

# International Journal of Innovative Research in Science, Engineering and Technology

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## Investigation on Hot Water and Refrigerating Supply System Using Solar Energy

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**ABSTRACT:** This article shows the results of the research, calculation, design and testing of a hot water and refrigerating supply system using solar energy in Vietnam. Solar energy is widely used to provide hot water in Vietnam, however, to combine hot water and cooling supply through an adsorption refrigeration system is a new problem. The author uses the knowledge of cooling adsorption techniques and solar energy to calculate the design and test the system. The results of the study can be used as reference to improve the performance of solar adsorption refrigeration systems.

**KEYWORDS:** solar energy; adsorption; methanol; activated carbon; adsorption refrigeration system

### I. INTRODUCTION

A solar hot water supply and refrigeration system is essentially a solar hot water system, which is coupled to a solar adsorption cooling system. A solar adsorption cooling system needs only heat for operation, which is supplied by the solar irradiation. Compared to compression refrigeration machines which are operated with electricity, it can be used in areas where there is no electrical energy, but strong solar radiation. The adsorption principle has hitherto been used in other fields (e.g., material separation); relatively rarely used for cooling/ air-conditioning.

The idea of using the adsorption process for refrigeration and air-conditioning was taken up between about 1970 and 1990 by Tchernev in the USA and Alefeld in Germany [1]. After that, Headley has built up in 1994 a methanol/ activated carbon adsorption refrigerator, powered by a solar collector with reflector mirror [2, 3]. The performance was low. To increase the overall efficiency and the effectiveness of the solar refrigeration system, we combine the solar water heating with adsorption refrigeration system.

### II. SOLAR HOT WATER AND REFRIGERATING SUPPLY SYSTEM

The solar hot water and refrigeration system is essentially a common arrangement, whereby a solar hot water supply combined with an absorption refrigeration.

#### 2.1 Principle of a solar hot water and refrigerating supply system

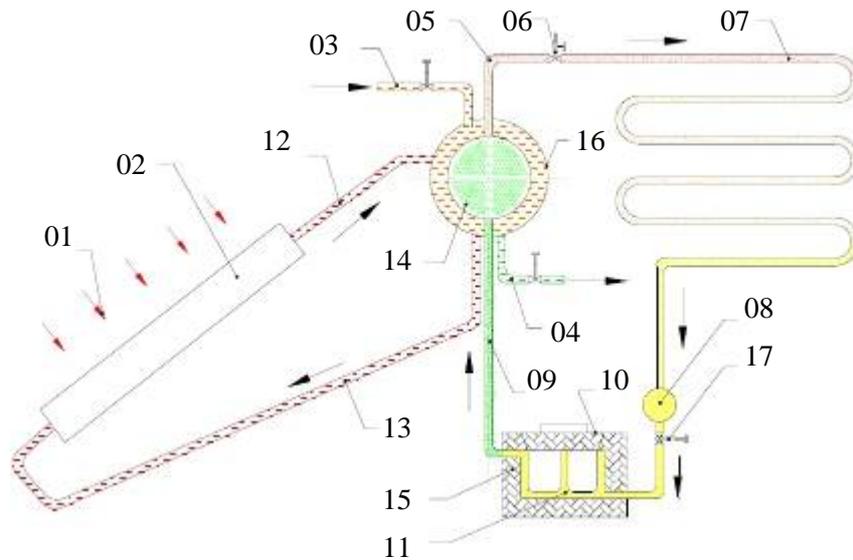
A schematic diagram of a solar hot water and cooling system is illustrated in Fig. 1. It essentially consists of: solar tube collector (2), Condenser (7), evaporator (11), cold box (10), and hot water vessel (16) with sorber (14). In the sorber, there is a heat exchanger consisting of numerous pipes and two perforated plates. Evaporator is insulated by Polyurethane foam.

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Vol. 6, Issue 10, October 2017



- |                                |  |
|--------------------------------|--|
| 01 Solar radiation             | 09 Adsorbed evaporated refrigerant inlet |
| 02 Solar Collector             | 10 Cold box                              |
| 03 Cold water inlet            | 11 Evaporator                            |
| 04 Hot water outlet            | 12 Warm water inlet                      |
| 05 Desorbed refrigerant outlet | 13 Cold water outlet                     |
| 06 Evacuating valve            | 14 Sorber (including heat exchanger)     |
| 07 Condenser                   | 15 Insulating layer                      |
| 08 Refrigerant receiver        | 16 Hot water vessel                      |
|                                | 17 Throttle valve                        |

Fig. 1 Scheme of a solar hot water and refrigeration system

## 2.2 Process diagram and functionality

To illustrate the ideal process of the entire sorption cycle, a pressure - temperature diagram with sorption isosteres is used as a parameter (Fig. 2). With the common application of  $\ln(p)$  above  $-1/T$ , as is generally known, approximate strains are obtained for vapor pressure, boiling pressure curves and isostere. The process sequence combines the vapor pressure line of the rich methanol ( $X \rightarrow \infty$ ), two isosteres ( $X = X_r$  and  $X_p$ ) and two isobars. For idealized,  $p_D = p_C$  and  $p_E = p_{Ad}$  [4, 5, 6]

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Vol. 6, Issue 10, October 2017

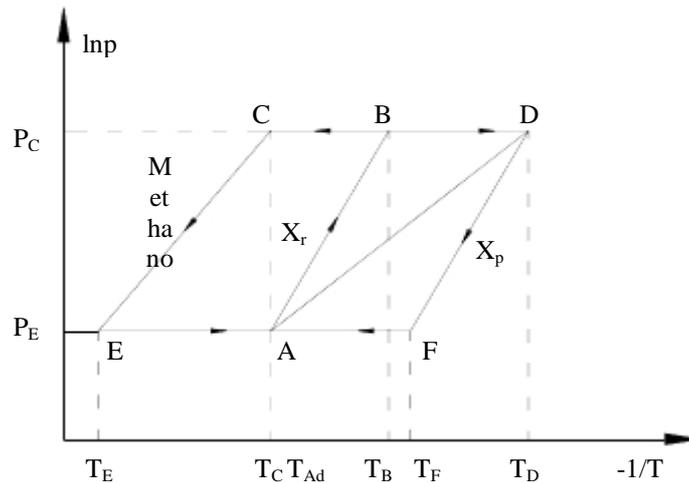


Fig. 2 Ideal process of an adsorption aggregate

In the pressure-temperature diagram in FIG. 2, A-B-D-F-A represents a combined cycle of desorption and adsorption processes. Beginning at point A, the adsorbent is at low temperature  $T_{Ad}$  and low pressure  $p_E$ . A – B presents the heating of the adsorbent with a constant concentration as the pressure increases. The progressive heating of the adsorbent from B to D causes the desorption, which is marked as a whole (C) B – D. The adsorbent condenses B – C. When the adsorbent has reached its highest possible temperature, the desorption process ceases. Now the state of the poor concentration is reached (point D). Cooling water is now added to the water vessel. The temperature of the adsorbent decreases from  $T_D$  to  $T_F$ . This causes the system pressure to decrease from  $p_C$  to  $p_E$ . When the adsorbent is further cooled from  $T_F$  to  $T_{Ad}$ , adsorption and evaporation begin. Cold is generated during this period. Methanol is adsorbed by activated carbon. During this period, heat is released to cooling water, both to reduce the temperature of the adsorbent and to lead away the heat of adsorption.

The solar hot water and refrigerating supply system operates daily in two phases.

During the day, the solar energy is collected by the collector to water in the vessel. This increases the temperature of the sorber. When the temperature of the adsorbent has risen to  $T_B$ , the desorption begins. With the continued heating of the adsorbent, the refrigerant is further desorbed until the greatest possible temperature  $T_D$  is reached. At the same time, the desorbed refrigerant in the condenser is cooled and liquefied. It flows into the collector. In this phase, the throttle valve is still closed. So, we get hot water and liquid methanol in the collector.

During the night, the hot water is drained or temporarily stored in an additional water vessel. It can also be used in the house. Cooling water is added to the vessel. This cools the sorber quickly, so that the adsorption - evaporation phase is initiated. The adsorbent temperature decreases from  $T_D$  to  $T_F$ . The pressure drops to at least  $p_E$ . After opening the throttle valve, the liquid methanol flows from the collector into the evaporator and evaporates there. During this process, the water is cooled into the cold box. Ice is produced.

### III. CALCULATION OF THE SYSTEM

The phases described above during the day and at night, i.e. the complete 24h cycle, are treated separately.

#### 3.1 Calculation of the day phase

##### 3.1.1 Accounting

The collector absorbs the solar irradiation, which warms up water. Finally, the desorption process is initiated and methanol vapour is released from the activated carbon. Therefore, the energy balance equation for the system in the day phase could be set as follows:

$$Q_H = Q_W + Q_{D,total} \tag{1}$$

where:  $Q_H$  – total heat absorbed, from the collector

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Vol. 6, Issue 10, October 2017

$Q_W$  – Heat for water heating, from  $T_{w1} = T_{ambient}$  to  $T_{w2} = T_D$   
 $Q_{D,total}$ – total desorption heat.

If the actual conditions are taken into account, the heat loss  $Q_{loss}$  is still to be applied by the heat insulation layer of the hot water vessel and the heat  $Q_m$  to be applied to the materials of pipes and vessels for heating ambient temperature to  $T_{w2}$ . Thus, the equation is:

$$Q_H = Q_W + Q_{D,total} + Q_{loss} + Q_m \quad (2)$$

The determination of the two last-mentioned heats is not complicated because the corresponding parameters of the heat-insulating and production material are known.

$$Q_m = m_m C_{pm} (T_{w2} - T_{w1}) = m_m C_{pm} (T_D - T_{ambient}) \quad (3)$$

The heat loss  $Q_{loss}$  is negligible. It can also be calculated by considering the dimensions and thermal conductivity of the insulating layer. The heat for heating the water is:

$$Q_W = m_w C_{pw} (T_{w2} - T_{w1}) = m_w C_{pw} (T_D - T_{ambient}) \quad (4)$$

The main problem is the determination of the total desorption heat. It is a challenging, complicated task to determine adsorption enthalpies. The known equations for the adsorption equilibria are not generally valid, i. e. in relation to the material combinations, as well as the pressure, temperature or concentration range, can only applicable with restrictions. In a further step, partial adsorption enthalpies can be derived from the temperature dependence of the equilibrium pressures or concentrations at constant concentration.

In the literature, only a few values can be found for the mass pairing of methanol/ activated carbon. We can't carry out our own measurements on the sorption behavior of methanol and activated carbon. Therefore, results from China [6, 7] with benzenes and activated carbon as adsorbents are used.

Value for benzene		Conversion for methanol $T_2 = 30 \text{ } ^\circ\text{C}$	
Concentration $X_B$ [kg/kg]	Pressure $p_B$ [Pa]	Concentration $X_M$ [kg/kg]	Pressure $p_M$ [Pa]
0.15	133	0.134	3198
0.20	333	0.182	4789
0.22	467	0.195	5553
0.25	1066	0.226	7993
0.26	1333	0.230	8819
0.28	2666	0.253	11700
0.30	7599	0.266	18980

Tab. 1 Compilation of values for isothermal adsorption [7]

### 3.1.2. Determination of methanol mass

The vapour methanol is liquefied by the condenser and stored in the receiver. When the pressure in the system decreases to the evaporation pressure  $p_E$ , the liquid methanol mass  $m_M$  is evaporated in the evaporator and the total cold  $Q_{cold}$  is generated. The energy balance equation for the evaporator can be set as follows:

$$Q_{cold} = Q_0 + Q_{cm} + Q_{loss,I} \quad (5)$$

Where:  $Q_0$  is the useful cold, which according to the required cold stress in the cold box can be calculated. For example, if you want to produce ice in the cold box, the refrigeration capacity can be calculated according to the following equation

$$Q_0 = m_i C_{pw} (T_{ambient} - 273) + m_i l_w + m_i C_{pi} (273 - T_0) \quad (6)$$

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Vol. 6, Issue 10, October 2017

With:  $m_i$  – Mass of water in coldbox[kg]  
 $l_w$ – specific enthalpy of fusion (specific melting) of water [kJ/kg]  
 $C_{pi}$  – specific heat capacity of ice[kJ/kgK]  
 $T_0$  – mean (medium) temperature in cold box [K]

$Q_{cm}$  is the cold to cool down the liquid refrigerant from the ambient temperature  $T_{ambient}$  to the evaporation temperature  $T_E$ . This cold is as follows

$$Q_{cm} = m_M C_{pM} (T_{ambient} - T_E) \quad (7)$$

With:  $C_{pm}$  – specific heat capacity of methanol [kJ/kgK]  
 $Q_{loss,I}$  is the cold through the walls of the cold box (through insulation layer)

$$Q_{loss,I} = \sum Q_{loss,i} = Q_{loss,S} + Q_{loss,B} + Q_{loss,C} \quad (8)$$

With  $Q_{loss,S}$ ,  $Q_{loss,B}$ ,  $Q_{loss,C}$  are the cold losses by side, bottom and cover.  
The total cold  $Q_{cold}$  can also be estimated according to the following equation

$$Q_{cold} = m_M \Delta h_E \quad (9)$$

Thereby

$\Delta h_E$  - the enthalpy difference by the evaporation process of methanol,  
 $\Delta h_E = 1120$  [kJ/kg]

According to Eqs. 6, 7, 8 and 9, the methanol mass can be determined

$$m_M = \frac{Q_0 + Q_{loss,I}}{\Delta h_E - C_{pm}(T_{ambient} - T_E)} \quad (10)$$

### 3.1.3 Determination of activated carbon mass

Using the isothermal curve for methanol, we can determine the required mass of activated carbon  $m_{AC}$ . This must be able to absorb the necessary methanol mass  $m_M$  as refrigerant under evaporator pressure  $p_E$  and at the adsorption temperature  $T_{Ad}$ .

The related pressure of the methanol is fixed with the evaporation temperature  $T_E$ . The concentration  $X$  can then be determined from the adsorption temperature  $T_{Ad}$  of the isotherm curve. The concentration  $X$  can be used to calculate the required activated carbon.

$$m_{AC} = \frac{m_M}{X} \quad (11)$$

### 3.1.4 Determination of total desorption heat

The solar energy is transferred to the hot water in the collector. The total desorption heat  $Q_{D,total}$  consists of the heating of the activated carbon  $Q_{AC}$  and the desorption heat  $Q_D$ :

$$Q_{D,total} = Q_{AC} + Q_D \quad (12)$$

It applies

$$Q_{AC} = m_{AC} C_{pAC} (T_D - T_{Ad}) \quad (13)$$

$C_{pAC} = 0.9$  kJ/kgK - specific heat capacity of activated carbon

$$Q_D = m_M C_{pM} (T_D - T_{Ad}) + h_D m_{AC} \Delta X \quad (14)$$

In which

$\Delta X$  – Concentration changes of methanol by the desorption

$$\Delta X = X_r - X_p \quad (15)$$

while:  $X_r$  – rich concentrator at  $T_{Ad}$

$X_p$  – poor concentrator at  $T_D$

The concentration at any temperature can be determined according to the Polanyi-Dininine relationship as follows [8, 6]

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Vol. 6, Issue 10, October 2017

$$X = X_0 \exp \left\{ -D \left[ \ln \left( \frac{p}{p_{M,S}} \right) \right]^2 \right\} \quad (16)$$

In which

$p_{M,S}$  – saturation pressure of the methanol

$D$  – structural constant of activated carbon. It is determined by experimentally and by the Polanyi - Dinine equation. According to Gao and Chen, [7] the activated charcoal produced from coconut has better adsorption properties than those derived from other materials. Unfortunately, this is not available in Vietnam. Therefore, three kinds of activated carbon from China, namely CHK-3, CJK-2 and ZX15 were used. The structural constants are given in Tab. 2 [6].

Activated charcoal type	Structural constant, D
CHK-3	$1.166 \times 10^{-6}$
CJK-2	$8.46 \times 10^{-7}$
ZX15	$8.9 \times 10^{-7}$

Tab. 2 Structural constants of the three activated carbon types

$C_{pM}$  – specific heat capacity of methanol  $C_{pM} = 2.6$  [kJ/kgK]

$h_D$  - desorption enthalpy, which is determined by equation (16) [8]. It depends on temperature and the pressure ratio

$$h_D = RT \ln \frac{p}{p_s} \quad (17)$$

### 3.2 Calculation of the night phase

#### 3.2.1 Energy balance in the water vessel

At night, hot water in the water vessel is replaced by cooling water to produce the adsorption process. Inlet temperature  $T_{w3}$  is normally a little below the ambient temperature. The heat from the adsorbent is transferred to the water in the tank through the heat transfer surface in the adsorber. This reduces the temperature of the active carbon from  $T_D$  to  $T_{w4}$  (cooling water temperature after the adsorption process). When the temperature in sorber reaches  $T_F$ , the adsorption begins, the total adsorption heat  $Q_{Ad,total}$  of adsorbent is delivered to cooling water by the adsorption process.

With the heat supply  $Q_{cW}$  from the adsorption process, the cooling water temperature is increased from  $T_{w3}$  to  $T_{w4}$ . The energy balance equation is:

$$Q_{cW} = Q_{Ad,total} + Q_{m,N} \quad (18)$$

With

$Q_{m,N}$  – The heat that cools down the tubing and container manufacturing material from the desorption temperature  $T_D$  to  $T_{w4}$ . For the design, the amount of cooling water must be calculated so that the temperature  $T_{w4}$  becomes as small as possible since the adsorption process is better at a lower temperature.

$$Q_{m,N} = m_m C_{pm} (T_D - T_{w4}) = m_m C_{pm} (T_D - T_{ambient}) \quad (19)$$

$Q_{Ad,total}$  – The total adsorption heat obtained can be determined by the following equation.

$$Q_{Ad,total} = Q_{AC} + Q_{Ad} \quad (20)$$

In which

$Q_{AC}$  – The heat removal for activated carbon from temperature  $T_D$  to temperature  $T_A = T_{ambient}$

$$Q_{AC} = m_{AC} C_{pAC} (T_D - T_{Ad}) = m_{AC} C_{pAC} (T_D - T_{ambient}) \quad (21)$$

$Q_{Ad}$  – The heat of adsorption, which can be determined by the following equation

$$Q_{Ad} = m_M \Delta h_{Ad} \quad (22)$$

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 6, Issue 10, October 2017

In theory, it is assumed that the adsorption process is a reversible process. Therefore, the adsorption enthalpy  $\Delta h_{Ad}$  is equal to the desorption enthalpy  $\Delta h_D$

$$\Delta h_{Ad} = \Delta h_D = 1120 [\text{kJ/kg}] \quad (23)$$

Thus, the heat balance equation is:

$$m_{cW} C_{pW} (T_{w4} - T_{w3}) = m_M \Delta h_{Ad} + m_m C_{pm} (T_D - T_{w4}) \quad (24)$$

With  $m_{cW}$  - the necessary amount of cooling water required for the adsorption process is consumed, so that the heat supply in the process removes.

### 3.2.2 Heat capacity ratio of the adsorption aggregate and the efficiency of the system

Based on the refrigerating capacity, the Coefficient of Performance of adsorption aggregates can be determined by the following equation:

$$\text{COP} = \frac{Q_0}{Q_D} = \frac{Q_{\text{cold}} - Q_{\text{cm}}}{Q_D} \quad (25)$$

### 3.3 Calculation of the other components in the system

#### 3.3.1 Condenser

The heat removal in the condenser ensures the cooling of the superheated methane vapour, the liquefaction and a certain subcooling.

$$Q_C = m_M r_M + m_M C_{pM} (T_D - T_C) \quad (26)$$

Where  $r_M$  - specific condensation enthalpy [kJ/kg]

The condenser is made in practice from copper tubes. It works with air as cooling.

Determination of the heat transfer coefficients  $k_C$  of the condenser

From experiments:  $k_C = 5 \dots 10$  [W/m<sup>2</sup>K] [9] or

$$\text{According to equation: } Q_C = k_C A_C (T_C - T_{\text{ambient}}) \quad (27)$$

$A_C$  - total heat exchange surface of condenser [m<sup>2</sup>]

And vice versa we can also calculate  $A_C$  if we have the condensation heat

$$A_C = \frac{Q_C}{k_C (T_C - T_{\text{ambient}})} \quad (28)$$

#### 3.3.2 Evaporator

Evaporator is made of stainless steel. The cold  $Q_0$  through the evaporator can be determined according to the following equation:

$$Q_0 = k_E A_E (T_0 - T_E) \quad (29)$$

With  $A_E$  - total heat exchange surface of the evaporator [m<sup>2</sup>]

$K_V$  - heat transfer coefficient of the evaporator [W/m<sup>2</sup>K]

$T_0$  - medium temperature in cold box [K]

$T_V$  - evaporator temperature of methanol [K]

Heat transfer coefficients can be determined by conductor heat and convection.

#### 3.3.3 Collector

The temperature of the hot water in the vessel should be from 85 to 95°C to perform safely the desorption process. Therefore, a tube collector should be used. The experiments were mostly carried out with natural circulation.

## IV. PRODUCTION AND CONSTRUCTION OF SYSTEM

The experimental system of a solar hot water and refrigeration supply was built based on the principle circuit diagram (Fig. 1). All components of the system were made and assembled in our workshop at The University of Danang.

The system has been designed and manufactured with two modules, a tube collector and an adsorption refrigeration unit with water vessel to make it easier and safer to transport. The two modules can be connected quickly and easily.

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Vol. 6, Issue 10, October 2017

In order to be able to test the adsorption refrigeration unit under laboratory conditions, an electric heating system was installed in the water vessel. Nevertheless, the adsorption refrigeration unit works better when it is connected to a tube collector. Since the sorption processes are slow and the system still has a circulation of the water, the heat transfer between adsorbent and hot water will be better.

### 4.1 Water vessel with Sorber

Water containers and sorbers are made of stainless steel. The most important part of the adsorption refrigeration unit is the sorber, which is located in the water vessel, consisting of a total of 172 stainless steel pipes with a diameter of 13 mm and two tube sheets (Fig. 3)

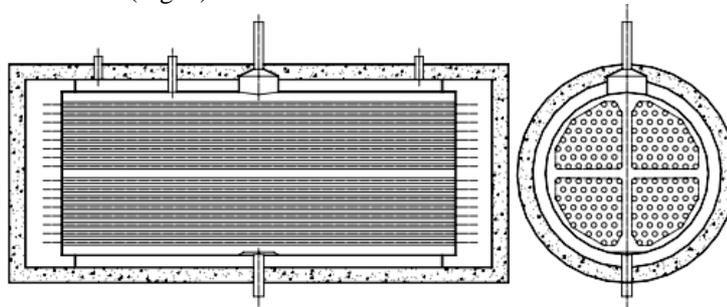


Fig. 3 Structure of the water vessel with sorber

### 4.2 Assembly

The condenser consists of vertical copper tubes with an outer diameter of 13 mm. During the desorption phase, methane vapours flow into the condenser from above and release heat into the air. Liquid is formed. This liquid methanol enters the collector by gravitational force.

Evaporator and receiver consist of thin stainless-steel plates and have been welded in argon ambient.

When designing the evaporator and receiver, it should be noted that the total volume of liquid methanol is received. In our test system, 5 liters of methanol were filled.

After production, all components of the adsorption refrigeration aggregate were assembled (Fig. 4)

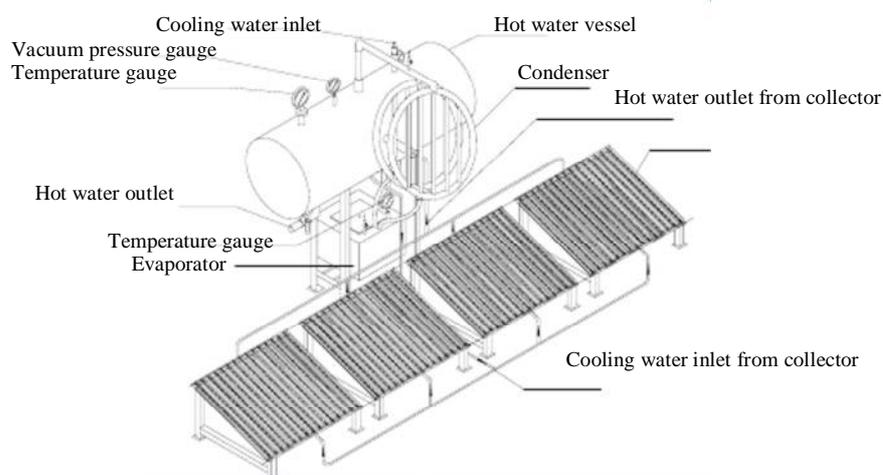


Fig. 4 Construction of a solar hot water and refrigeration supply system

Although the assembly of the experimental system is not complicated, it should be noted that the system operates under vacuum pressure. Therefore, all connections between the parts must be tight. This is very important as the system will not reach low temperatures. If there is any leak, the pressure will slowly increase as a result of external air intake.

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 6, Issue 10, October 2017

In the experiment, the desorption process of activated carbon is initiated at 9:00 am in summer and ceases at around 4:30 pm. Then the adsorption process starts from 5.30 pm until 3.00 am next day.

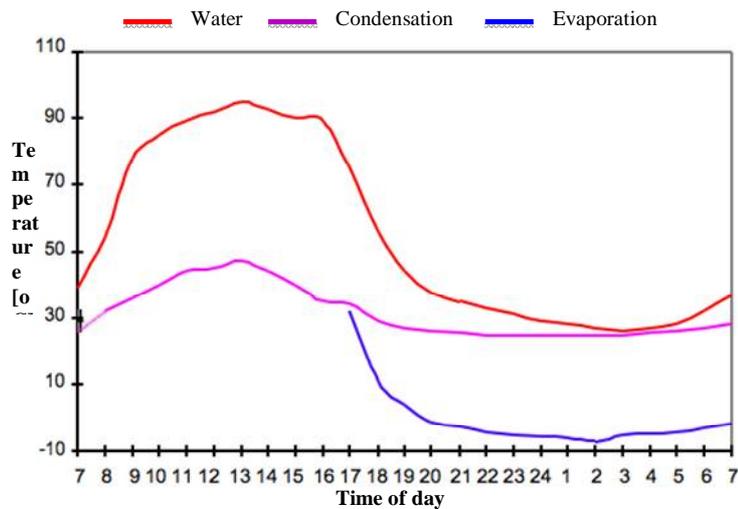


Fig. 5 Temperature curves in experimental system

Fig. 5 shows the experimentally determined temporal temperature curves of hot water, condensation and evaporation. It can be seen that the hot water temperature can reach a maximum value of about 95°C. By the value of the evaporation temperature, it should be noted that the corresponding temperature sensor was placed on the inside wall of the cold box. With this arrangement, minimum temperatures around -10°C are measured.



Fig. 6 Lowest temperature achieved

The condensation temperature reaches the maximum approximately 47°C. at about 1pm and then drops towards the ambient temperature, with the desorption of the activated carbon ceases at about 4.30 pm. The temperature remains at ambient level during the adsorption phase at night.

## V. CONCLUSIONS

This article explained the methods, relationships and balance sheets to calculate and apply a solar hot water and refrigerating supply system. The task of designing an adsorption aggregate is difficult because the adsorption is dependent on many conditions such as pressure, temperature, properties of the adsorbent and of the adsorbate and as well as on their interactions. In practice, safety margins should be considered in order to achieve the required hot water and cooling supply in the case of the existing simplifications and uncertainties in the calculations.

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Vol. 6, Issue 10, October 2017

The production as well as experimental and theoretical investigations of the solar hot water and adsorption refrigeration system with activated carbon and methanol as a medium pair are treated.

Since the refrigeration capacity of the system depends mainly on the collector area, the amount of water and the amount of adsorbent, the investigation has been made to improve the system performance by optimizing the mixtures of its components.

Activated carbon and methanol are well suited for operation under the given conditions. The respective amounts have been calculated and are to be carefully adjusted. The density of the sorption aggregate is important because of the prevailing vacuum pressure.

The use of a solar hot water and refrigeration supply system is advantageous and favorable as it does not require conventional energy supply nor moving parts. This system could be useful in tropical regions, where there is plenty of sunshine, especially in places which do not have any electrical power supply.

## REFERENCES

- [1] D. I. Tchernev, "The use of zeolites for solar cooling", Proc. of the Int. Conf. on Zeolites, Vol. 5, pp. 788 – 94, 1980
- [2] Ph. Grenier, J. J. Guilleminot, F. Meunier, M. Pons, "Solar powered solid adsorption cold store", J. of Sol. Energy Eng., Vol. 110, 1988
- [3] Ph. Grenier, M. Pons, A. Diby, "Modelization of a solar refrigerator working with a solid adsorbent", Proceedings of the 9th Biennial Congress of the International Solar Energy Society (Intersol), Montreal, June 1985
- [4] S. Eichengrün, "Theoretische und experimentelle Untersuchung des dynamischen Verhaltens von periodisch arbeitenden Sorptionskälteaggregaten", Münschen, VDI Verlag, 1994, ISBN 3-18-307719-1, S. 4 – 76
- [5] A. Gassel, "Kraft- Wärme- Kälte- Kopplung und solare Klimatisierung, Habilitationsschrift", 2004, Seite 1 – 37
- [6] K.H. Yeung, K. Sumathy, "Thermodynamic analysis and optimization of a combined adsorption heating and cooling system", Int. J. Energy Res., No. 27, pp. 1299 – 1315, 2003
- [7] S. Y. Gao, W. Chen, "Basic and Application of Activated carbon", The Chinese Forestry Publishing House, 1984
- [8] M. M. Dubinin, "Microporous structures of carbonaceous adsorbents", Theorie der Adsorption an Zeolithen, AdW der DDR, 1981
- [9] Đức Lợi, Nguyễn, "Hướng dẫn thiết kế hệ thống Lạnh", Vietnam, Science and Technology publishing, 2003, pp. 213