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Water generation from atmospheric air by using composite desiccant material through fixed focus concentrating solar thermal power

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ABSTRACT

In this manuscript, experimental investigations have been performed in order to generate water from atmospheric air by using different composite materials under atmospheric condition of NIT, Kurukshetra, Haryana, India [29°58′ (latitude) North and 76°53′ (longitude) East]. In this analysis, three composite materials named LiCl/sand(CM-1), $CaCl_2$/sand(CM-2) and LiBr/sand (CM-3) have been used as salt with 37% concentration and sand as a host material. The absorption and regeneration processes have been performed to generate water from atmospheric air. The absorption process has been carried out at night in the open atmosphere whereas regeneration process took place during the day time by using newly designed 1.54 m^2 Scheffler reflector. The maximum amount of water generated from CM-1, CM-2 and CM-3 are 90 ml/day, 115 ml/day and 73 ml/day in 330 min, 270 min and 270 min respectively and the annual cost of water generation are $0.71, $0.53 and $0.86 respectively.

1. Introduction

Water is the most valuable resource and it is imperative for human survivor. According to a survey by World health organization (WHO) only 2.5% of water is considered as fresh water and rest is a part of oceans and is salty. Further 2.5% of fresh water constitute of 30% groundwater and 70% for ice and snow. so only less than 1% is available for direct human consumption (El-Ghonemy, 2012). At present, most of the world water crisis is in Northern Africa, Middle East and Central and Southern Asia. Many researchers and scientists proposed various methods to solve this problem. Water extraction from atmospheric air is one of the method to fulfil the scarcity of fresh water. In every cubic meter, water vapours and density varies with geographical location, time and season. By volume water vapours, is 4% of atmospheric gas mixture and 3% of air by mass (El-Ghonemy, 2012)

Mainly two common methods have been used to collect water from atmospheric air. In the first method, atmospheric air is cooled below the dew point temperature and thus water is collected, this is very complex & expensive technique. In second method, moisture is adsorbed/absorbed from atmospheric air and then regenerated by using solar energy which is followed by condensation. This technique is relatively cheaper and easy to follow. Many investigators have presented their work in the field of water extraction from atmospheric air by using solid, liquid and composite desiccant materials. Tygarinov (1947) was patented very first work in the field of water production from atmospheric air in Russia. Kobayashi (1963) was contributed in this field, by making an apparatus which consist of vertical and inclined channel in the earth and condense water vapours below dew point temperature. Hall (1966) was used ethylene glycol as a liquid desiccant absorbent in solar still for the recovery of water particles. Sofrata (1981) was used solid desiccant material to collect water from atmospheric air by absorption-desorption process. The paper also deliberated the possibility of air conditioning system for collecting water from atmospheric air. Alayli et al. (1987) was used S-shaped composite material for water production from atmospheric air. Hamed (1993) was proposed two methods; in the first method, LiBr-H_2O solar absorption cooling system was used and moist air cooled to below the dew point temperature. In the second method $CaCl_2$ was used as a desiccant for absorption of moisture during night and recovery of absorbed moisture in the form of water particle during day by solar heating. Abualhamayel and Gandhidasan (1997) were constructed a system; consists of a flat, blackened, tilted surface, single glazed with air gap height of about 45 cm. The process took place in two phases. In first phase, at night the absorbent $CaCl_2$ flow down as a thin film over the glass cover in contact with air. Due to vapour pressure difference between absorbent and atmospheric air the absorbent becomes diluted. In the second phase, during the day water rich absorbent heated to recover moisture from air. Extracted water in desert region by using sandy bed impregnated with 30% concentration of $CaCl_2$. Both experimentally and theoretically analysis was studied by Kabeel. The productivity of the system per square meter of glass cover

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Nomenclature

A	initial cost of the system
S	salvage value
p	useful life of the system
k	annual interest rate
CRF	capital recovery factor
SFF	sinking fund factor
Ga	absorption rate (kg/h)
Gr	regeneration rate (kg/h)
mws	weight of composite desiccant material on wet basis (kg)
mds	weight of composite desiccant material on dry basis (kg)
dw/dt	rate moisture content in composite desiccant material (kg/h)
Mw	mass of the water (kg/h)
L	latent heat of water (kJ/kg)
I	solar intensity in W/m^2
δ	declination angle
Ap	aperture area (m^2)
A_f	primary receiver area
n	number of days from January 1

touched to 1.2 L (Kabeel, 2004). Kabeel (2007) in the same field, pyramid shape type system was built with multi-shelf solar system. For experiments two types of pyramid were used with different types of beds. In the first pyramid bed was made of saw wood while in second it was of cloth. Both beds were saturated with solution of 30% concentrated $CaCl_2$. While comparing performance, cloth bed showed good results compare to saw wood bed. The absorption of cloth was found to be 9 kg with water production of 2.5 L/day m^2. Gordeeva et al., 1998) was developed a new materials named selective water sorbent at the Boreskov institute of catalysis, Novosibirsk, Russia for fresh water production from atmospheric air. The output of the system was 3–5 tones of water per 10 ton of the dry sorbent per day. Ji et al. (2007) were used new highly efficient water selective composite adsorbent named MCM-41 and $CaCl_2$ for water production from atmospheric air. MCM-41 was used as host material and $CaCl_2$ as a salt. The results showed that composite material had better adsorvitivity than silica gel and also have very low desorption temperature. The productivity of the system was more than 1.2 kg per unit square of solar collector area per day (Kumar and Yadav, 2015a, 2015b) were presented a new novel design, solar glass desiccant box type system (SGDBS) for water production from atmospheric air. The new composite material, $CaCl_2$ and saw wood was used. Saw wood was used as a host material and $CaCl_2$ as a hygroscopic salt. Experiments were performed for different concentration of salt during night and day for absorption and water production respectively. The best result was obtained for 60% concentration and the production was found to be 180 ml/kg. Kumar and Yadav (2016a, 2016b) were performed with $CaCl_2$ and floral foam with 37% concentration of $CaCl_2$ and the efficiency of the system was achieved to 76.44%. Kabeel et al. (2016)) was proposed a new numerically method for water production from atmospheric air. The numerically work was simulated in 3D using CFD software called star CCM+. In this system a TE (Thermoelectric) technology was used which increased the evaporation rate and hence productivity of the system. The fresh water production was 3.9 L/h/m^2. William et al. (2015) was designed a trapezoidal prism of fiber glass and constructed for water production from atmospheric air by using solar energy. The collector consists of multi-shelves bed so that increase the bed surface area. Two types of host materials i.e. cloth and sand were impregnated with $CaCl_2$. For 30% concentration of $CaCl_2$, the total evaporated water for cloth and sand bed are 2.32 and 1.23 silt/days m^2 and the system efficiency were 2.93 and 17.76% respectively. Wang et al. (2017a, 2017b) were focused on development of nobel composite material which have high sorption capacity, low regeneration temperature and optimal structure design for filling in sorption bed. For that four matrixes of ACF, E, ES and SC and two salts named $CaCl_2$ and LiCl were tested. From the test result showed that consolidating matrix ACF and LiCl had best sorption capacity and lower desorption amount 0.6 g/g at 77 °C and 20% RH. Wang et al. (2017a, 2017b) were prepared semi opened system for fresh water production system by using active carbon felt with lithium chloride (LiCl) as a salt. The 14.7 kg of water collected by using 40.8 kg of sorbents. At different weather conditions sorption and desorption performances of device had been carried out. In sorption process, maximum 14.7 kg and in case of desorption process maximum 14.5 kg of water produced. Talaat (2018) were investigate the parameters which affect the performance of a finned type solar-powered portable apparatus for extracting water vapours from atmospheric air using a cloth layer impregnated with $CaCl_2$ solution. The apparatus consists of doubled faced conical finned absorber and transparent surface. During night, conical absorber absorbed the moisture and at day time, the absorber was covered tightly by conical transparent surface and exposed to solar radiation. The productivity of the system was in the range from 0.3295 kg/m^2/day to 0.6310 kg/m^2/day.

To the best knowledge of the present manuscript author, not enough work has been done on water generation by using fixed focus concentrator. Majority of the work in this field involves flat plate collector. To generate water from atmospheric air, different composite materials i.e. LiCl sand, $CaCl_2$/sand, LiBr sand have been used. Sand has been used as a host material and Lithium chloride (LiCl), Calcium Chloride ($CaCl_2$) & Lithium bromide (LiBr) have been used as a hygroscopic salts. Here fixed point concentrator, Scheffler reflector has been coupled with the system so that water generation rate could be increased and also, the time span for water generation could be reduced. The water produced by using this technology is clean, non-polluted and can be used for daily purpose. For easy identification of research gaps, work done by different investigators in the field of water generation has been presented in tabular form in Table 1.

2. Experiment setup

The experimental setup is shown in Fig. 1, installed at National Institute of Technology, Kurukshetra, Haryana, India (29°58′ (latitude) North, 76°53′ (longitude)) and altitude of 258 m above sea level. The setup consists of following parts:

2.1. Scheffler reflector
2.2. Material handling box
2.3. Water measuring vicker

2.1. Scheffler reflector

Scheffler reflector is a small section of paraboloid which concentrated the Sun's rays at a fixed point, hence called fixed focus type concentrator. The Scheffler reflector of 1.54 m^2 surface area has been used for water generation. The reflector frame which collects the Sun's rays, has been made of number of flat shaped aluminium sheets. To achieve fixed focus at a receiver, requires tracking of Sun from East to West. The seasonal Sun deviation also adjusted by 'seasonal adjustment screw'. Here, daily tracking has been performed by manually during the experiments. The Scheffler reflector has been screwed on the steel pipes dish stand.

2.2. Material handling box

The material handling box of dimensions 11 cm × 13 cm × 1 cm is