DESIGN AND FABRICATION OF PORTABLE REFRIGERATION SYSTEM USING VACUUM PUMP AND ZEOLITE

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Abstract

All around the world conservation of energy is a growing concern which has prompted the researchers to find feasible solutions. The increasing costs of fossils fuel and the refinement of ecological issues endorse numerous imminent alternatives to warm controlled adsorption cooling. The countries which are undeveloped or developing are still using Chlorofluorocarbons (CFCs) as refrigerants which leads to ozone depletion because of the presence of chlorine in CFCs. This study is aimed to design an alternative environment friendly refrigeration system using zeolite as a refrigerant which can replace CFCs. It is portable and could run without or with least energy.

1. INTRODUCTION

The process of cooling a body below ambient temperature and maintaining that is known as refrigeration. It is a process of cooling a space or substance below ambient temperature. It can be achieved in many ways. We can see it in the form of vapour compression refrigeration systems such as common household refrigerator. Apart from this, it has numerous applications such as in cryogenics, paper mills, textile industry and Dairy industry to name a few. One of the most noteworthy usage of refrigeration has been the protection of transient things by taking care of them at low temperatures. But it also consumes large quantity of power for its efficient operation. In ancient times, refrigeration was accomplished by common methods, for example, the utilization of ice or evaporative cooling. Researchers have devised a new refrigeration system which produces cooling by consuming no or very less power. The principle used is adsorption.

Maggio et al. (2006) demonstrated a mathematical model of an adsorption cooling machine which consists of a consolidated diuble adsorbent bed with internal heat recovery which increases the COP. To further improve the results, thickness of adsorbent should be kept 2 to 3 mm. Saha et al (2003) analysed dual mode silica gel liquid adsorption chillers model in various temperature ranges. In the range of 50°C and 55 °C, best results were obtained.

Kong et al. (2005) did the experimental analysis of gas engine-driven micro-combined cooling-heating control systems efficiency. Refrigeration temperature of 13°C was attained with a COP of 0.3. This can provide for 12 KW of electricity and 28 kW of heat load and 9 kW of cooling power. The portable zeolite vacuum refrigarator project is the development and the introduction of a new type of technology for the refrigeration systems based on the innovative zeolite/ (vacuum) principle. This modern and eco-friendly cooling system has the benefit of using natural elements (no environmentally harmful refrigeration gas is required). In fact, due to their independence from the power grid, the new refrigerators offer increased mobility. This new refrigeration system developed generates cooling capacity by using two natural elements (instead of cooling gases): Zeolite and methanol. Zeolite is a mineral that has the property to adsorb vacuum vapour while releasing heat at the same time. It represents an interesting element to store energy and to transform it in heating or cooling agents. Due to its capacity of working independently from the power source for a specific period of time, the new technology suits mostly for the transport of food and other perishables. It could also be used in the medical field (transport of vaccines, storage of medicines etc.). This refrigeration system can be used in those areas where electricity is not available very frequently. In those areas it can be used for food storage or transportation of food and vegetables. The energy stored in the zeolite elements is used to keep the desired temperature in the refrigerators during the transport time. Due to increased energy consumption, compared with the conventional refrigerators during the regeneration phased, the Zeolite systems are economically feasible under specific circumstances. Moreover using methanol as a refrigerant makes it environmental friendly because of no presence of chlorine in it.The objectives of this project are:

- To make a refrigeration system which is portable and at the same time uses less power (for vacuum pump).
- A cooling system, that does not use CFC refrigerant, and thus protect ozone layers over the atmosphere.
- To use less number of mechanical components and reduce dependency from power grid for a specific period of time.
- To find out the most suitable and promising Adsorbent – adsorbate pair to be used in the refrigeration system with high adsorption capacity

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2. RESEARCH, DESIGN METHODOLOGY AND THEORY

This section deals with the selection of material for the designing of evaporator and cooling unit. It also deals with research and the selection of proper adsorbent – adsorbate pair based on their properties.

2.1 Design of Evaporator

A device which is utilized to convert liquid into gas is known as evaporator. The refrigerant present in liquid form is evaporated by absorbing the latent heat from the cooling unit. The refrigerant absorbs the latent heat of vaporization from the medium which needs to be cooled.

2.1.1 Size of evaporator

Evaporator is the rectangular box made of copper by performing the mechanical operations on a copper sheet. Dimensions of the evaporator box are:

Length of thebox = 30 cm

Width of the box = 30cm

Height of the box = 10cm

Area of the box = 3000 square cm

Thickness of the wall is 1.63mm

Other factors to be considered in designing an evaporator is its material, velocity of refrigerant, thickness of evaporator wall etc.The material to be used for the construction of evaporator wall should be highly conductive. Here we have selected copper which is suitable to be used with all type of refrigerants except ammonia. The velocity of refrigerant selected should also be optimum as the increased velocity of refrigerant though increases heat transfer but also cause a greater drop in pressure.

2.2 Design of cooling unit

Cooling unit is an air tight box which is to be cooled. The materials to be cooled are kept in this space. The box is insulated properly from all the sides. The copper box (evaporator) is kept in the box.

2.2.1 Material of cooling unit

Cooling unit is insulated from all sides. It is made up of metal sheet by performing different metal sheet operations. It is made air tight so that no heat transfer takes place as it is the space which is being cooled.

2.2.2 Size of cooling unit

Dimensions of the cooling units are given as:

Height of the cooling unit = 25cm

Length of the cooling unit = 35 cm

Width of the cooling unit = 35 cm

2.3 Selection of adsorbent – adsorbate pair

Along with the system design, collector choice and other arrangements, the selection of adsorbent-adsorbate pair also plays an important role for the smooth run of systems.

Characteristics of good adsorbent

- Good adsorption tendency
- Good compatibility with refrigerant
- Good thermal conductivity
- Inexpensive and easily available

Characteristics of a good refrigerant(adsorbate)

- High Latent heat capacity
- Non-toxic, non inflammable
- Less viscosity
- Less specific heat
- Good thermal stability

We are using adsorption phenomena to produce cooling. Adsorption is classified into physical and chemical adsorption on the basis of attraction force between adsorbate and adsorbent. In physical adsorption, Vanderwaal's force exists between both. Due to weak nature of force, adsorption can be easily recovered on heating. Zeolite,silica gel, activated carbon are most used physical adsorbents. Methanol is the most suitable refrigerant paired with zeolite. In chemical adsorption, attraction force between adsorbate and adsorpant is strong which completely alter their original state after adsorption process.

Zeolite is a type of alumina silicate crystal composed of alkali or alkali soil. The adsorption heat of zeolite–water is higher than that of silica gel–water, at about 3300 to 4200 kJ·kg–1 (1418.7 to 1805.7 Btu/lb). The desorption temperature of zeolite–water is higher than 200°C (392°F) due to its stable performance at high temperatures. The drawbacks of zeolite–water are the same as for silica gel–water, low adsorption quantity and inability to produce evaporating temperatures below 0°C (32°F).

3) COMPONENTS USED AND FABRICATION

This section deals with the components and materials used in the project along with their specification.

3.1 Components

3.1.1 Refrigerator body

It is there to keep the space cooled. The evaporator is a rectangular box made of copper which is there to evaporate the refrigerant and cool the unit by absorbing the heat from the unit. The evaporator is placed at the top inside the cooling chamber to maintain a low temperature during desorption.

Fig1: Evaporator

3.1.2 Cooling unit

It is an air tight box where cooling is to be done. It is the unit where substances are kept to be cooled or are preserved. It contains the material which we are required for cooling purposes.

Fig 2: Cooling unit

3.1.3 Vacuum pump

Vacuum pump is used to remove gas molecules from an enclosed space. Vacuum pump used here is of power 0.5 HP. It is connected to the two components Adsorber and Evaporator through piping with pneumatic valves. It is used to create vacuum firstly in the adsorber and then after closing the valves of adsorber vacuum is created in the evaporator using vacuum pump. Here Vacuum pump used is operated with electric power. It can also be powered by pedalling.

Fig 3: Vacuum pump

3.1.4 Pneumatic valves

To increase or decrease the flow rate of refrigerant through the pipe, valve is used. Here two pneumatic valves are used one controlling the flow towards adsorber and other to control the flow towards the evaporator.

3.1.5 Pressure gauges

Two pressure gauges are used in the project. One pressure gauge tells the pressure of the evaporator and other pressure gauge tells the pressure of the adsorber.

3.1.6 Adsorber

Adsorber is the unit which stores the adsorbent used in the refrigeration system. It is the zeolite container as it stores zeolite in it in this refrigeration system.

Here we have used a pressure cooker of 2 litre capacity and zeolite used as adsorbent of mass 1 kg is kept in the container.

Fig 4: Adsorber

3.2 Adsorbent – adsorbate pair

For our project **zeolite - methanol** pair were chosen as a composite pair based on the fulfilment of required properties discussed in the previous section. Here some of their properties are discussed.

Zeolite (Adsorbent)

Zeolite is a porous crystalline alumino silicate salt represented by the following formula: xM2/no.AL2O3.SIO2.zH2O . In our work, zeolite acts as adsorbent and methanol is refrigerant.

Zeolite is the adsorbent used in the refrigeration system which adsorbes the vacuum vapour. We have used 1 kg of Zeolite as adsorbent.

Fig 5: Zeolite

Refrigerant (Adsorbate)

Methanol is used as the refrigerant in this refrigeration system. It is the heat carrying medium which moves from evaporator after absorbing the heat from cooling unit to the adsorber and gets adsorbed by the adsorbent (Zeolite) in the adsorber. 1 litre of methanol is used as the refrigerant in the refrigeration system.

4) EXPERIMENTAL SET UP AND WORKING

4.1 Experimental set up

Vacuum Pump: - It is required to create vacuum in cooling unit.

Zeolite: - Used as absorber.

Zeolite Container: - To store the zeolite powder.

Valve: - To control the supply of methanol and vacuum generated.

Cooling Unit: - It contains the material which we required for cooling purpose.

Refrigerator Body: - To keep the space cooled.

Methanol:-Used as refrigerant.

Fig 6: Set – up of the refrigeration system

4.2 Working

First off, by using vacuum pump, vacuum is maintained in adsorbent (zeolite) unit. Then, the valve which connects vacuum pump with the evaporator chamber is opened keeping the valve of adsorbent container closed. In the evaporator box, vacuum is produced which in turn reduces the partial pressure of methanol, converting it from liquid to vapour form. The latent heat of vaporization absorbed by liquid comes from the evaporator itself. After this, compressor valve is shut down and that of zeolite evaporator is opened. With this, a passage is created for zeolite to absorb the vapours which is known as physical adsorption process.

It results in a little drop in temperature in the evaporator chamber. As per the requirement of the cooling, the whole cycle can be repeated as many number of times. This system works on adsorption principle. When the molecules, atoms or ions from any gas, liquid or dissolved solid adheres to a surface, that is called adsorption. Basically it takes place at the interface of 2 phases. In this refrigerator, adsorbate (zeolite) forms a film on the adsorbent (zeolite). Adsorption continues till the time whole zeolite is saturated with water. After, desorption takes place which reverses the adsorption by heating up the zeolite. The water is desorbed from the zeolite in the vapour form and liquefies in the evaporation vessel.

5) RESULTS AND DISCUSSIONS

This section deals with the observations, calculations and discussions of the results obtained from the experiment performed on the refrigeration system.

5.1 OBSERVATIONS

Exp. No.	Refrigerant Temperature(during recharging) (°C)	Initial cooling unit temperature (°C)	Evaporator pressure	Adsorber Pressure	Power of compressor	Final temperature of cooling unit (°C)
1.	20	35	130 mm of Hg	100 mm of Hg	0.5 HP	28
2.	20	36	150 mm of Hg	120 mm of Hg	0.5 HP	31

Table1: Observation table

We performed two experiments by reducing the vapour pressure using vacuum pump, which was run for 30 minutes to reduce the given pressures. After two hours, we observed a slight depression in the temperature of the cooling unit.

5.2 CALCULATIONS AND DISCUSSIONS

Coefficient of performance

Refrigeration effect

"The quantity of heat that unit mass of refrigerant absorbs from the refrigerated space to produce useful cooling"

Refrigeration effect can be calculated as

$R.E = m (h_g – h_f) + m\ C_p\ \Delta t$

Where, m = mass flow rate = 6 gm per minute

h_g = vapour enthalpy of methanol at 25℃ (KJ/kg)

h_f = Liquid enthalpy of methanol at 25℃ (KJ/kg) C_p =

vapour specific heat of methanol at 28℃

Δt = temperature difference

At 130 mm of Hg, boiling point of methanol is 25℃. h_g

=1063.4 KJ/kg

h_f = -105.57 KJ/kg

On putting the values in above equation of R.E. we get

R.E. = 7.03668 KJ/min.

Power consumption by vacuum pump = 20.28 KJ/min. COP

of system = $\frac{R.E}{Power\ consumed}$

= 0.3469

In this experiment, we are not showing the continuous cycle and not performing the desorption process, so we have not considered the heat given to the adsorber. With only considering the pump work, the COP of the system is around 0.35. But if we also consider the heat given and other losses, the COP drops down upto 0.25 to 0.3.

5.2.1 Limitations

One of the downside of this adsorption refrigeration system is that COP is relatively less than that of conventional vapour compression refrigeration system. Further research could be done on finding the ways to increase the COP. Other drawbacks include the low energy efficiency and maintenance of vacuum due to leakage. New pair of adsorbent-adsorbate can also be formed and researched.

5.2.2 Advantages

The main advantage of this system is it can be operated by low grade heat energy which makes it suitable for using in areas where electricity supply is less or not at all. It is also very much portable as it does not require continuous supply of energy and thus can be transported.
The refrigerant (methanol) used is less harmful for ozone layer and global warming which make sit environmental friendly. Zeolite used here can be reused for a longer period of time even after numerous cycles of adsorption and desorption. It is superior to vapour absorption refrigeration system in a way that it can be operated in the conditions of severe vibrations also such as in the automobiles or in boats due to the solid form of adsorbents.

6) CONCLUSION

The basic idea of doing this work was to make our refrigeration system portable and less power consuming. And in our project we used less number of mechanical components and used vapour adsorption technology to make it portable.

We have successfully fabricated an experimental, novel, transportable adsorption refrigeration system design powered by vacuum pump. The main advantage of this system is it can be operated by low grade heat energy which makes it suitable for using in areas where electricity supply is less or not at all. It is also very much portable as it does not require continuous supply of energy and thus can be transported.
The refrigerant (methanol) used is less harmful for ozone layer and global warming which make sit environmental friendly. Zeolite used here can be reused for a longer period of time even after numerous cycles of adsorption and desorption. It is superior to vapour absorption refrigeration system in a way that it can be operated in the conditions of severe vibrations also such as in the automobiles or in boats due to the solid form of adsorbents.

Adsorption refrigeration is a budding technology. Extensive research can be done in this area to make it common to use in household devices as well as in industries.

REFERENCES

[1] A textbook of refrigeration and Air Conditioning by R.S. khurmi & J. k. Gupta 5th edition, 2006.

[2] Heat and Mass Transfer by M.M Rathore 7th edition Vol. 5, 2008

[3] International Journal for Research in Applied Science & Engineering Technology (IJRASET) Volume 4 Issue VI, June 2016, Pedal Powered Refrigerator on www.ijraset.com

[4] International Journal of Innovative and Emerging Research in Engineering Volume 2, Special Issue 1 MEPCON 2015, on www.ijiere.com

[5] Primary-refrigerant by Wilson, David Gordon 30 Aug 2013

[6] International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 6, June 2015, Adsorption Cooling System Powered By Exhaust Heat of an Automobile on www.ijirset.com

[7] L.W. Wang, R.Z. Wang, J.Y. Wu and K. Wang; Compound adsorbent for adsorption ice maker on fishing boats; International journal of refrigeration (2004).

[8] International Journal of Emerging Research in Management &Technology, Volume-4, Issue-5 May 2015

[9] Wang L W, Wang R Z, Oliveira R G. A review on adsorption working pairs for refrigeration .Renewable and Sustainable Energy Reviews2009.

[10] Mr. Anieban Sur, Dr. Randip K. Das Review on solar adsorption cycle IJMET July – Aug 2010.