Extraction of Water from Air using Adsorption Refrigeration System

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Abstract: **Water, precisely fresh water is essential for drinking. However, due to ever increasing population of the world, as well as the pollution caused by people, there is a huge scarcity of pure drinking water. The atmosphere contains a large quantity of water in the form of water vapor and this endless source of water can be recovered for general drinking purpose. A new innovative method available for extracting water from air is Adsorption Refrigeration (AR). Adsorption refrigeration is clean source of energy and uses environment friendly refrigerants. Moreover, adsorption refrigeration systems can be driven by low temperature heat source. The present work is focused towards the design and development of refrigeration system for producing water from air for 6 minutes cycle on the working principle of adsorption system by using Activated carbon and ammonia selected as working pair. Amount of water collected from the system depends upon the atmospheric conditions (like DBT, DPT, and RH) and the amount of air blown on the evaporator. The location selected for installing our project is Pune, Maharashtra. The principal feature of the water obtained by use of this method is the absence of harmful microorganisms and bacteria in it. At the same time, the water obtained from this process has certain trace elements which are necessary. This method used for extracting water from air are much effective than other methods as they do not use ground water, but atmospheric air.**

Keywords: Extraction of Water from Air, Activated Carbon, Ammonia, Water, Adsorption Refrigeration (AR), Pune.

Nomenclatures

T_{ad}-Temperature of Absorber-Generator (^{0}C)
AR-Adsorption Refrigeration
AWG-Atmospheric Water Generator
VCR-Vapor Compression Refrigeration
RH-Relative humidity
T-Temperature Difference (^{0}C)
U-Overall Heat Transfer Coefficient (W/mK)

I. INTRODUCTION

Water, precisely fresh water, is a basic necessity of people to live along with food and air. Severe water shortages are currently experienced by 470 million people and it is projected that by 2025, the number of people living in water-stressed countries will increase to 3 billion. It is also estimated that 2.4 billion people in the world lack access to safe drinking water and that there are about 1.7 million deaths per year worldwide because of diseases found in poor water quality. In Maharashtra also, especially in the regions like Marathwada, there has been a severe water scarcity since past 5 years. The ambient atmosphere contains a large quantity ofwater in the form of vapor in varying amounts, ranging at saturation temperatures between 15^{0}C– 30^{0}C from between 10.7 and 27 gm. per kg of dry air. This endless source of water can be recovered for general use and the water recovered from the atmosphere is salt less.

T. Anbarasu et. al developed a system for the conditions of Chennai, which generates fresh drinking water and extracts water from humid ambient air by using cooling condensation process in an Atmospheric Water Generator. An Atmospheric Water Generator (AWG) is a device that extracts water from humid ambient air. In a cooling condensation based AWG, a compressor compresses the refrigerant which is circulated through a condenser and an evaporator coil which cools the air surrounding it, lowering the dew point temperature of air and causing water to condense. A controlled-speed fan pushes filtered air over the coil.

The resulting water is then passed into a holding tank with purification and filtration system to keep the water pure. In the initial optimized tests, it generated 18.3 liters of water in 24 hours in ambient air conditions with an average relative humidity of 70% RH. Within this period of operation, it consumed 2 kilowatt-hours of energy per liter of water generated.

Thippeswamy J B et al. in their thesis work Extraction of water from atmospheric moisture used a simple AWG in the setup to extract water from air. The refrigerants used were mainly R134a, R290, HC-R290. This system gave good economy results for HC-R290. Therefore HC-R290 was the refrigerant used. The amount of water collected from the atmosphere was 250 ml of water in 1.5 hr. The water

produced is cold water. The temperature of the evaporator decreases as there is ice formation on its surface at around 0^0C.

The VCR based AWG system is popular and advantageous due to its small size, low weight and high coefficient of performance. The main disadvantage is that the refrigerants used in the VCR systems have chlorofluorocarbon (CFC), Hydro chlorofluorocarbon (CHFC) which in turn leads to global warming and Ozone Layer Depletion along with high energy consumption. Vapor Absorption Refrigeration system is one of the potential alternative, which can replace the vapor compression refrigeration. Vapour absorption refrigeration system is a refrigeration system, where the compressor of the vapour compression refrigeration system is replaced by a combination of an absorber and a generator. In vapour absorption refrigeration a combination of liquid absorbent and refrigerant is used. Vapour absorption refrigeration system is a heat operated system of refrigeration where the generator is heated by using a heat source. The refrigerant is separated from the absorbent when the generator is heated, and is compressed in the generator. The compressed refrigerant is passed to the condenser and the liquid absorbent is pumped back to the absorber to absorb the refrigerant coming out from evaporator. Ammonia-water and LiBr-Water are the common working fluid pairs used in absorption system.

Adsorption refrigeration system is similar to absorption refrigeration system with the difference of a solid adsorbing material in place of liquid absorbing material. Adsorption Refrigeration (AR) technology operates on low grade energy i.e. heat. In this refrigeration system, the refrigerants used have zero ozone depletion potential and very low global warming potential. Any kind of acceptable heat energy, which can be obtained from combustion of fuel, waste heat from engine exhaust, or engine coolant can provide the necessary input to produce cooling effect. This makes the adsorption refrigeration system attractive for exploring new potentials and energy conservation. In adsorption, the compressor of a conventional VCR system is replaced by an Adsorber, which gives thermal compression powered by heat from a suitable heat source. Adsorption system has very few moving parts like the throttle valves. It is simple in operation and requires very less maintenance. Other advantages include noise free operation, ability to work in mobile conditions, and capability to handle variable temperature heat sources. There are some materials which show the property of adsorbing certain gases when they are cooled and reject the gases when heated. This phenomenon is known as adsorption and desorption. These materials include activated charcoal (carbon)-ammonia, activated charcoal-methanol, silica gel-water etc. Earlier, many researchers have carried out the research in adsorption refrigeration system, but no researcher has focused to develop a system to extract water from air using adsorption refrigeration for domestic drinking purpose and this is an entirely new concept.

R.Z.Wang et. al have discussed Solid adsorption refrigeration and according to the nature of the forces involved in the adsorption process, the sorbents utilized can be divided into physical, chemical and composite sorbents. The types, characteristics, advantages and disadvantages of different adsorbents, refrigerants and working pairs are summarized in this work. Different working pairs are used for different situation which depends mainly on the adsorption heat, the adaptability to the driving temperature and the desired working pressure. The methods to measure the adsorption quantity of different working pairs are compared in this work.

Lambert and Jones in their work they have demonstrated design of air conditioner for a car using heat of engine exhaust. They have also presented the design of the main components of the proposed system. The system has two absorbers heated by thermic fluid. The thermic fluid is heated by engine exhaust in a heat exchanger. The overall weight of the system is approximately 3.5 percent to the total vehicle weight, which is at par with the weight of current vapour compression refrigeration systems. The cooling power per unit mass of adsorber for the presented design has been claimed as 0.5kW per kg of adsorbing material with a cycle time of 900s.

Q.R.Zheng et. al in their research paper Preliminary study of Extracting water from air utilizing ship's waste heat from the cylinder jacket cooling water found that the huge amount of waste heat present in the cylinder jacket of the main engine is enough to power the unit of water extraction from air by using adsorption. Silica gel-water is used as the adsorbent-adsorbate pair in work. Due to high relative humidity in the marine environment, silica gel with pores larger than mesopores will be more beneficial to the adsorption of water. He also found that the water vapor adsorption performance compounded by silica gel with calcium chloride can greatly be enhanced by three to four times of that on silica gel, but the vibration and bumping of the ship degrades the performance of the system.

H. Tiwari et al. presented design development and experimentation of adsorption refrigeration system powered by exhaust heat with only two control valves. The cooling capacity for a truck cabin is estimated as 1 TR a scale of 3.5:1 is in his work decided and a prototype of 1 kW has been designed and developed and tested in laboratory. A cooling effect of 1 to 1.2 kW has been obtained. The COP of the system is in the range of 0.4 to 0.45 and a compact system has been designed. It can be easily accommodated on a Transport Truck. The total weight of the system for a cooling capacity of 1 kW is 30 kg and the heating time required to achieve the cooling effect is around 10 minutes.

II. EXPERIMENTAL DETAILS AND WORKING PRINCIPLE

Experimental Setup consists of different components like 1) Adsorber 2) Selector Valve 3) Evaporator 4) Condensor/Receiver 5) Throttling Valves 6) K Type Thermocouple 7) Water collection tank 8) Air blower/Fan 9) Pressure gauges etc.

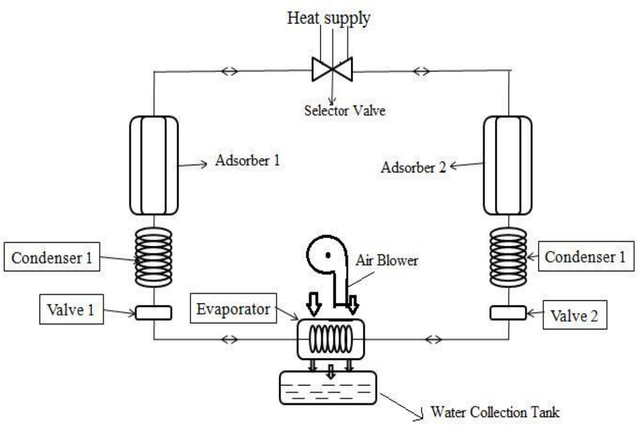

Fig.1:- Schematic of Experimental Setup

Above fig. 1 shows the schematic diagram of extracting water from air using adsorption refrigeration system with equipments used for experimental work. Adsorber is the heart of the system and it is a tube-in-tube type heat exchanger which is made up of 3 concentric pipes, the inner two pipes are made up of Stainless steel, (SS304) and the outer pipe which acts as the water jacket is made up of PVC Pipe. In the

current work, Activated charcoal and ammonia has been selected as the adsorbate-adsorbent pair because it can withstand temperatures as high as 200^{0}C or even more. The gap between the two inner pipes is filled with a mixture of granules of activated charcoal and aluminum chips. The activated charcoal and aluminum chips are mixed approximately 5:1 by weight. The ammonia is charged in the system with the help of charging coil from the ammonia the cylinder. Activated charcoal adsorbs ammonia due to its adsorbing nature. 1 kg of activated charcoal adsorbs approximately 250 grams of ammonia. Heat is supplied to the absorber 1 for 6 minutes. In the adsorber 1, ammonia is heated the pressure rises to 15 bar. At 15 bar pressure, the ammonia desorbs from the charcoal and it vaporizes and it moves out of the adsorber. It is collected in the condenser/receiver. The ammonia continuously moves out of the adsorber 1 and flows slowly to the condenser 1. The absorber 2 does not perform any action as both the valves are perfectly closed during this period. After all the ammonia from the adsorber 1 flows to the condensor, valve 1 is gradually opened and this condensed ammonia flows to the evaporator region. Due to this, there is a pressure drop in the evaporator region. Due to the pressure drop, the temperature of ammonia also drops in the evaporator region. When the air is blown over the evaporator coil with the help of a blower/fan, the temperature of the air reduces as the temperature of the evaporator coil is very low. The temperature of the air reduces below the dew point temperature and the water will get condensed in the water storage tank. This water obtained from the system is potable. After some time, the valve 2 is gradually opened. The cool ammonia is adsorbed by the activated charcoal in adsorber 2. After all the ammonia is adsorbed by the adsorber 2, valve 1 is closed. The system will be operated vice-versa for adsorber 2.

Properties of ammonia are as shown in table 1. Each adsorber has 2.1 kg of activated charcoal and 400 grams of aluminium chips. The size of activated charcoal is 4-4.5 mm granule size whereas the size of aluminium chips is 5 mm as shown in figure 2. The standard S.S. Pipes of Ø114.3 mm and Ø88.2 mm are used in the system. The length of pipes is 1000 mm and 1200 mm respectively. The size of PVC pipe is Ø150 mm and length is 900 mm. The pressure in the adsorber varies from 5 bar to 15 bar. Standard pressure gauges are calibrated and mounted over the adsorber. A small fan is mounted in the air handling unit to blow the air over the evaporator coil. The mass flow rate of air blown by the fan is adjusted to 0.0211 m^3/sec. The Adsorptivity of Activated Carbon for Ammonia below 75^0C is around 30% and that above 165^0C is around 0%. Hence, the adsorber bed temperatures are decided as $T_{(ad)_M} = 165^0$C and $T_{(ad)_N} = 75\ ^0$C. The system is designed time of 6 minutes = 360 sec i.e. the time required for adsorption or desorption. Latent heat of Evaporation of Ammonia (L) at Evaporator pressure of 5 bar is 1250kJ/kg. Total Refrigerating effect is 1.25 kW. The condensor is a tube in tube type heat exchanger. Here, water is used as cooling medium and refrigerant flows in inner coil. The dimensions of the condensor are Inner diameter (D_i) and outer diameter (D_o) is 12 mm and 15 mm respectively. The uncoiled length of the condensor tube is 6500 mm. Similarly, an evaporator is a coil made up of steel. It has diameter of 12 mm and the overall uncoiled length of the evaporator is 15760 mm. Density of stainless steel is 7800 kg/m^3. Specific heat of Activated carbon is 1:033kJ/kg.K whereas the Specific heat of Steel is 0:46kJ/kg.K.

Fig.2:- Actual Granules of Activated Charcoal and Aluminum

Table 1:- Properties of Ammonia

Properties	Ammonia
Chemical formula	NH_3
Normal boiling point (^0C)	-34
Molecular weight	17
Latent heat of vaporization(kJ/kg)	1368
Density (Kg/ m^3)	681

a. Instrumentation:-

1. 100mm (4") Heavy Duty Model SS Ammonia Gauge -

The pressure gauges listed below have a 100mm dial and have a stainless steel bezel.

- Thread connection - 1/4" bsp
- Dual scale - PSI & Bar.
- **Range-**1 to 25 bar
- **Max temperature:** Max+65°C
- **Working pressure:** Max 75% of the full scale value.

2. Thermocouple

- **Type**: K type Chromel (+) Yellow Alumel (-) Red.
- **Temperature Range for Standard Limits of Error:** (0 to 293°C)
- **Standard Limits of Error:** (± 2.2°C) **Special Limits of Error:** (± 1.1°C)

Fig.3:- Actual Experimental setup of Extraction of Water from Air using Adsorption Refrigeration System

III. METHODOLOGY

The pressure gauges are tightly mounted over the adsorber bed. Heat source is given to the system with the help of a kerosene burner or any waste heat energy source like the solar energy. The waste heat is supplied to the selector valve or directly to the inner pipe of the adsorber section. The valves used in the system are made of stainless steel as they have to withstand the corrosive action of ammonia as well as to achieve accurate throttling action of the refrigerant. The system is designed for 6 minutes cycle. Hence, the system is designed for 6 minutes of adsorption and 6 minutes of desorption.

IV. CONCLUSIONS

1. The operating cost of the system is low as compared to VCR based system.
2. The maintenance cost of the system will also be very less.
3. The system is extremely beneficial in the remote areas of the country where there is no electricity supply.
4. As the water is directly condensed from the atmosphere, it is entirely potable.
5. VCR based system works only on electricity supply, where as in this system, the waste heat energy source can be changed according to the availability.
6. A system will be developed for producing 8 liters of water per day.

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