# Investigation and performance analysis of hybrid solar powered water heater and adsorption refrigeration system.

**A Synopsis of the Ph. D. Thesis**

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# GUJARAT TECHNOLOGICAL UNIVERSITY
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*INVESTIGATION AND PERFORMANCE ANALYSIS OF HYBRID SOLAR POWERED WATER HEATER AND ADSORPTION REFRIGERATION SYSTEM.*

**Abstract:**

It is estimated that more than 25% of the power consumed in water heating and cooling technologies throughout the world. Both technologies affect ecology in direct as well indirect ways. Indian government already installed solar collector for different applications (MNRE installed - 7 million square meters area solar thermal collector). Solar water heaters are idle during summer. By utilizing the same infrastructure, one can produce cooling during summer. Solar cooling technology is a boom for non-electric grid area where the spoilage of food, medicine, and milk occurs. In solar cooling technology, Solar powered adsorption refrigeration system has potential to compete with other non-conventional cooling technology i.e. Absorption, PV based, Waste heat driven and Biogas cooling technology.  Solar powered adsorption refrigeration system utilizes the total solar radiation (UV, Visible and Infrared) for producing refrigeration effect. Adsorption Refrigerator works on physio sorption or chemisorption principle. In physio sorption, weak wander walls bonds can easily break by low generation temperature. A cooling effect in physio sorption-based refrigerator can produce by adsorption and desorption of adsorbate (refrigerant) over adsorbent.

In present work, the adsorption capacity of a different working pair has been measured for selecting the best pair for the water chiller. For Adsorption capacity, the test set-up has been developed and experiments were performed in the range of temperature 15-80°C with isobaric adsorption. From series of experiments, it has been found that the maximum adsorption capacity is 0.44 kg/kg by maintaining packing density of bed as 110 kg/m3. The effect of generator temperature on adsorption capacity has been also studied in this investigation.

There are two types (intermittent and continuous) cycles available in adsorption refrigerator. The Intermittent and Continuous solar powered Adsorption water chiller have their own advantages and limitations. In this research work semi-continuous solar powered Adsorption water chiller has been developed for cooling of 10 kg water in 3 hours with a temperature drop of 10° C. The design of the main component includes adsorber bed, condenser, an expansion device and evaporator of adsorption water. For experiment purpose, the electrical heater is used in a water tank to simulate

solar powered water heater. This arrangement gives controlled temperature and flexibility throughout the experimentation schedule. With 65 °C generator temperature, 25 °C condenser water temperature, and 30°C cold water temperature, the highest value of specific cooling power (SCP-75.4 W/kg) and COP (0.45) have been achieved. The mass of activated carbon fiber (ACF) is 450 gram, which reduces the size of adsorber bed and charged methanol is 650 ml, which reduces the size of an evaporator, condenser, and tubing. Hence with the small size refrigeration system, effective cooling is produced by solar energy through ETC collector. By series of experiment, an appropriate working environment has been suggested for better performance.

**Introduction**

Adsorption Refrigeration system works on physio sorption principle where in adsorbet vapors (Refrigerant) accumulates over the surface of the adsorbent. Various working pairs are available for adsorption refrigerator includes silica gel-water, zeolite-water, activate carbon-ammonia, barium chloride-ammonia etc. With available heat source, cooling requirement, and available space, one may choose an appropriate working pair. The working pair has various properties like desorption temperature, working pressure, and adsorption capacity.

Due to the nature of solar energy, an intermittent system has been developed by the researcher for getting better synchronization between refrigerator and availability of solar energy. This will not satisfy the cooling requirement like food preservation, vaccine storage, space cooling and water chilling which needs lower cycle time. The continuous adsorption system requires double or multi adsorber bed, pumps and better refrigerating & hydraulic circuit design which ultimately add complexity & overall cost to the system.

In the chiller, Adsorption process accelerates by cold temperature of bed (60 – 90 °C). The refrigeration effect is produced by cyclic heating & cooling of Adsorber bed by hot & cold water. The solar powered Adsorption Refrigeration system consists of the Water Tank (Hot/Cold), Adsorber Bed, Condenser, an Expansion device, and Evaporator. During Experiment hot water is simulated by an electric heater. By keeping separate hot water Tank and cold water tank (Tap water), adsorber bed to gets heating and cooling for the process. The line diagram of solar adsorption chiller as shown in Fig. 1.

_**Heating & Desorption Cycle:**_ Initially Adsorber bed is saturated with refrigerant (Methanol) i.e. Methanol completely adsorbed in ACF. By supplying hot water from hot water tank to the bed, desorption of methanol begins, and methanol is moving towards condenser. In Condenser, it will condense and transfers to an evaporator.
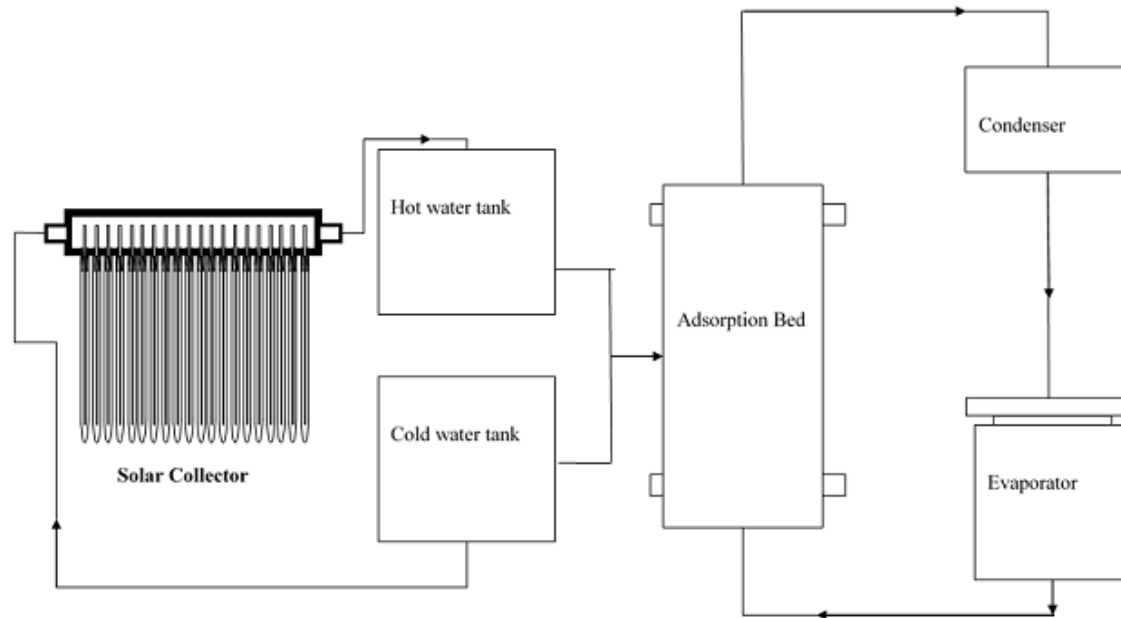


Fig.1. Line diagram of solar adsorption chiller

_**Cooling & Adsorption Cycle:**_ Now the maximum amount of methanol is desorbed from the bed. In the second phase, Cold Water (25°C) is supplied to bed and the bed is ready for adsorption of methanol. ACF bed adsorbs methanol from the evaporator. During Adsorption, Methanol in the evaporator is extracting heat from surrounding (Cooling Effect). By cyclic supplying hot and cold water to the ACF bed, refrigeration will produce.

**Brief description on the state of the art of the research topic**

Intermittent adsorption chiller have 24 hours of cycle time and in a continuous cycle, have 5 – 30 minutes for cooling. In this research work, the semi-continuous cycle was developed and desire cooling effect was produced. The state of art of this works is mentioned in Table 1.

Table 1.

| Parameter/ Author | A. Boubakri | L. R. Rodrı et.al. | H. Z. Hassan | M. Pons | R. Suleiman et.al. | R. Z. Wang et.al. | E.E. Anyanwu |
|---|---|---|---|---|---|---|---|
| **Product Load** | 5.2 kg of Ice/day | 2.2 MJ/ sqm. Per day | 12.15 MJ per cycle | 30kg of Ice/day | 4814.83 KJ | 10kg of Ice/day | 3 kg of Ice/day |
| **Cooling Effect ( KJ)** | 2392 | 2200 | 12150 | 13800 | 4814.83 | 4600 | 1380 |
| **Cooling Effect ( W)** | 27.68 | 25.46 | 143.75 | 159.72 | 55.73 | 53.24 | 15.97 |
| **Generation Temp.($\bullet$ C)** | 95 | 120 | 120 | 100-110 | 80 | 98 | 100 |
| **Adsorption Temp. ($\bullet$ C)** | 22 | 18 | 30 | 25 | 25 | 20 | 20 |
| **Cycle Time ( hour)** | 24 | 24 | 24 | 24 | - | 24 | 20 |
| **Condenser Temp. ($\bullet$ C)** | 20 | - | 35 | 25-40 | 25 | 30 | 35 |
| **Evaporator Temp. ($\bullet$ C)** | -10 | 0.7 | -5 | -3 | 0 | -2 | -10 |
| **COP** | 0.14 | 0.086 | 0.616 | 0.12 | 0.608 | 0.067 | 0.015 |
| **SCP ( W/kg)** | 1.384 | 3.53 | 3.19 | 1.22 | 2.13 | 1.9 | 1.9 |
| **Mass of AC (kg)** | 20 | 7.2 | 45 | 130 | 26.07 | 28 | 8.4 |
| **Mass of Methanol (kg)** | - | 2.2 | 10.79 | - | 8.1 | 8 | - |
| **Collector** | FPC – 1 sqm. | CPC - 0.55 Aperture Area | - | FPC – 6 sqm | FPC – 2 sqm | Heat pipe ETC – 2 sqm | FPC – 1.2 sqm |

From above review table, it has been observed that the overall cycle time is in terms of hours (20-24 hours), Generator temperature ranges between 80- 120 °C, mass of adsorbent is from few kgs to hundred's kgs and a poor value of SCP. These parameters i.e. large cycle time, higher generator temperature, a large mass of adsorbent and poor SCP restrict the performance of the system.

**Definition of the Problem**

*"Hybridizing of solar water heater with adsorption refrigerator can satisfy the cooling requirement of the water chiller."*

**Objective and Scope of work**

From the literature, it is found that intermittent cycle solar adsorption refrigerator have large cycle time, more adsorbent mass, poor SCP and lower COP. The continuous cycle needs special attention in term of multi bed, hydraulic circuit and pumps. So made optimization between intermittent and continuous cycle, Semi-continuous cycle is proposed with following objectives.

**Objectives:**

- To study and investigate the best working (adsorbent- refrigerant) pair for adsorption water chiller system through adsorption capacity measurement.
- To design and develop semi-continuous Adsorption water chiller and to carry out experimentation for investigating best environment.
- To identify the range of hot water (generator) temperature for deciding type of collectors through parametric analysis on Adsorption water chiller.
- To investigate the effect of generator (hot water) temperature on COP and SCP of Adsorption water chiller through series of an experiment.
- To identify best working environment ( system pressure, hot/cold water temperature, time of hot/cold water supply and condenser water temperature) for better performance of system through series of experiment at  the end of the fifth year with ACF-Methanol based chiller

**Scope of work**

- ACF-Methanol as a working pair
- Temperature drop of 10° C in 10 kg water in  180 minutes through Semi-continuous system
- Design and develop  shell & tube type adsorber bed, immersed coil evaporator, and water cooled condenser
- Simulation of a solar water heater by hot water tank with an electric heater.

**Original contribution by the thesis.**

- Identification of research problem after literature survey is reflected in the review paper published in SESI Journal.

- Development of Adsorption capacity measurement set up which can measure adsorption capacity of a different working pair used in adsorption refrigerator. This work is reflected in the research paper published in Ambient Energy, A Taylor Francis Journal.

- Design and develop semi-continuous adsorption refrigeration system for water chiller with ACF-Methanol as working pair and low generator temperature (65 °) which can be easily achieved by Evacuated tube collector. This work is reflected in research paper communicated in Frontier in Mechanical Engineering, A Springer Journal.

**Methodology of Research, Results / Comparisons**

The present research work comprises of two parts i.e. Adsorption capacity measurement and Development of semi-continuous adsorption chiller.

- Adsorption capacity is the ratio of a mass of refrigerant adsorbed per unit mass of adsorbent. In this research work, the adsorption capacity of methanol on Indian ACF (Environ make) have been measured considering the isobaric adsorption. In Isobaric adsorption, the bed temperature decreases stepwise but need to control the water bath temperature so the refrigerant pressure remains constant. Adsorption experiments were carried out at constant evaporator temperature, and the adsorbent temperature was varied over a range of 15 to 80 ° C. Fig. 2 shows experimental setup, which comprises of an adsorber bed, a cylindrical transparent fiber evaporator, and water bath. Fig.3 shows photographs of Experimental set up of Adsorption Capacity.

  Following results have been obtained for a different working pair.

  - ACF-Methanol:  **0.434 kg/kg**

  - ACF-Ethanol:     0.282 kg/kg
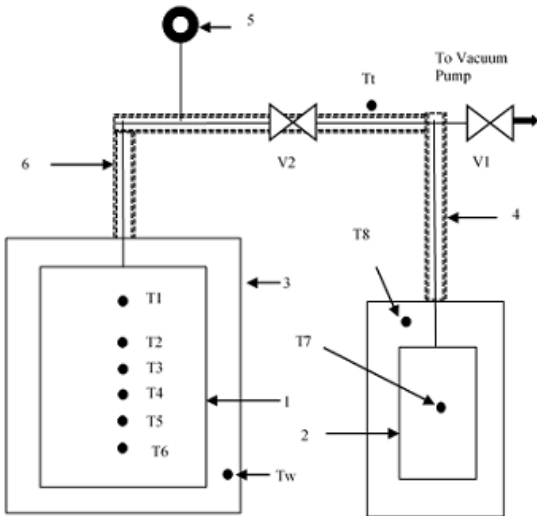
  - AC Pallet- Ethanol : 0.225 kg / kg

Fig. 2. Schematic diagram of the experimental setup
( 1:Adsorber;2:Evaporator;3:Water Bath;4:Connecting tube;5:Pressure Gauge;6: Tap Heater;T: Thermocouple; V1:Methanol Charging Valve; V2: Adsorber-Evaporator Connecting Valve)
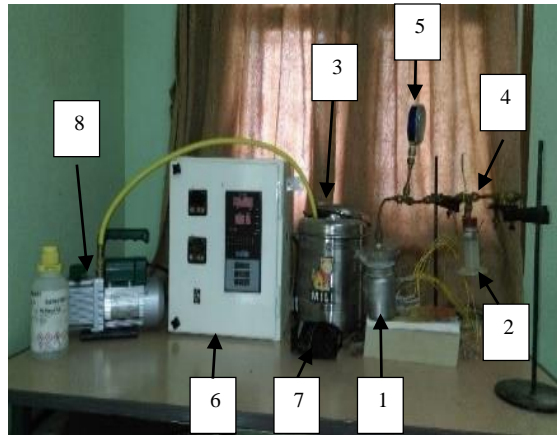


Fig.3. Photographs of experimental set up1:adsorber;2:evaporator;3:water bath;4:connecting tubes;5:pressure gauge;6:digital temperature scanner;7:ACF;8:vacuum pump

- The ACF-Methanol based semi-continuous adsorption chiller has been designed and developed by considering the input factor as Hot water temperature, Cold water temperature, Condenser water temperature and Frequency (ratio of time of hot water to cold water supply) for getting a response in terms of COP and SCP. With the physio sorption phenomenon and requirement of cooling, the design of a system is performed. The adsorption chiller is designed for producing water temperature at 8-10 ° C in three hours. The cycle time for this complete process is 180 minutes so it works as a semi-continuous system. The mass of refrigerant is obtained by cooling effect and adsorption capacity. The obtained refrigerant mass decides the overall size of a system. This system can easily be coupled with the solar water heater to give dual advantages of hot water and cooling effect. The system is designed in a way that is efficient, economical, compact and eases in fabrication with readily available resources. The overall system is designed and developed for better cooling effect and to identify the best combination of a parameter for efficient performance. The solar powered adsorption refrigeration system consists of a Hot water tank, Cold water tank, Adsorption bed, Condenser, and Evaporator. The photograph of semi-continuous solar powered adsorption chiller is shown in Fig.4. This system consists of a hot water tank with the temperature controller to simulate solar water heater. With this

arrangement, there is a convenience for experimentation at any time and at any location for simulating conditions.

- To identify best working environment of semi-continuous solar power adsorption water chiller, series of an experiment performed by varying different parameters like hot water temperature, cold water temperature, a flow of water, condenser temperature, time of supply (hot water and cold water) etc. During experiments, drop in temperature of water available in the evaporator is observed as a cooling effect. The important performance parameters SCP and COP are obtained by cooling effect and electric input to the water heater. It is observed a fluctuation in system pressure due to cyclic heating and cooling of bed by hot & cold water. After heating cycle, the system needs cool down time for next adsorption cycle. By performing parametric analysis, it is found that best COP and SCP can be achieved by low generation temperature ( 60 -80 ° C).

Following are the outcomes from the observations and results

- With 65 °C, generator temperature, 30°C cold water temperature and25 °C, condenser water temperature, the higher value of COP and SCP can be achieved.

- The mass of ACF is 450 gram, which reduces the size of adsorber bed and charged methanol is 650 ml, which reduces the size of the evaporator, condenser, and tubing. Hence with the small size refrigeration system, effective cooling is produced by solar energy through ETC collector.

- The difficulties found during development and experimentation are mounting of ACF on copper tubes, vacuum maintenance, charging of methanol, maintain the hot/cold water flow, cycle time optimization, environmental effect, response of measuring instruments and periodic observation.

- By providing a higher capacity pump, a system can operate at a higher flow rate of hot/cold water which ultimately improve the performance.
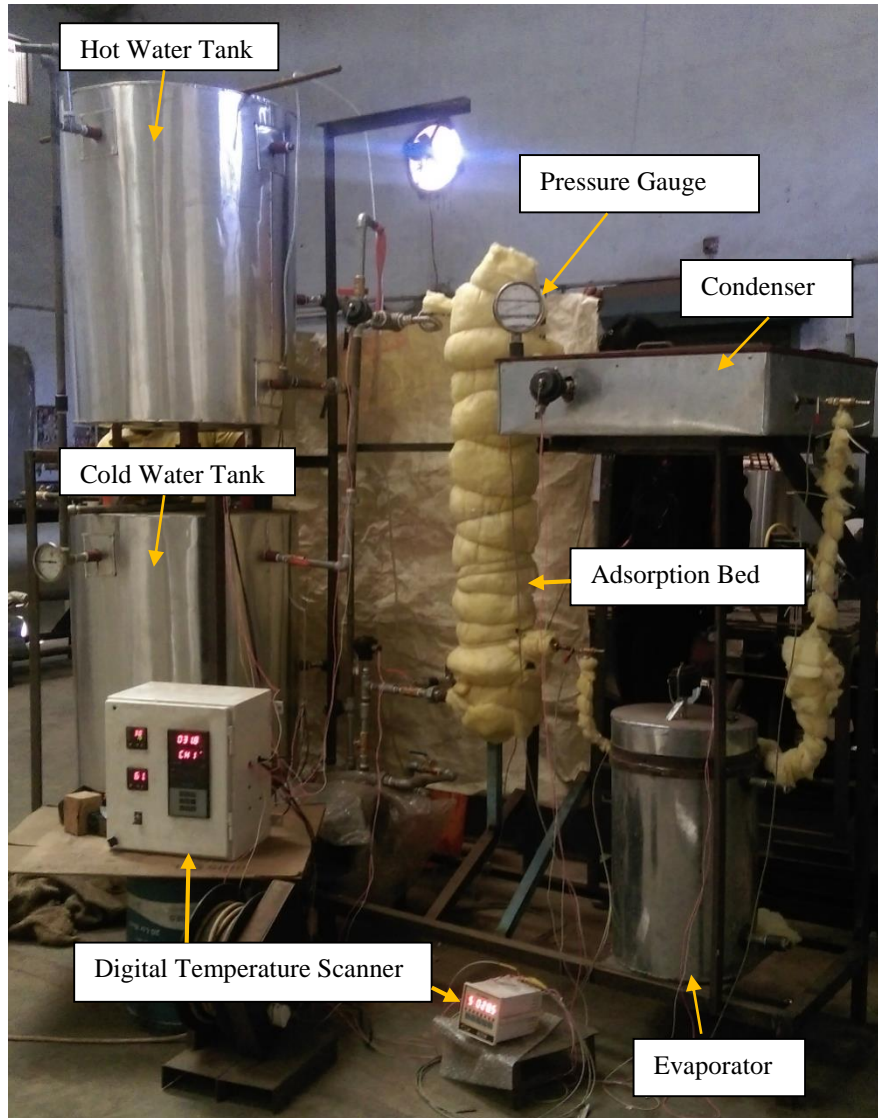
Fig. 4. Photograph of Adsorption Chiller

- By providing data logger and automatic switch for switching cycle and flow, helps for better cooling effect is achieved in short time.

- Overall cycle time can be reduced by higher generator temperature and high mass flow rate of hot/cold water.

- For better performance, keep condenser and evaporator water flowing rather than steady or store.

- The highest COP is 0.45 and SCP is 75.4 W/kg.

**Achievements with respect to objectives**

| Objectives | Achievements |
|---|---|
| To study and investigate the best working (adsorbent- refrigerant) pair for adsorption water chiller system. An experimental set up has been fabricated and operated for the adsorption capacity measurement. | An experimental set up has been fabricated and operated for the adsorption capacity measurement. ACF-Methanol has adsorption capacity of 0.44 kg/kg. |
| To design and develop semi-continuous Adsorption water chiller and to carry out experimentation for investigating best environment. | Developed semi-continuous Adsorption chiller for reducing temperature of 10°C for 10 kg of water in 3 hours |
| To identify the range of hot water (generator) temperature for deciding type of collectors through parametric analysis on Adsorption water chiller. | Hot water available at 60- 85°C can produce cooling effect and which can be achieved by Flat plate or Evacuated tube type solar water heater |
| To investigate the effect of generator (hot water) temperature on COP and SCP of Adsorption water chiller through series of an experiment. | Generator temperature of 60-70 °C can give better performance in ACF-Methanol based semi-continuous adsorption chiller. |
| To identify best working environment (system pressure, hot/cold water temperature, time of hot/cold water supply and condenser water temperature) for better performance of system through series of experiment at the end of the fifth year with ACF-Methanol based chiller | For ACF-Methanol based semi-continuous adsorption chiller, system pressure- 244 to 485 mm of Hg, hot water temperature-63°C, cold water temperature-33°C and condenser water temperature-27°C is the best working environment. |

**Conclusion**

This system is designed to produce 10 to 15° C temperature drop in water which can be useful for food preservation. By maintaining hot water and cold water flow of 360 kg/hour at 27° C condenser temperature, achieved temperature drop in evaporator water is 10.9 ° C. The system pressure varies between 244 mm of Hg. (33 kPa) to 485 mm of Hg. (65 kPa) for desorption and adsorption process during experimentation. The time taken for 457 kJ cooling is 4 hours which can be reduced by increasing flow rate of hot and cold water. By keeping electronic control, the frequency of hot water to the cold water supply can be managed well which provides better COP. ACF-Methanol based semi-continuous system operate by low generator temperature which can easily be achieved by FPC/ETC based solar water heater. The overall cycle time is found comparative less (4 hours vs 24 hours) with reference to intermittent cycle. By lower mass of ACF (0.5 kg), this system produces higher COP (0.45) and SCP (75.4 W/kg). From achieved results, it is concluded that hybridizing of solar water heater with adsorption refrigerator can satisfy water chilling as well as food preservation requirement.

**PUBLICATIONS DETAILS**

1. Bhargav HA, Ramani BM, HYBRID SOLAR WATER HEATING AND ADSORPTION REFRIGERATION TECHNOLOGIES - A REVIEW, Published in the SESI Journal, June-2016, Vol-2

2. Bhargav HA, Ramani BM, Reddy VS. EXPERIMENTAL INVESTIGATION ON ADSORPTION CAPACITY OF ACF-METHANOL PAIRS FOR COOLING APPLICATION, Published in April-17, Ambient Energy,  Taylor Francis Journal

3. Bhargav HA, Ramani BM, Reddy VS., Lai FC, DEVELOPMENT OF SEMI-CONTINUOUS SOLAR POWERED ADSORPTION WATER CHILLER FOR FOOD PRESERVATION, Communicated in Frontier in Mechanical Engineering, Springer Journal

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