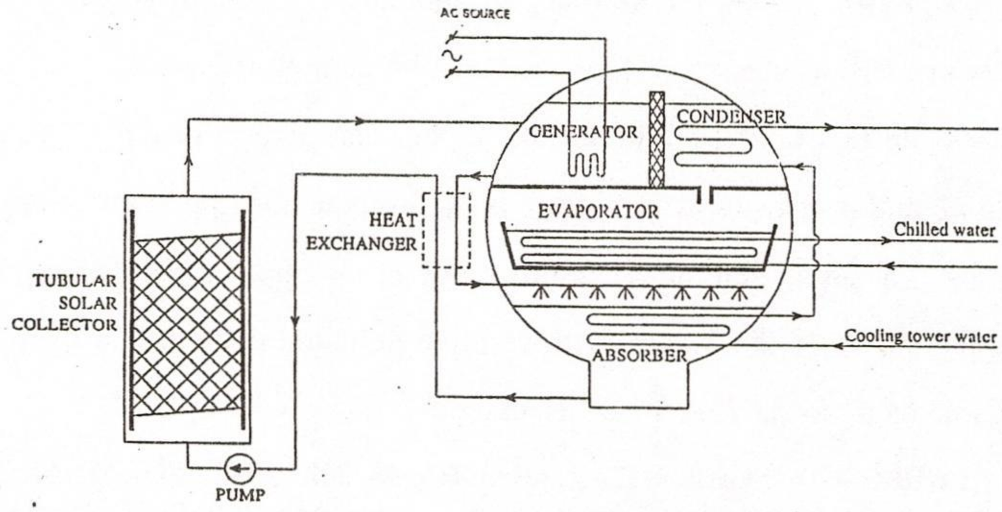

Fig.2. Water/LiBr absorption air conditioning system with tubular solar collector

In these two figures, the water/LiBr solution is directly heated by solar energy. However, the diagram where the solution is heated indirectly by means of hot water is also estimated. If needed, the electricity or waste heat may be used as the additional source for satisfying the energy demand and for maintaining the stable operation of the system.

Mentioning about the shape of solar collector, the following ideas are concerned :

- First cost,
- Area of installation,
- Specific roof shape in Vietnam,
- In-country fabrication (in developing countries).

From these points of view, some prototypes of tubular solar collector have been produced [11]. The practical results show that the tubular solar collector may be produced as an in-country product, this kind of collector needs smaller area of installation, it suits the specific roof shape in Vietnam and it is cheaper in comparison with the flat plate collector. The evaluation of heat capacity supplied by each collector is discussed later in some next paragraphs. Depending upon each situation, either flat-plate or tubular solar collector is selected.

2.2. Evaluation of collector heat capacity

Experiments on both solar collectors have been realised over the past three years for supplying hot water and for evaluating their primary heat capacity. With demonstration purpose, figure 3 shows the variation with time of solar radiation gained on corresponding surfaces of tubular collector [11]. The variation with time of water temperature and of solar radiation gained on inclined surface of flat plate collector need not to be presented because it is well known already. From figure 3, it is clear that the solar radiation reaching the absorption surface of the testing tubular collector is quite stable, whereas the solar radiation gained on flat plate collector varies strongly with time.

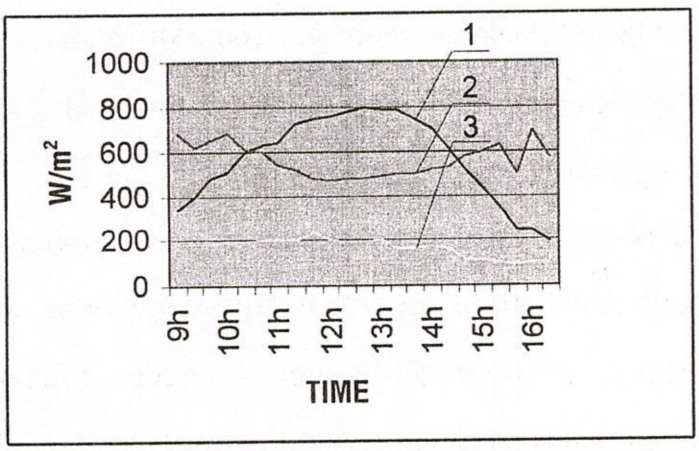

Fig.3. A variation of solar radiation with time
1. On horizontal surface
2. On vertical surface in the direction of beam radiation
3. On vertical surface in the opposite direction of beam radiation

The tested tubular collector has cylindrical shape with outer diameter and height of 0.6 m and 1.1 m, respectively. The water volume heated by solar energy is 200 litres. The experimental results show that the mean heat capacity supplied by this prototype is around 16720 kJ/day (from 8 am to 4 pm).

Compared with the tubular collector, the maximum and the mean water temperatures gained by flat plate collector with single cover are around 70°C and 62°C, respectively. For 1 m^2-flat plate collector, the corresponding water volume is 70 litres. Based on these data, the mean heat capacity supplied by flat plate collector is around 9363.2 kJ/m^2/day (from 8 am to 4 pm).

Due to the large difference in shape between these two collectors, the efficiency comparison is done by another way based on the mentioned prototype of tubular collector. The above-mentioned results lead to the conclusion that the heat capacity of the considered prototype is equal to that supplied by 1.785 m^2-flat plate collector, the price is reduced around 50 % and the area of installation decreases considerably.

It is necessary to emphasize that the heat capacities of solar collectors presented in this section are not considered as the final data for doing further calculations, they must be adjusted because there are some differences between the tested solar hot water systems and the proposed diagrams such as working temperature and operation regime (see table 2).

2.3. Some thermodynamic data of water/LiBr absorption air conditioning system

Figures 1 and 2 present schematic diagrams of one-stage solar absorption refrigeration system working with water/lithium bromide solution. The thermodynamic estimation and calculation corresponding to these diagrams have been realised and are presented in table 1.

Table 1

Initial and intermediate data used to determine the cooling capacity

Description	Temp.,°C	Press.,bar
Temperature of cooling water	32	
Temperature of cooling water leaving absorber	36.5	
Temperature of cooling water entering condenser	36.5	
Temperature of cooling water leaving condenser	40	
Condensing temperature of refrigerant (water)	45	
Temperature of chilled water at evaporator exit	7	
Temperature of chilled water at evaporator inlet	12	
Saturation temperature of refrigerant in evaporator	5	
Temperature of refrigerant leaving generator	91.5	
Temperature of concentrated solution leaving generator	96	
Temperature of concentrated solution leaving heat exchanger	58.5	
Temperature of dilute solution leaving absorber	40	
Temperature of dilute solution leaving heat exchanger	73.5	
Mean temperature of solution ejected in absorber	44.5	
Boiling temperature of dilute solution in generator	88	
Pressure of high pressure side		0.09584
Pressure of low pressure side		0.00872

In the presented calculation, the concentrated and dilute concentrations of the considered solution are 62 % and 58 %, respectively. The concentration in this paper is defined as the ratio between the mass of lithium bromide and the mass of the corresponding solution. Using the enthalpy-concentration diagram of water/lithium bromide solution, the further calculation shows that the specific cooling capacity is 2316.98 kJ/kg of refrigerant and the circulation ratio is 15.5 kg of dilute solution/kg of refrigerant.

3. DISCUSSION

3.1. Selection of solar collector

As mentioned above , the selection of solar collector used to supply heat to the discussed air conditioning systems should be considered carefully under each practical situation. However, it can be seen generally that the tubular collector has much more advantages than the flat plate collector. Its main advantages are:

simple structure, in-country fabrication, small area of installation, low cost and light maintenance. Experiences show that, in these two presented diagrams, the electricity or another kind of heat energy such as flue gas should be installed permanently in the system for maintaining the stable operation of the system in cloudy or bad weather condition and, in the case of intermittent operation, for increasing the temperature either of the solution in the direct heating or of the water in the indirect heating to the needed value at the beginning of each day (see table 1).

Concerning this idea, the proposed systems are evaluated not only as the way for reducing the unbalance between the electricity supply and the demand, especially in developing countries like Vietnam, but also as the solution for energy savings and environmental protection.

3.2. Feasibility study of the proposed systems

One-stage water/LiBr absorption refrigeration machine has been a commercial product for many years. In scale of low and medium cooling capacity, it may be produced even by small and medium enterprises in developing countries. Therefore, there is no any difficulty in terms of refrigeration unit.

The problems which attract the attention of researchers specialised in solar cooling are the solution for improving the total efficiency and the linking between the refrigeration unit and the heat source. In this case, the total efficiency means the combination of technical and economical demands in such a way so that the system efficiency may reach a value as high as possible for being accepted in practice, and the linking means the way for supplying heat to the system. Concerning about the linking, two ways of direct and indirect heating are discussed in this paper.

As mentioned in section *2.2*, there are some differences between the tested solar hot water systems and the proposed diagrams which are presented in table 2.

Table 2
Differences between the tested solar hot water systems and the proposed diagrams

System	Operation regime	Temperature
Tested solar hot water	Intermittent	Initial water temperature: 30 °C
Proposed diagrams		
-Direct heating	Continuous	Solution temperature at the collector inlet : around 73.5°C
-Indirect heating	Continuous	Water temperature at the collector inlet : higher than 96°C

The data in tables 1 and 2 show that the mean temperatures of the fluid working in proposed direct heating and indirect heating diagrams are higher than 73.5 °C and 96 °C, respectively. This means that the working temperature in these diagrams is higher than that presented in the above-shown experiments with hot water. Due to the temperature increase, the heat loss of collector increases. The calculation determines that the heat capacities supplied by flat plate collector and by tubular collector are reduced. In the case of direct heating diagram, they are around 5877.1 kJ/m^2/day and 7720.5 kJ/prototype/day, respectively. And in the case of indirect heating diagram, they are a little lower. These data are called as adjusted heat capacities and they are used for doing further calculations, especially for calculating the cooling capacity of proposed diagrams.

- Direct heating diagram: the dilute solution flows through the collector and its temperature increases eventually from the inlet to the exit of the collector.The solution temperature at the collector inlet is around 73.5°C. For reducing the cost and the heat needed to warm the solution at the beginning of each day, the collector volume containing the solution should be designed as small as possible. The daily efficiency of flat plate collector is estimated about 38.5 %. Linking these adjusted collector heat capacities and the calculated thermodynamic results presented in section *2.3*, the cooling capacities of the air conditioning system corresponding to flat plate collector and to tubular collector are 0.1418 kW/m^2 and 0.1865 kW/prototype, respectively. The main disadvantage of this diagram is the low working pressure in the collector which is about 0.09584 bar, therefore the system may be broken by the air leakage.

- Indirect heating diagram: hot water plays the role of intermediate fluid which is used to heat the solution in the generator. From table 2, it is clear that the water temperature at the collector inlet must be higher than 96°C. This means that the mean temperature of the working fluid in this diagram is higher than that of the direct heating diagram.For increasing the water temperature to the needed value and for maintaining the stable operation of the system, it is impossible to put the resistance inside the generator, but outside it. These lead to some disadvantages such as the need of expansion tank, the increase of the first cost and the reduction of collector efficiency. Due to the increase of the collector heat loss, the cooling capacity of the indirect heating diagram reduces about 6% to 8% in comparison with the direct heating diagram.The main advantages of this diagram are the mass reduction of the used solution and the high working pressure in the collector which is estimated nearly the same or a little higher than that of the surroundings.

3.3. Other alternative solutions

There are some other alternative solutions which could be applied in solar air conditioning engineering of which the solution using liquid desiccant for dehumidifying the fresh air is recently discussed much more. Studies of F.Steimle [5], S.Biel [6] and R.M.Lazzarin et al.[10] show that this alternative method could be considered as one of the promising solutions to solve the problem. Discussing about this solution in conditions of Vietnam, the following features should be concerned:

- The climate in Vietnam is quite hot and humid, the relative humidity of the fresh air is about 75 % to 90 %, or higher in raining season. In the south regions of the country, there is no winter, the mean air temperature is about 30°C-32°C, the annual variation range of fresh air temperature is normally around 26°C to 37°C.

- The heat load in conditioned spaces often comprises not only sensible heat, but also considerable latent heat.

- The conditioned spaces in Vietnam presently consist mainly of office buildings, hotels and restaurants.

These features lead to some following problems which must be considered carefully when the A/C plant with evaporative cooling and dehumidification by absorption is discussed:

- Due to the high latent heat load, the moisture content difference between the room air and the supplied air must be large. The combination of this demand and of the above presented fresh air requests a higher reduction of moisture content of the fresh air flowing through the absorber which is estimated around 15 - 18 $g_{water}/kg_{dry\ air}$. This means the absorption surface of the absorber must be increased and the absorber must be divided into some parts, in addition, the solution entering the absorber should be cooled by cooling tower for improving the efficiency of the absorption process.

- The capacity of water vapour absorption of liquid desiccant decreases when the mass of water vapour contained in liquid desiccant increases. Therefore, the parts of the absorber should be arranged in series connection on fresh air side, but in parallel connection on liquid desiccant side.

- The efficiency of the regeneration process depends not only on the temperature of the water or of the air flowing through the regenerator, but also on the moisture content of the outdoor air. Therefore, in conditions of Vietnam, because of the high moisture content of the outdoor air, the needed temperature of the water or of the air flowing through the regenerator must be higher than that in conditions of European countries.

- The A/C plant with evaporative cooling and dehumidification by absorption is one of all air systems which may be installed in large spaces such as conference rooms or theaters. In conditioned spaces like hotels, restaurants or office buildings, this system is not suitable because these spaces often need air-water systems. Therefore, the mentioned system should be divided into two separated parts: the first one is used for dehumidifying fresh air by using liquid desiccants and the second one is used for supplying cold water which cools the air in conditioned spaces by using conventional vapour-compression refrigeration machine. In this modified system, solar energy could be used for regenerating liquid desiccants returning from absorber. Calculations show that the mentioned system may save around 25 % of the needed energy.

4. CONCLUSIONS

The following conclusions can be drawn from this study:

- In conditions of Vietnam, the most suitable solution for solar-assisted air conditioning systems is one-stage water/LiBr absorption refrigeration machine.

- Depending on each practical situation, either flat plate or tubular collector is selected in indirect heating diagram. In direct heating diagram, the tubular collector should be the first selection because the flat plate collector needs a larger area of installation which leads to the longer connection piping, and this long piping may break the system due to the air leakage.

- Discussing about the heat loss of solar collector, the direct heating diagram may be considered as a more suitable way because its mean working temperature is lower than that of the indirect heating diagram.

- The proposed systems should not be applied in scale of very low or very high cooling capacity. The suitable range of cooling capacity is assumed from 10 kW to 100 kW.

- Other alternative solutions currently are not practical in terms of economic factor yet. However, the method in which a liquid desiccant is used for dehumidifying fresh air, solar energy is used for regenerating the dilute solution and indirect evaporative cooler accompanied by conventional vapour-compression refrigeration machine is used for cooling the air in conditioned spaces is evaluated as the more promising alternative one and it should be studied much more in hot and humid climate like conditions of Vietnam.

CÁC PHƯƠNG ÁN SỬ DỤNG NĂNG LƯỢNG MẶT TRỜI VÀO KỸ THUẬT ĐIỀU HÒA KHÔNG KHÍ TRONG ĐIỀU KIỆN CỦA VIỆT NAM

Lê Chí Hiệp

TÓM TẮT : Việt Nam là một trong số các quốc gia có nhiều điều kiện thuận lợi để ứng dụng năng lượng mặt trời. Trong những năm vừa qua, cùng với sự phát triển kinh tế của đất nước, các nhu cầu tiêu dùng nói chung và nhu cầu sử dụng các máy điều hòa không khí nói riêng đang gia tăng mạnh mẽ. Tuy nhiên, do sự mất cân đối giữa cung và cầu trong lãnh vực điện năng, do yêu cầu tiết kiệm năng lượng và bảo vệ môi trường, cần phải hạn chế bớt việc sử dụng các máy lạnh có máy nén hơi.

Nhằm giải quyết các mâu thuẫn này, trên cơ sở các nghiên cứu lý thuyết và thực nghiệm, bài báo sẽ trình bày và phân tích một số phương án sử dụng năng lượng mặt trời để điều hòa không khí phù hợp với điều kiện của Việt Nam.

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