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RESEARCH ARTICLE

FEASIBILITY STUDY OF HARVESTING WATER FROM ATMOSPHERIC AIR.

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Abstract

Fresh water demand is increasing globally and numerous research is being carried out to develop efficient technology for harvesting water from atmospheric air. This paper highlights water harvesting experiments from atmospheric air by using CaCl₂ desiccants and as well as heat pump method. Experimental studies showed that water vapor attraction capacity of LiBr, LiCl and CaCl₂ desiccants were relatively higher than of Silica Gel, Molecular sieve or Activated Carbon. Experiment with 35% solution of CaCl₂, using solar heat for desorption of water vapor, yielded 15 ml of water in 24 hrs at an average humidity of 65%. When auxiliary heat from electrical source was applied for desorption of water vapor from CaCl₂ solution, 10 ml of water was harvested in 4 hrs at an average humidity of 65%. Experiment using gas compression method to condense water vapor from air generated 300ml of water in 6 hrs at an average humidity of 63%.

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Introduction:-

Water is unique of all renewable resources as it is essential for sustaining all forms of life. It is required in domestic life, agriculture, and industry and energy production. Water affects the livelihood of billions and is important for economic development, environmental protection and ecosystem [1]. And although there are abundant water resources, only 3% of water on earth is fresh water. Furthermore most of the fresh water is out of reach for human use and only less than 1% of total water is accessible in the form of lakes, rivers, soil moisture and ground water [2]. In addition, their unequal distribution has led to the situation of scarcity and need for fresh water. About 1.6 billion people, live in countries with physical water scarcity. Particularly, in the regions of Northern Africa, Middle East, and Central and Southern Asia shortage of drinking water is severe [3].

Besides less amount of fresh water availability, rapid industrial growth, population growth and urbanization have escalated the demand for fresh water and water resources are being consumed at unsustainable rate. Fresh water demand globally would increase by 55% by 2050 due to the forecasted urban population growth of the world to 9.1 billion people [1].

Demand for freshwater will lead to increasingly global water deficit, and so in realization of this critical situation, it is requisite to look for alternative source of fresh water other than available on earth. One such alternative resource is water vapor, gaseous form of water, contained in atmospheric air. Atmospheric air contains 0-4%, by volume, variable water vapor and is renewable reservoir of water. Atmospheric air contains around 12900 km³ of fresh water,

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wherein 98% is water vapor and 2% clouds [4]. One square kilometer of atmospheric air contains, in most regions around the globe, 10,000 to 30,000 m³ of pure water [5].

Therefore, significant efforts are being made worldwide to produce fresh water from atmospheric air by different means and techniques. Numerous research are inspired from nature, particularly Namib desert beetle in South Africa [6-7], *Cotula fallax* plant native to south Africa [8], green tree frogs in tropical northern Australia [9] and Australian desert lizards [10]. All of these nature species tend to collect water by condensing water vapor from air through some mechanisms. Hence, biomimetic research is being carried out to perceive solutions to harvest water from atmospheric air and tackle global problem of water scarcity [11]. Some research work reported are related to recovering water from dew, which forms on cold surfaces by condensing water vapors in the air [12-17]. A number of efforts for harvesting water from atmospheric air are also being reported by surface mimicking Namib desert beetle, whereby these surfaces having distinct properties of wettability and hydrophobic and hydrophilic features are able to condense water from air [18-24]. Water collection by capturing water drops from fog, by using suitable nets and materials, is also a viable solution to water scarcity problems and several studies have been carried out [25-32]. Quite a few materials like CaCl₂, LiCl, Silica Gel etc have the properties of collecting water via absorption/adsorption from atmospheric air humidity and various research work are being reported of water harvesting based on this method [33-40]. An alternative technique to produce water from atmospheric air is by condensing water vapor in air by using heat pumps, whereby intensive energy is used for directly condensing water vapor [41-44].

The objective of work reported in this manuscript is to perform experimental trials for studying the feasibility of harvesting water from air using different techniques. The manuscript examines the water absorption/adsorption capabilities of different desiccant materials from atmospheric air. Furthermore, possibility of harvesting water from air by desiccant route and by gas compression method is highlighted in this report.

Theoretical Background

Water vapor absorption/adsorption by desiccants

Desiccants, like CaCl₂, LiCl, LiBr, silica gel, etc are substances that attract water-vapor molecules from the air via an adsorptive or absorptive process. Water vapor transfer is enabled by the difference in vapor pressures at the desiccant surface versus the air passing over it. Due to low surface vapor pressure of desiccants water vapor from air is attracted to desiccants. Furthermore, hydrogen bond formation with water molecule, trapping of water molecule in voids, capillary condensation of water vapor in pores and thermodynamic favorability for reaction of water with desiccants are some of the mechanisms which makes the desiccants harvest water from air. The performance of any desiccant varies with temperature and relative humidity. Since relative humidity is a function of vapor pressure, when the relative humidity of the process air is high, the desiccant can absorb more water vapor from that air stream. Desiccant efficiency is measured by the ratio of water storable in the desiccant relative to the mass of desiccant. Investigations and experiments reveal that calcium chloride is the cheapest and most readily available desiccant. Calcium chloride has hygroscopic and deliquescence properties. The reaction of Calcium chloride with water and thereby absorption water is exothermic and hence it is thermodynamically favorable. Calcium chloride forms the hydrate CaCl₂.6H₂O, which remains stable up to 29.8°C; at high temperatures, crystalline hydrates are precipitated from the saturated solution with four, two, and one molecules of H₂O.

Compared to solid desiccants, liquid desiccants, such as solution of CaCl₂, LiCl and LiBr, have many advantages. Their capacity to absorb moisture is generally greater due to the fact that dissociation of ions of the desiccants occurs in solution state and thereby larger number of ions is available for bonding with the H₂O molecule in air. Moreover regenerative temperatures of liquid desiccants are lower than of solid desiccants. Regeneration of desiccant and thereby desorption of water vapor from desiccant is very important process. Low regeneration temperature of desiccant results in easy desorption of water vapor from the desiccant.

Water vapor condensation using gas compression method

In gas compression method, heat adsorbed during expansion of cooling gas is utilized for cooling the atmospheric air below its dew point. This principle is used to cool a surface such as copper pipes and condense water vapor from atmospheric air on these surfaces.

Experimental trials & results

Water vapor intake capacity of desiccants.

The desiccant materials selected to study water vapor absorption/adsorption capabilities from atmospheric air were Lithium Chloride anhydrous, Lithium Bromide Anhydrous, Calcium Chloride fused, self indicating coarse Silica Gel and activated Carbon powders. Two sets of experiments were carried out, one in open atmosphere condition and another inside closing glass casings with higher humidity. 10g each of the above desiccant materials were kept for 192 hrs in glass beakers; one set in open atmospheric condition and another set inside closed glass casings with disc containing water as shown in figure 1.



Figure 1: Image showing experimental setup for obtaining water vapor absorption/adsorption capacities of desiccants.

The outside air temperature and humidity were recorded to vary between 21°C to 26°C and 50% to 70% respectively during the duration of experiment. In case of closed casing experiments, humidity was observed to be 100% due to the water contained in the disc. Mass gained by the desiccants, due to absorption/adsorption of water vapor, in both the sets of experiments was recorded at various intervals of time during the experiment. Percentage of water vapor collected from atmospheric air, relative to the mass of desiccant, was obtained for all the desiccants in both sets of experiments. Percentage of water vapor collected from atmospheric air by the desiccants kept in open air condition and in closed casings are shown in figure 2 and figure 3 respectively.

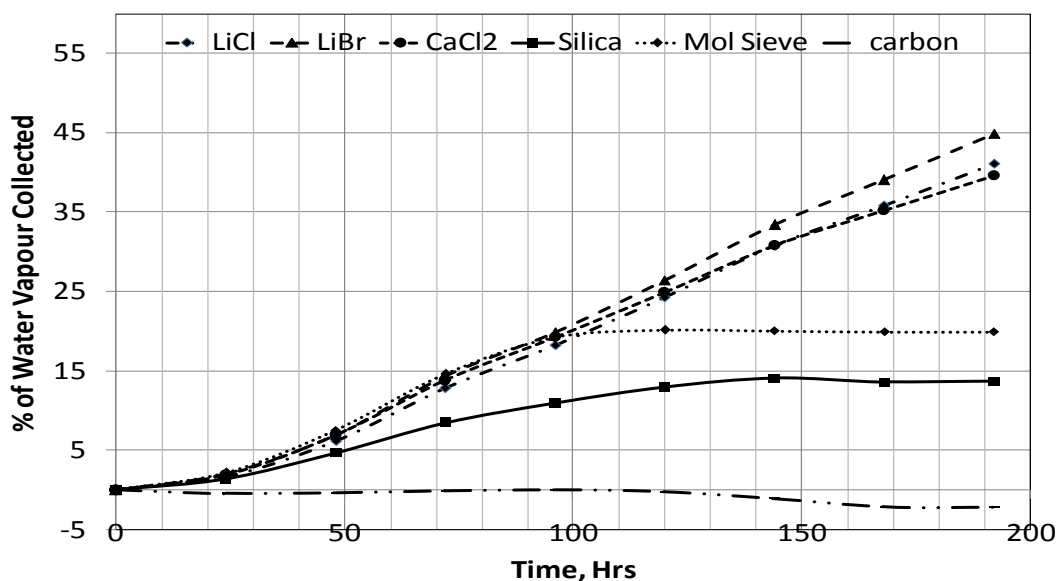


Figure 2. Graph showing percentage of water vapor collected relative to the mass of the desiccants in open atmosphere condition.

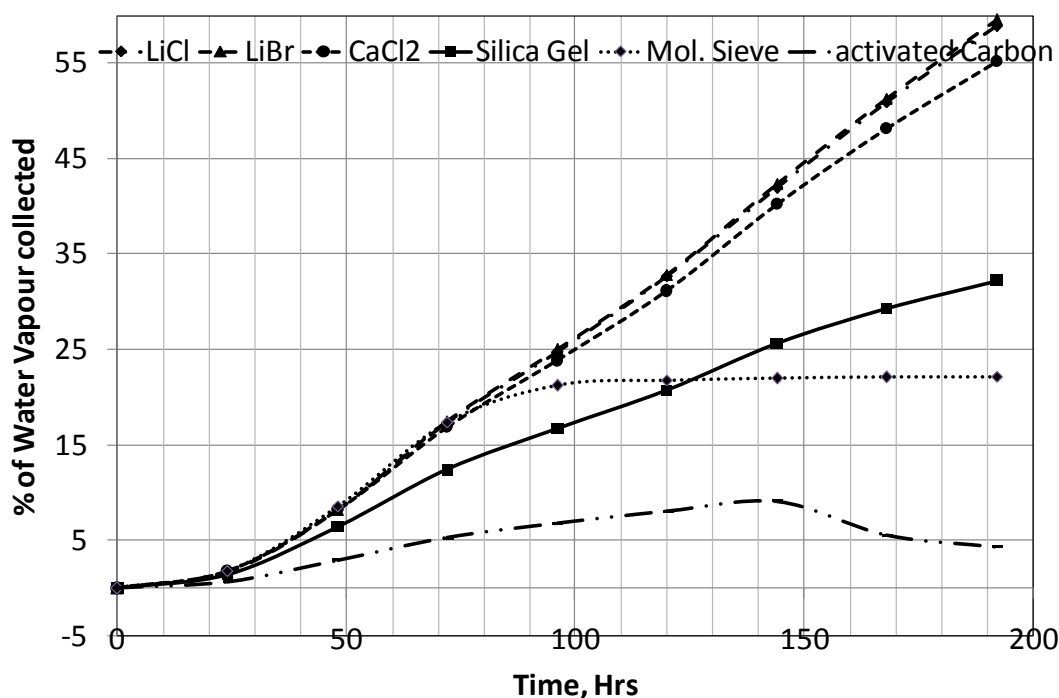


Figure 3:-Graph showing percentage of water vapor collected relative to the mass of the desiccants in closed casing conditions.

In both sets of experiments, desiccants were observed to increasingly absorbed/adsorb more moisture with time. LiBr, LiCl and CaCl₂ desiccants were observed to absorb higher water vapor content than other desiccants in open atmosphere condition and in closed casings as well. And relatively LiBr desiccant was found to be superior desiccant as it absorbed highest percentage of water vapor, 44.95% in open atmosphere and 59.53% in closed casing. Furthermore, all the desiccants, except Molecular sieve, were found to attract more water vapor from atmospheric air in closed casing condition than in open atmosphere due to availability of higher humidity in closed casing. Molecular sieve did not show much effect of humidity variation in water vapor adsorption, as the trend of water vapor adsorption was more or less similar in both the case of open atmosphere and in closed chamber. Whereas Silica gel absorbed 32.26% water vapor in closed casing and 13.78% in open atmosphere, showing the higher adsorption capacity in higher humidity condition. As far as activated carbon was concerned, it was found to be the poorest desiccant with negligible quantity water vapor adsorption.

Water harvesting trials from atmospheric air using solid CaCl₂ desiccant.

In order to practically realize water harvesting possibility from atmospheric air using solid desiccant, experimental trials were carried out using fused CaCl₂ desiccant. 6 Kg of CaCl₂ was distributed along the racks of the stainless steel tray as shown in figure 4.



Figure 4:-Photograph showing stainless tray containing solid CaCl_2 desiccant for absorption of water vapor from air.

The tray was kept open during the night time for water vapor absorption and covered by glass during the day for regeneration of CaCl_2 and release water vapor. The experiment was continued for 4 days and humidity recorded varied from 50 to 70%. During the period of experiment water solution containing CaCl_2 , formed by absorbing water vapor from atmosphere by CaCl_2 and thereafter desorption of water vapor during regeneration process and condensation on the glass cover, was collected periodically as shown in figure 5. Total water, containing CaCl_2 solution, collected in 4 days was 8.13 liters. The system was observed to be inefficient for desorption of water vapor collected by desiccant during day time and furthermore, high amount of CaCl_2 in solution form dispensed into the collection tray without regenerating.



Figure 5:-Photograph showing water solution collection from atmospheric air from tray containing solid CaCl_2 desiccant.

Water harvesting trials from atmospheric air using CaCl_2 as liquid desiccant.

Another experiment was conducted based on 35% solution of CaCl_2 instead of solid CaCl_2 desiccant. 3 Kg of CaCl_2 was used for making the solution. Solution of CaCl_2 was placed in a stainless steel tray and kept for water vapor

absorption during the night. During the day time, a metallic container was kept within the tray containing the CaCl_2 solution and the tray was covered with pyramid shape glass cover as shown in figure 6.

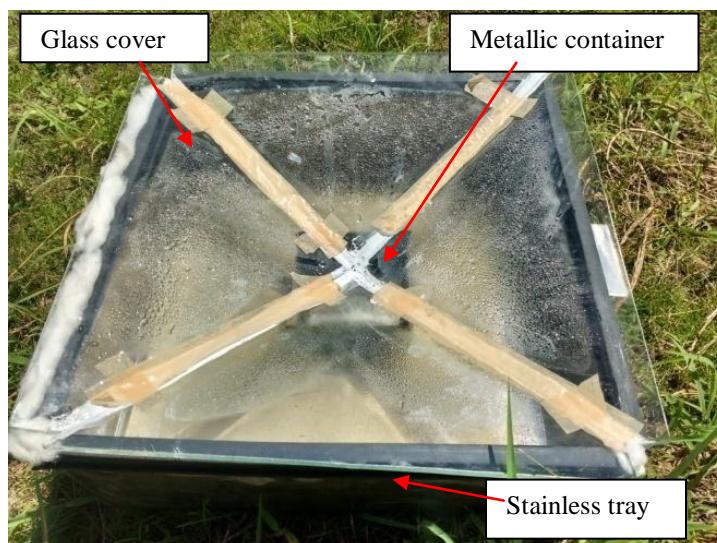


Figure 6:-Photograph showing experimental setup for harvesting water from atmospheric based on 35% solution of CaCl_2 .

Idea behind the design of the set up was to collect water vapor from atmospheric air during night time by the solution and regenerate back water vapor during day time due to solar heat. Due to heat, the desorbed water vapor was found to ascend from the solution and come in contact with the glass cover, which resulted in condensation of vapor into water. Eventually, the condensed water dropped back into the metallic container due to the inclined slope design of glass cover. The whole process of absorption and desorption of water vapor resulted in collection of water in metallic container. The experiment conducted yielded 15ml of water in 24 hours at an average humidity of 65%.

Water harvesting trials from atmospheric air using CaCl_2 as liquid desiccant and auxiliary heat for desorption of water vapor.

Desorption of water vapor from CaCl_2 solution containing absorbed water from atmospheric air is enhanced when external heat is applied. In this regard, a system was designed and fabricated as shown in figure 7.

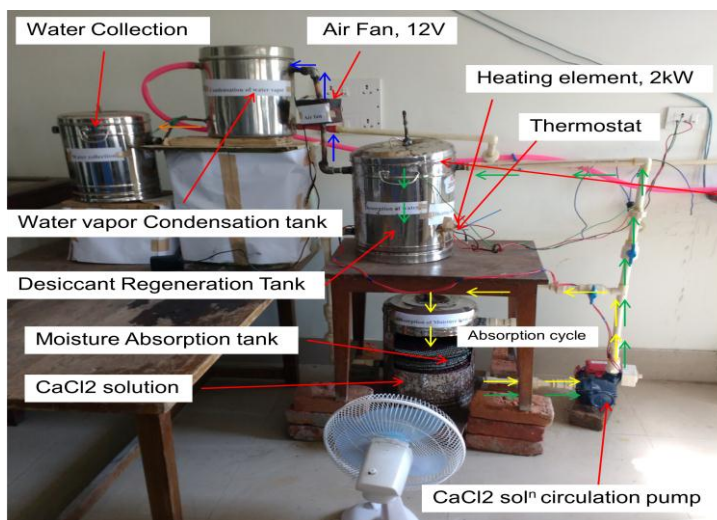


Figure 7:-Photograph showing experimental setup for harvesting water from atmospheric air based on liquid CaCl_2 desiccant and auxiliary heat for desorption of water vapor.

The system consists of absorption tank containing 35% solution of CaCl_2 , having 2 Kg of CaCl_2 , in lower section. The solution is circulated, by a 0.25 hp water pump, from lower section to top section of the tank, then through several PVC threaded discs and finally back to lower section of tank. PVC threaded discs helps in better distribution of CaCl_2 solution and mixing of solution with atmospheric air, thereby improved water vapor absorption. And during this continuous cycle of desiccant circulation, atmospheric air is being blown across the PVC threaded discs inside the tank by air fan. This whole process of solution circulation and water vapor absorption is continued for 3hrs and average humidity and temperature were recorded as 65% and 28°C respectively. After 3 hrs of absorption process by CaCl_2 solution, it is made to enter regeneration tank for desorption of water vapor from the solution. The CaCl_2 solution containing absorbed water is then heated in desorption tank by 2kW heating element for 1 hour and temperature is maintained at 70°C using thermostat. During this process of desorption and regeneration 12V air fan is switched on for suction of desorbed water vapor released from desiccant solution due to heat. The suction due to air fan moves water vapor through copper pipe into the condensation tank which is being cooled by running tap water as shown in figure 8.



Figure 8:-Photograph showing water vapor condensation tank containing water-cooled copper tube.

Due to the cooling effect, water vapor inside the copper tube is condensed into water and finally collected in water collection tank. The water collected in single cycle of 3 hours absorption and 1 hour of desorption was 10ml. It was observed that the system needs further improvement in design, related to cooling of desorbed water vapor, for condensation to occur efficiently.

Water harvesting from atmospheric air using gas compression method for condensation of water vapor.

Use of electrical energy is one of the methods to harvest water from air. In this regard, a system was designed comprising of 1/6 HP compressor, air cooled wire condenser and evaporator coil made of 1/4 inch diameter copper pipe, as shown in figure 9. The refrigerant, R134A, was used as the cooling fluid to condense water vapor from atmospheric air. The design of the system was such that the upper stainless box served as condensation unit and lower stainless box housed the compressor system.



Figure 9:-Photograph showing experimental setup for harvesting water from atmospheric air based on gas compression method for condensation of water vapor.

Experimental trial is started by switching on the compressor which generates high pressure R134A refrigerant to pass through condenser which transforms the refrigerant into sub-cooled liquid. This sub-cooled refrigerant enters the condensation unit containing evaporator coils. The condensation unit, as shown in figure 10, contains copper coils inside which the refrigerant flows, thermostat for controlling the temperature and air fan carrying the outside air into the condensation unit for water vapor condensation. The refrigerant thereby extracts heat from the copper coils making it cool enough to condense water vapor from the atmosphere. The experiment was conducted at an average humidity of 63% and was able to produce 300ml of water in 6 hours time.



Figure 10:-Photograph showing condensation of water vapor along the copper coils in the condensation unit.

Conclusion:-

Water harvesting from atmospheric air is feasible using either desiccant method or by heat pump. Applying gas compression method for condensation of water vapor requires high amount of electrical energy while by desiccant route consumption of electrical is either nil or very less. As far as desiccant route is concerned, desorption of water vapor or regeneration of CaCl_2 and further condensation into water is a complex process and requires sophisticated design and engineering for successful collection of water from air. Using gas compression technology for condensation, though consumption of electrical energy is higher, is relatively less complex and yield of water more. Use of solar heat technology in desiccant method for regeneration of desiccant and desorption of water vapor from desiccant can provide a wider scope for harvesting water from air.

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