

Innovative Way to Decrease the Water Consumption of Direct Evaporative Air-Cooler

Jahidul Haque Chaudhuri, Rohan Deb, Jhinuk De

Abstract: In the present study the existing direct evaporative coolers (DEC) is modified in such a way that DEC consume less amount of water and provide better cooling effect. In desert area, water consumption by air cooler is a serious problem. Therefore, the present study addressed this issue and primary objective of the study is to minimize the consumption of water. For this purpose, the property of the endothermic reaction is utilized. There are few salts that produce endothermic reaction if it is diluted in water. Those salt crystals absorb heat from the surrounding environment (water) and ultimately the temperature of the overall solution gets reduced. This cold solution is then passed through honeycomb cooling pad, as a result more amount of air can be cooled using the same volume of water as compared to the traditional air-cooler. Ammonium Chloride (NH_4Cl), Ammonium Nitrite (NH_4NO_3) salts satisfy the basic criteria for the endothermic reaction but NH_4Cl will be more useful to use in the air-coolers, as Ammonium Nitrite is costlier and also hazardous. A salt water separator arrangement also attached with modified air-cooler which will help to regenerate Ammonium Chloride crystal from solution with the help of solar energy. In this study, firstly discussed about proposed design of an air-cooler system, which is able to nicely handle chemical solution. Then compared the study with experimental outcome which have been carried out with and without using salt. From the result it has been observed that modified design of air cooler has great potential to improve the traditional air cooler in terms of cooling effect and water consumption.

Keywords: direct evaporative cooler; NH_4Cl ; honeycomb cooling pad; modified air-cooler design.

I. INTRODUCTION

Direct evaporative air-cooling system is a well-known technology with various applications. This type of air cooler mainly used in dry area. Compared to air conditioner it is less expensive, environment friendly and less energy input is required. In the developing countries, 50% energy of the building consumed by heating, ventilation and air conditioning. Bishoyi and Sudhakar [1] presented experimental research on evaporative cooling, where the authors used two different type of cooling pad namely honeycomb and aspen pad to obtain the performance of these cooling pads. Kovačević and Sourbron [2] designed metallic evaporative pad in an innovative way, which enhanced

air-water interaction and presented numerical model for compact direct contact cross flow heat exchanger. Franco et al [3] represented mathematical and experimental observations on implementation of evaporative cooling. Sellami et al [4] proposed a new mathematical approach to analyze the influence of the various parameter on the preformation of direct evaporation on porous layer. Heat and mass transfer modelling are represented by Heidarinejad and Bozorgmehr [5]. Using wet honeycomb paper Dai and sumathy [6] investigated a cross flow direct evaporative cooler. Al-Badri and Al-Waaly [7] investigated how chilled water influenced the performance of direct evaporative cooler. Dhamneya et al. [8] thermodynamically analyzed the performance of direct evaporative cooler. Guan et al. [9] investigated the potential use of direct evaporative air cooler in Australia. Kavaklioglu et al. [10] introduced Radial basis function network method for modelling of direct evaporative cooling system. A hybrid system i.e. integrated direct and indirect air cooler was analyzed by Kim and Jeong [11]. Wu et al. [12] theoretically investigated heat and mass transfer of DEC. Roux et al. [13] calculated molar heat capacity of various salt. Kabeel and Bassuoni [14] theoretically and experimentally work on DEC to reduce water consumption using saline water.

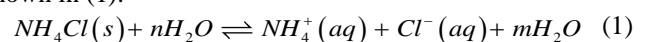
Based on the previous research works it has been realized that the ammonium chloride (NH_4Cl) salt has potential to reduce the amount of water consumption in direct evaporative cooler system as well as it will be improving overall cooling effect. As NH_4Cl has much higher evaporative temperature with respect to water, there is no chance of NH_4Cl to evaporate along with water. The main objectives of the present work are:

- 1) to design an air-cooler system, which is nicely able to handle the chemical solution used.
- 2) to develop an idea to separate salt and water for reuse.
- 3) to investigate the performance of modified direct evaporative air cooler (DEC) by comparative study with and without salt.

II. MECHANISM

In the present work, first NH_4Cl is dissolved in water and then the solution is passed through the cooling pad.

The chemical reaction of NH_4Cl with water (H_2O) is as shown in (1):



Dissolution of the ammonium chloride in water can also be thought as two separate processes as shown in (2):

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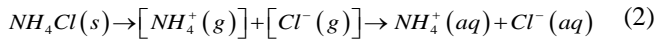
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Further (2) can also be written in single enthalpy (ΔH) terms as shown in (3):

$$\Delta H_{total} = \Delta H_{lattice}(NH_4Cl) + \Delta H_{solv}(NH_4^+) + \Delta H_{solv}(Cl^-) \quad (3)$$

From the Table I and Fig. 1,2, it is realized that to break the crystal lattice of NH_4Cl energy is required. The energy is typically heat energy (excluding photochemical reactions - not the case here) which is simply drawn from the surroundings, and in this case is primarily the water in which to dissolve the ammonium chloride. (Of course, the solution will then further exchange heat with whatever it's around, in this case it's hot air which will enter into air cooler.)

Table- I: Enthalpy gain

Lattice energy (kJ/mol)	Enthalpy of Hydration (kJ/mol)	
$NH_4Cl(s)$	$NH_4^+(g)$	$Cl^-(g)$
-705	-307	-381
$\Delta H_{total} = -(-705) + (-307) + (-381) = +17 \text{ kJ/mol}$		

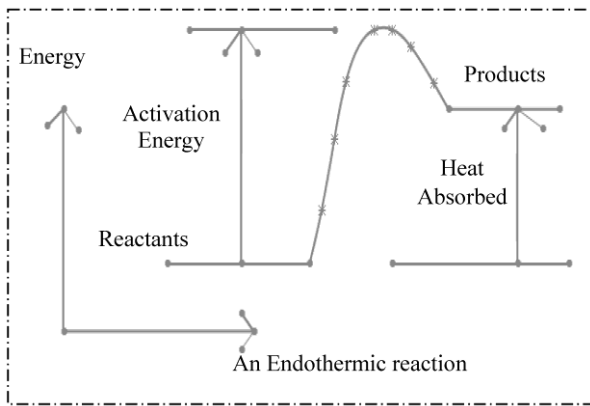


Fig. 1: Energy diagram

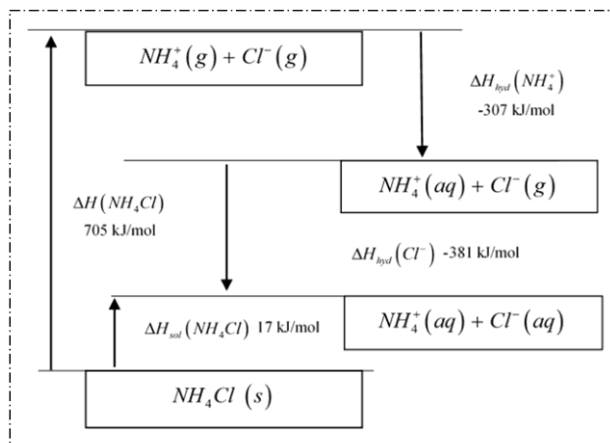


Fig. 2: Energy diagram

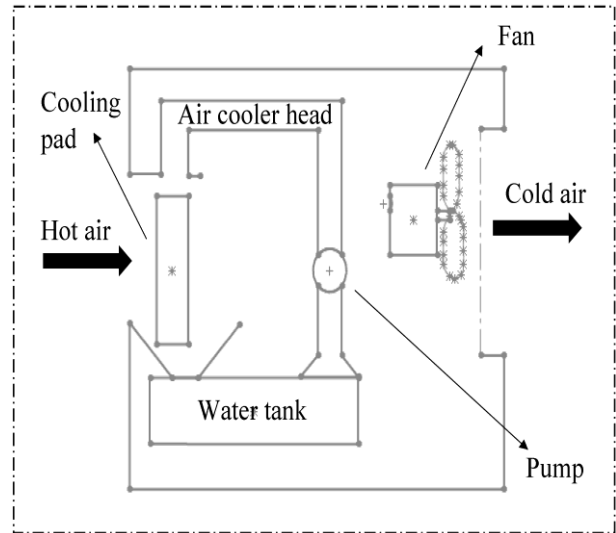


Fig. 3: Direct evaporative air cooler working principle

III. DESIGN MODEL AND COMPONENTS OF AIR COOLER

From Fig. 3, it can be easily understood that how air cooler works. As mentioned earlier, NH_4Cl is used with water. So, some modifications are required in the process. Fig. 4-6 shows the proposed modifications. Broadly two different arrangements should be attached with traditional direct evaporating cooler. One is ammonium chloride feeder system and another one is water - salt separator arrangement.

The main components of modified air cooler are Sensors, control circuit, solenoid valve, modified storage tank, salt water separator arrangement, NH_4Cl storage tank

A. Sensors

Two sensors that are required in this modified air cooler namely thermocouple sensor and water level indicator sensor. Thermocouple measure storage tank temperature and water level indicator sensor measure indirectly amount (volume) of water in storage tank.

B. Control circuit

This circuit control whole operation. This circuit collect information from sensors and operate solenoids valve. Controlling circuit consists of Aurdino, relay etc.

C. Solenoid valve

This valve controls the NH_4Cl storage tank. When signal comes from control circuit solenoid valve will be open otherwise it will remain in closed position.

D. Salt water separator arrangement

This is the one of the established techniques in salt industries. This arrangement separates salt from solution (with the help of solar energy) which will be reused again in the process. Thus, the whole process will be cost effective.

E. NH_4Cl storage tank

This tank only store NH_4Cl salt, which will be used entire process of cooling system.



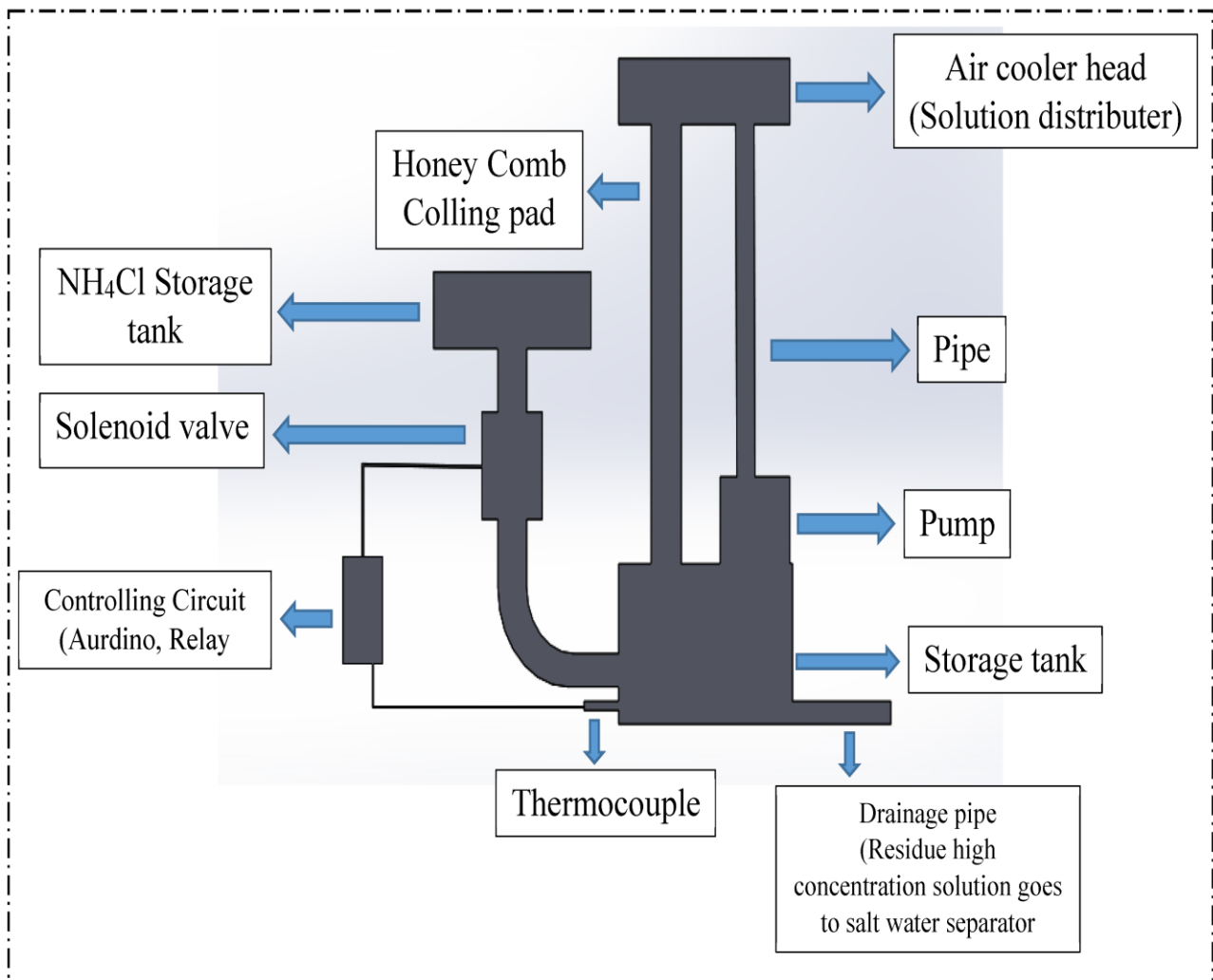


Fig. 4: Components of modified air-cooler

IV. WORKING METHODOLOGY

When air cooler starts, sensor system (Fig. 4) will measure the temperature and amount of water in storage tank. After that sensors send the data in control circuit. Control circuit will operate solenoid valve depending on sensor data. As a result, NH_4Cl salt will pass from NH_4Cl storage tank and gets mixed with water and create salt-water cold solution. When the solution passed through the cooling pads, initially solution is heated up and then started evaporating. As a result, concentration of salt in the solution became higher. As the same solution is circulated repeatedly from the storage tank, a time will come when the solution will become saturated and NH_4Cl will start forming crystals. To avoid this the water tank is designed in such a way that the amount of solution in the tank will never fall below a desired level and thus the concentration of NH_4Cl can be controlled so that it will not go beyond a predefined range (Fig. 5). Then high concentration of NH_4Cl will be transferred to a water and salt separator arrangement (Fig. 6) through the Outlet of storage tank of the air cooler at a regular interval (2-3days as per design). The salt-water separator works on the basic principle of the evaporation and condensation of water (by solar radiation) as shown in the Fig. 6. The solution is poured into the inner chamber where it absorbs solar energy coming through the glass lid. Then the water gets evaporated which again gets

condensed on the inner surface of the glass. After condensation, due to the adhesive force between glass and water, fresh water gets collected in the outer chamber of the tank (which can be transferred to a storage tank through an outlet pipe) and the NH_4Cl salt crystals are left in the inner chamber. Thus, NH_4Cl salt and water can be separated very easily. So, the NH_4Cl salt and water can be reused in the air-cooler again and again.

V. EXPERIMENTAL METHODOLOGY

A. Instrument used

- Two air coolers (traditional and modified):
 - Air deliver $650 \text{ m}^3/\text{hr}$
 - Motor speed 1350 rpm
 - Water tank capacity 14 L
 - Power consumption - Cooling 160 W
 - Size of honeycomb cooling Pad $680 \text{ mm} \times 770 \text{ mm} \times 100 \text{ mm}$ (efficiency 85%)
- Thermometer (dry & wet)
- Insulating materials.
- Weight measuring machine:
 - Capacity 10 kg
 - Accuracy 0.1 g

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5. Dehumidifier.

B. Experimental Setup

1. Two air-cooler (traditional and modified) are placed in a series in the same room.
2. Dehumidifier was fixed with the inlet of the air coolers (as experiment done in high humid region).
3. Each air cooler inlet is instrumented with two the ammeter (wet and dry) and similar arrangements is done for the outlet.

C. Experimental Procedure

1. Both air coolers are started simultaneously.
2. Weight measuring instrument was used to mix an optimum amount of NH_4Cl salt in water.
3. Noted down all temperature readings from thermometer.
4. Calculated inlet and outlet humidity. Humidity calculated with the help of psychrometric chart.
5. Temperature difference (inlet and outlet) were calculated for both air cooler.
6. Finally, performance difference evaluated for both air-cooler (traditional and modified).

II shows the performance of traditional air-cooler and Table III shows the performance of modified air cooler.

The amount of heat transfer depends on evaporation rate, further evaporation rate depends on temperature and humidity. At high humidity condition, very less evaporation takes place. As the experiment is performed in humid region, dehumidifier is placed at the inlet of air cooler. Direct evaporative cooler generally is used in dry area. From the results (Table. II and Table. III) it is realized that NH_4Cl have great potential to decrease the amount of water used.

In traditional direct evaporative air cooler, 1 kg of water can extract around 2260 kJ of heat from the air. But in the proposed modified air cooler system, 1 kg of water will be able to extract around 2323 kJ (NH_4Cl 200 gm/L) to 2355 kJ (NH_4Cl 300 gm/L) of heat from air, which is much higher as compared to the traditional DEC.

Due to honeycomb structure in cooling pad, water retain much longer time. Therefore, when hot air passed through the cooling pad air is cooled down in a faster rate as water is retained in the chambers of the cooling media. Fig. 8 shows the how performance improve with the use of new design model.

VI. EXPERIMENTAL RESULTS

Experiment was performed in Agartala City (State-Tripura, India) in February 2019 to March 2019. Table

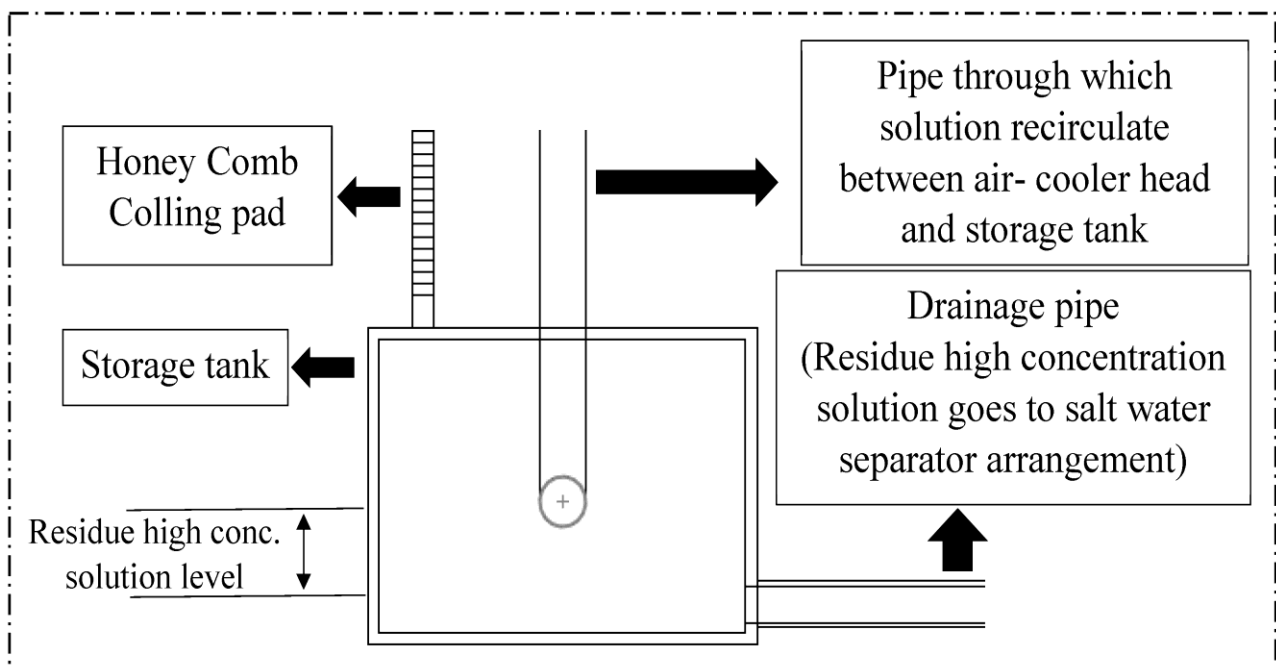


Fig. 5: storage tank (Air-cooler lower tank)

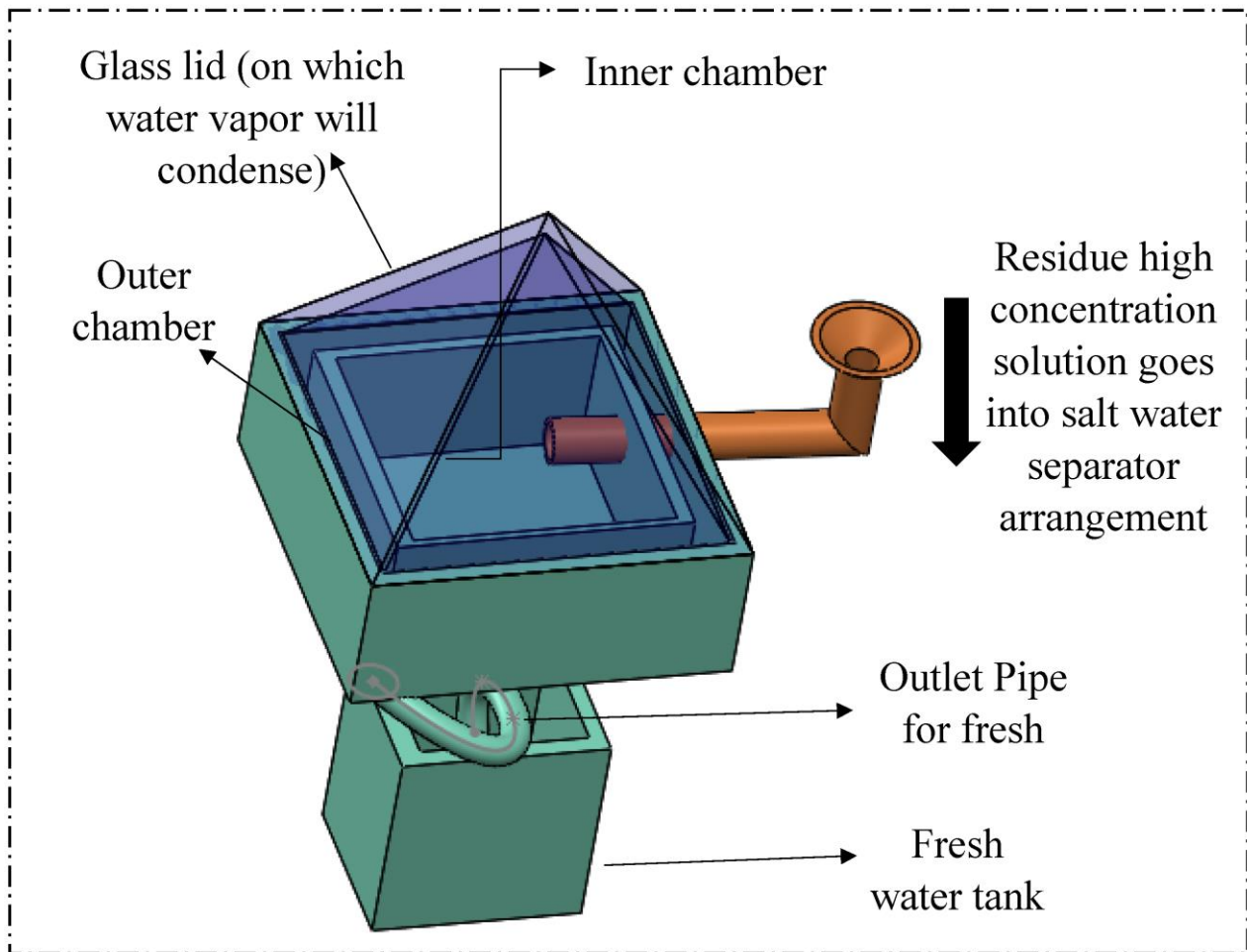


Fig. 6: Salt water separator arrangement

Table- II: Experimental result of DEC performance with traditional air-cooler

Sl. No.	Cooler inlet temperature (°C)		Cooler outlet temperature (°C)		Relative humidity (%)		Dry Bulb temperature difference (°C)
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	at Inlet	at Outlet	
1	35.0	24.0	31.0	24.1	40.2	58.0	4.0
2	36.0	25.3	32.4	25.2	41.0	60.0	3.6
3	38.0	26.1	33.0	26.2	38.0	57.0	5.0
4	34.0	22.0	28.9	22.1	36.0	55.0	5.1

Table- III: Experimental result of DEC performance with modified air-cooler (using water-salt solution)

Sl. No.	Cooler inlet temperature (°C)		Cooler outlet temperature (°C)		Relative humidity (%)		Dry Bulb temperature difference (°C)
	Dry bulb	Wet bulb	Dry bulb	Wet bulb	at Inlet	at Outlet	
1	35.0	24.0	29.0	24.0	40.2	68.0	6.0
2	36.0	25.2	30.2	25.1	41.0	69.0	5.8
3	38.0	26.1	31.2	26.0	38.0	69.0	6.8
4	34.0	22.0	27.0	22.0	36.0	70.0	7.0



Fig. 7: Some experimental components (a) NH_4Cl salt (b) Weight measuring instrument (c) DEC (d) Specifications of DEC.

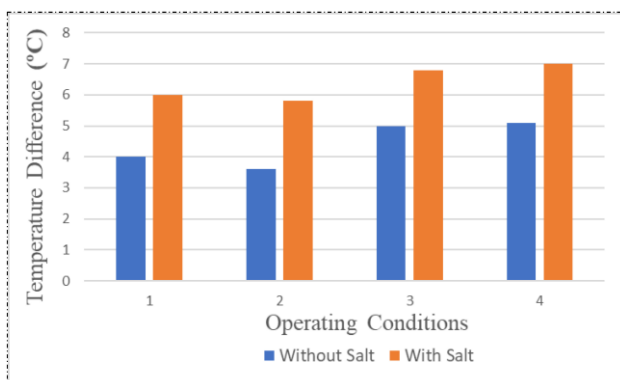


Fig. 8: A comparison between test results - with & without using NH_4Cl salt

VII. LIMITATION AND FUTURE WORK SCOPE

Theoretically and experimentally we can determine the amount of salt in solution that gives best and optimum performance. In addition, NH_4Cl is an acidic salt, it will give a slightly acidic solution, which may cause a little bit corrosion to the parts of the cooler but it can be prevented by changing the water used in the cooler at a regular interval. This issue is also need to be addressed in future.

VIII. CONCLUSION

As mentioned earlier, the water will become cold under the action of endothermic reaction with NH_4Cl . When hot air will come in contact of this cold-water, the water will absorb heat from the hot air due to temperature difference and simultaneously air temperature will reduce. Preliminary, rate of evaporation of water will be low as the temperature of solution is low. Gradually the solution will become hotter and then rate of evaporation will increase causing losses of water in the atmosphere. At this stage water will absorb the latent heat of evaporation from the air and will evaporate, thus air temperature further reduces.

So, the whole mechanism can be divided into two parts:

1. The heating up stage or preliminary stage, at that time the rate of evaporation of water will be low. This is the key point of our solution as at this stage rate of loss (i.e. evaporation) of water is very low.
2. The evaporation stage or second stage when the water will evaporate comparatively at a higher rate. Thus, humidity in the air at the second stage will be higher as compared to the earlier case

By using salt water separator arrangement easily salt and water can be separated, which can be used further. In this process, no energy will consume because here only solar radiation is used. Also, in desert area solar radiation is comparatively high at day-time, so this process will be work fast. Initial investment will be high but for longer time period this design will be profitable because it consumes less amount of water and water is an essential substance for desert area.

IX. DECLARATION

A. Funding

The funders had no rule in present study design, data collection and analysis to preparation of the manuscript.

B. Conflicts of interest

Author Jahidul Haque Chaudhuri declares that he has no conflict of interest. Author Rohan Deb declares that he has no conflict of interest. Author Jhinuk De declares that she has no conflict of interest.

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AUTHORS PROFILE



Mr. Jahidul Haque Chaudhuri currently pursuing his B.Tech. (Mechanical Engineering) final year (8th semester) in IIT Madras under Direct Ph.D. MOU program. He attended various seminars (Sustainable Cooling Technologies, National Workshop On Vedic Mathematics) and workshops (3D Printing) He has done different projects during his B.Tech, such as “50 MW parabolic trough based power plant designed for Tamilnadu conditions with 16 hours energy storage”, “Design Samosa Making Machine in an Innovative Way”(Selected Round 1 SMART INDIA HACKATHON 2019), “Robotic arm”(Skyfilabs), “Design of dish washing machine”. He knows various design and simulation software namely SOLIDWORKS, CATIA, ANSYS, and MATLAB. He selected for summer internship at IIT Madras under “Summer Research Fellowship programme for students and teachers 2019”. He also participated GUINNESS WORLD RECORD, “The most people folding origami sculptures simultaneously is 895”.



Mr. Rohan Deb completed his B.Tech. in Civil Engineering from National Institute of Technology Agartala. He attended various seminars such as National Workshop on Vedic Mathematics, Advanced Seismology, Seismic Hazards & Earthquake Engineering: Theory, Simulation & Observations etc. He worked on a project entitled: “Seismic bearing capacity of strip footing embedded in slope situated below water table”, published in Indian Geotechnical Conference (IGC) 2019 at Surat (Also Recommended for SPRINGER Publication). He also worked on a project titled “Influence of soil characteristics on rate of infiltration and developing a multiple linear regression (MLR) model”. Further, he knows various design and coding softwares namely Auto CAD, RocScience, MATLAB, C programing etc. He also participated in GUINNESS WORLD RECORD on

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