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Fabrication and Experimental Investigation on Thermal Desalination System by using Humidification and Dehumidification Technique

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Abstract: Fresh and potable water is an urgent need of the hour for every human being, as many regions in the world are facing a severe shortage of potable water. Thermal humidification and dehumidification desalination technology are become a possible solution for freshwater production in isolated coastal areas and islands, as such a system is easy to design and it can be fabricated with low-cost material. From the literature, it was analyzed that the capacity of humidification and dehumidification units is between that produced by solar stills and conventional methods. The objective of this work is to fabricate a prototype of a thermal desalination system using HDH desalination technique, which gives sufficient purified water for a family with minimal cost.

The prototype is a box of 40×30×30 cm3 rectangular cross-section made of Galvanized Iron (GI) sheets, with a separator placed in the middle of the chamber to distinguish humidifier and de-humidifier sections. The tubes of 8 mm diameter made up of copper are joined to the chamber through soldering operation. Thermal insulation for chamber is allotted with thermocol sheets. For generating more vapor inside the chamber, a sprayer is used in the humidifier section. From the experimental investigation on the prototype of fabricated thermal desalination unit it is identified that, the production of water will be high with higher humidifier inlet water temperature (i.e.< 90° C), less dehumidifier water inlet temperature, more humidifier inlet water flow rate and low relative humidity of atmospheric air. The fabricated prototype is established to fulfil the drinking water needs of a family for one day at affordable cost.

Keywords: Thermal desalination, humidification, de-humidification, purified water, potable water production.

I. INTRODUCTION

Water is one of the nature's most vital gifts to mankind. It is essential to mankind, as a person survival depends on drinking water. Our earth seems to be unique among the other known planets. It has water, which contains two-thirds of its surface and comprises 65-70% weight of the living world. Actually, only 1% of the water in the world is useful for us. Around 97% of water is salty sea water and 2% of the water is frozen in polar ice caps and glaciers. Thus, 1% of the world's fresh water supply is a valuable asset for our survival. Freshwater is one of the earth most precious renewable resources. It is the essence of life and is a basic human requirement for industrial, domestic, and agricultural purposes. Sufficient fresh water resources are vital for the development of any country. For a country, a civilization, a division, securing an adequate water supply has been one of the crucial prerequisites, not only to its development; but truly, to its survival. The literature analogous with water desalination is presented here. The literature associated with water desalination is presented here.

An assessment of the global water crises was carried out base on the availability and consumption of water, water scarcity, and possible solutions. Hence the review of desalination as one possible solution to the growing crises due to the scarcity of nature's most abundant resource. This includes a review of the growing trend in adopting desalination for fresh water supply. Various techniques for water desalination by humidification and dehumidification are introduced. The suitability of uniting renewable energy sources like geothermal energy, solar energy, wind energy, etc. to desalination is analyzed. Apart from renewable energy, use of waste exhaust heat for humidification and dehumidification process is reviewed. And finally, the technique to optimize the production of water with the expense of low cost is analyzed.

P.G. Youssef et al. [1] as the population of the world is growing, the need for fresh water is increasing. Water desalination is a process of converting saline water of seas and oceans into fresh water. Various methods have been used to desalinate saline water with different performance characteristics. This paper explains the various desalination techniques and compares their performance in terms of input and output water quality, environmental impact, amount of energy required and cost. Desalination technology is increasingly more popular to meet increasing worldwide freshwater demand. Various methods are available but they have some drawbacks like large input and high CO2 emissions. Humidification and dehumidification process (HDH) is a promising technique for desalination which can be implemented with low cost and no environmental impact. Mostafa H. Sharqwy et al [2] humidification-dehumidification (HDH) process is used for producing fresh potable water from saline water at sub-boiling temperature. This process utilizes a low-temperature source such as waste heat source solar energy. In this work, the design and performance characteristics are investigated for two humidification and dehumidification cycles namely, water heater and air heated cycles. Furthermore, increasing the temperature of the water entering the humidifier minifies GOR for the water heated cycle whereas it increases for the air heated cycle. A comparison is also made between the two cycles to provide valuable guidelines for designers in terms of, components size and power requirements. A.E.Kabeel et al [3]: It is concluded that the humidification and dehumidification desalination process will be a satisfactory choice for fresh potable water production when the demand is localized. Humidification and De-humidification desalination process is the low-temperature process where solar energy is utilized to extract required thermal energy. The capacity of HDH units is between that generated by solar stills and conventional methods. Moreover, HDH is differentiated by simple operation and maintenance. From the condensed review, it was derived that an increase in condenser and evaporator surface areas remarkably improves system productivity there are many simulation studies has been conducted in the past, further design simulation is essential to fully understand the complicated effects of water and air flow rates. It is also useful to an optimum size of individual components of the unit and to create a comprehensive model for the system.

II. FABRICATION OF PROTOTYPE FOR HUMIDIFICATION AND DEHUMIDIFICATION TECHNIQUE

A. Experimental set-up:

The experimental setup is as shown in fig.1. It consists of the desalination unit with dimensions of 40×30cm. the unit incorporates the humidifier and dehumidifier sections in the system. An electric heater of 4KW heat capacity is used to supply the energy required. Two pumps are used to circulate the feed water to the system; one pump circulates the feed water through the dehumidifier section and the other pump for circulation of feed water (sea water) through the electric heater to the humidifier section.

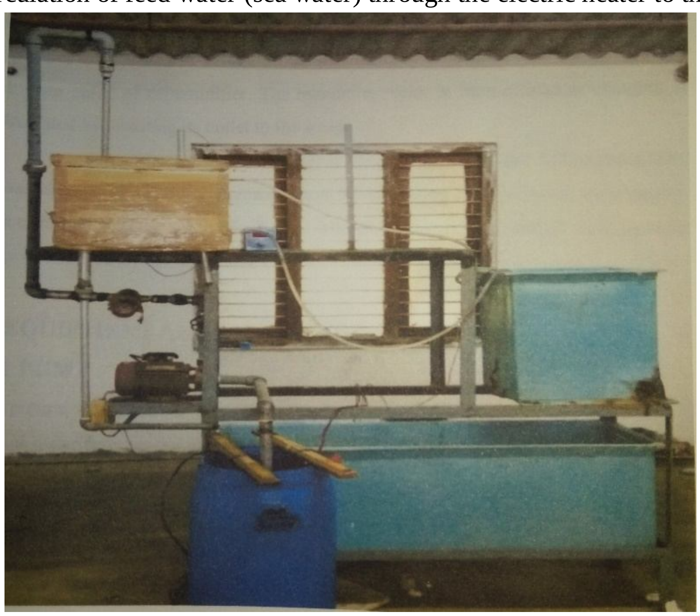

Fig. 1. Experimental set-up

B. Equipment And Accessories

1) *Humidifier and Dehumidifier Chamber:* Figure 2 shows the chamber used for thermal desalination. This chamber is a rectangular shaped box in which, it is divided into two sections. One section is for the humidification and another is for the dehumidification. In between these two sections one separator will be placed in order to ensure no escaping of water droplet from humidifier section to dehumidifier section. The chamber is made up of GI (galvanized iron) steel sheet. The fabrication process adopted is soldering. The sprayer is attached to the inlet of humidification chamber by soldering. The copper coil is first bent to form helical structure and finally attached to the dehumidification chamber by using soldering. The condensing coil is adjusted in a dehumidification chamber in such a way that it occupies the maximum space.

Fig. 2. fabrication of humidification and de-humidification Chamber with GI steel

2) *Pump:* Two pumps are used to run the feed water in the system; one pump circulates the feed water through the dehumidification chamber and the other pump circulates the feed water through the electric heater to the humidification chamber.

Fig. 3. pump for humidification

Fig. 4. pump for de-humidifier

3) *Flow Meter:* Turbine flow meter is equipped to measure the feed water flow rate. It discharges 10 litres of water for one revolution of dial.

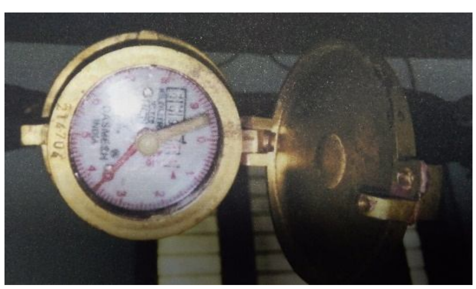

Fig. 5. flow meter

4) *Control Valve:* Control valve is used to modulates the feed water flow rate in humidification chamber. The type of control valve used is of multi-turn valve.

Fig. 6. control valve

5) *Humidifier:* The humidifiers are most valuable part of the humidification and dehumidification process. In this work adiabatic humidifiers are used namely: the spray humidifiers and pad humidifiers. In the spray humidifiers liquid is sprayed into the gas stream commonly by means of nozzle, which discharges the liquid into a fine spray of drops. Pad humidifiers uses contact surfaces where water and air are mixed for evaporation. Though pad humidifiers are more competent its pumping power is lower than spray humidifier, it is used in this project because of ease of fabrication and least cost.

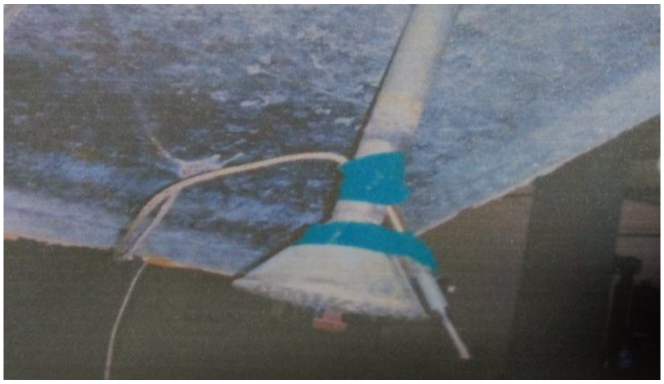

Fig. 7. humidifier section with thermocouple

6) *Dehumidifier:* The condensing heat exchangers are generally employed as de-humidifiers. Here copper coil of diameter 8mm is used as dehumidifier by circulating cooling ambient water in it. Copper is a superior electrical conductor. Most of its use is depends on this property or the fact that it is also a good thermal conductor.

Fig. 8. de-humidifier section

7) *Thermocouple and Temperature Indicator:* Thermocouples are mostly used type of temperature sensors. A thermocouple produces a temperature dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. The type of thermocouples used is K-type thermocouple material. Temperature indicator is a sensor that display the temperature sensed by the thermocouple.

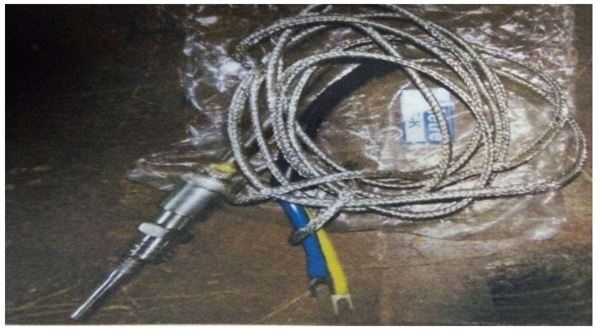

Fig. 9. K-type thermocouple

Fig. 10. temperature indicator

8) *Sling Psychrometer:* There are numerous types of psychrometer but the sling psychrometer is mostly used. It consists of a dry bulb thermometer and wet bulb thermometer mounted side by side in a protective case that is connected to a handle by a swivel connection so that the case can be easily rotated. The sling psychrometer is rotated in an air for approximately one minute after which the readings from both the thermometers are taken. This process is repeated several times to make sure that the lowest possible wet bulb temperature is recorded. The sling psychrometer is shown in fig.11

Fig. 11. sling psychrometer

III.EXPERIMENTAL PROCEDURE

The set up consists of air tight and insulated chamber. The chamber is a container box which is divided into two parts by keeping one separator as shown in fig.2 one fitted with humidification chamber and other with copper condenser coil is called dehumidification chamber. In the sump filled with 20 liters of water, two electric heaters of each 2KW capacity is placed. Heater supplies thermal energy to the sea water up to maximum of 90□C. this hot sea water is then pumped to the humidifier chamber by using pump. The regulating valve (control valve) is provided in order to vary the inlet water flow rate. In humidifier chamber water is sprayed by using sprayer. By this the humidification takes place i.e. water vapour is added to the air. Now the natural convection allows these hot vapours to enter the dehumidification chamber where these vapour transfer its heat with the cooling water circulated inside the copper coil. Small capacity pump is provided for cooling water i.e. ambient water circulation. Due to the contact of vapour with cooling coil it condenses and hence pure water is collected in dehumidification chamber. It is then collected in storage tank from outlet of dehumidifier. The remaining water in humidification chamber is recirculated by directing its outlet to the sump. Whenever the hot water is sprayed in air, the dry bulb temperature as well as relative humidity increases there by increasing its dew point temperature. Hence these hot water vapour condenses whenever it comes in contact with ambient water of temperature around 25-29□C.

1) *Stage-1:* In order to analyze the performance of humidification and de-humidification system in the first stage experimentation is done by varying humidifier in-let water i.e., salt water temperature by keeping de-humidifier in-let water temperature, flow rate of water and relative humidity constant. In order to perform experiment 20 litres of feed water which is available in the sump is heated by two electric heaters of 2 KW capacity until required temperature is achieved. The temperatures of feed water maintained are 60□C, 70□C and 80□C respectively. The indication of temperature is given by thermocouple which is calibrated to show the value of temperature in the temperature indicator. The flow rate is kept constant by using turbine flow meter. For maintaining same relative humidity each experiment is carried out in the same atmospheric condition for around 30 minutes. Here de-humidifier in-let water used is same salt water but not heated it is supplied from another sump by using small pump. The output of these experiments that are done is quantity of fresh water in de-humidification chamber.
2) *Stage-2:* In this stage by keeping humidifier inlet water temperature, flow rate of water and relative humidity the de-humidifier inlet water temperature are varied. The different temperatures for de-humidifier inlet water are maintained by keeping ice blocks. Indication of temperature is achieved by using thermocouple. In this stage also the output is the amount of fresh water collected in the outlet of de-humidification chamber.
3) *Satge-3:* In this stage experiments are done by varying humidifier inlet water flow rate. The variation is done using turbine flow meter. Each experiment is carried out by keeping de-humidifier inlet water temperature, humidifier inlet water temperature and relative humidity constant. Five experiments are carried out each for a duration of 30 minutes. The input and output parameters in this stage of experiment is humidifier inlet water flow rate and amount of water collected in the de-humidification chamber respectively.
4) *Satge-4:* By varying relative humidity of atmosphere and keeping humidifier inlet water temperature, de-humidifier inlet water temperature and flow rate constant experimentation is carried out. The variation in relative humidity is obtained by doing experiments in different time periods of the day (i.e. Morning, afternoon and evening) and similar experimentation is repeated for other two days too. The output of these experiments is quantity of fresh water.
5) *Stage-5:* The fresh water collected by doing different experiments in humidification and de-humidification desalination system is taken for its quality test to determine different contents of it. Water testing is carried out for different parameters like pH, ammonia, calcium, magnesium, total hardness, alkalinity and nitrite.

TABLE I Experimentation Table

S.no	Variable Parameters	Constant Parameters	Input	Water Collected (ml)
1	Humidifier inlet water temperature (□C)	De-Humidifier inlet water temperature, flow rate, relative humidity	60	90
			70	140
			80	170
2	De-Humidifier inlet water temperature (□C)	Humidifier inlet water temperature, flow rate, relative humidity	20	125
			50	105
			29	95
3	Flow rate m^3/Sec	Humidifier inlet water temperature, De-Humidifier inlet water temperature, relative humidity	7.59	65
			9.83	80
			10.71	90
			12.5	100
			20	180
4	Relative humidity (□C)	Humidifier inlet water temperature, De-Humidifier inlet water temperature, flow rate	76	100
			78	90
			80	80
			83	60

IV. RESULTS AND DISCUSSION

A. Effect of humidifier inlet water temperature on quantity of fresh water

The experiments are carried out by keeping following parameter constant.
Flow rate of feed water = 9.83 litres/minute
Dehumidifier inlet water temperature = 29□C
DBT of atmosphere = 36□C
WBT of atmosphere = 34□C
Relative humidity = 76%
The graph showing the amount of water collected by varying the humidifier inlet water temperature is shown in Fig. 12

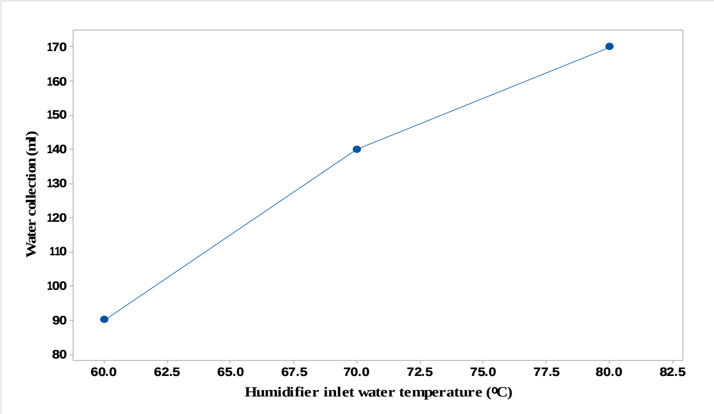

Fig. 12. humidifier inlet temperature VS water collection

Based on the above result we can conclude that more water will be collected if we increase the feed water temperature. The higher the temperature of hot feed, the higher the rate of evaporation and thus fresh water out.

B. Effect of dehumidifier inlet water temperature on quantity of fresh water

The experiments are carried out by keeping following parameter constant.
Flow rate of feed water = 9.83 litres/minute
Humidifier inlet water temperature = 60□C
DBT of atmosphere = 35□C
WBT of atmosphere = 33□C
Relative humidity = 80%
The graph showing the amount of water collected by varying the dehumidifier inlet water temperature is shown in Fig. 13

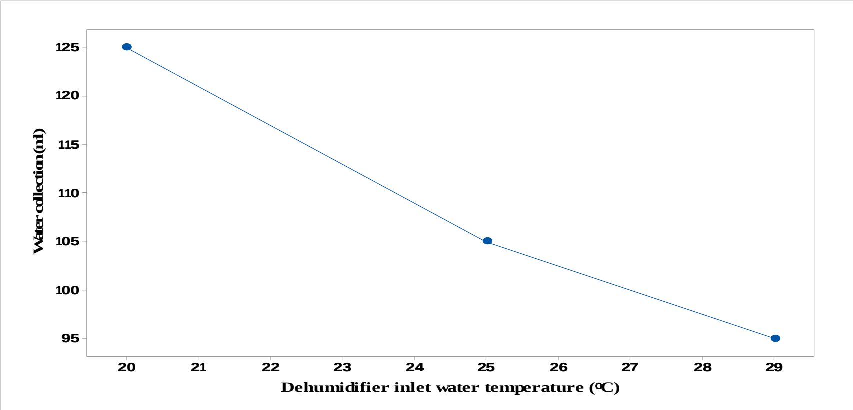

Fig. 13. Dehumidifier inlet temperature VS water collection

Based on the above data it is clear that the quantity of fresh water production increases if cooling water temperature in dehumidification chamber is less. It is because the range of difference between dew point temperature in the chamber and condenser temperature increases by decreasing cooling water temperature there by increasing the condensation.

C. Effect Of Humidifier Inlet Water Flow Rate On Quantity Of Fresh Water

The experiments are carried out by keeping following parameter constant.
Humidifier inlet water temperature = 70□C
Dehumidifier inlet water temperature = 29□C
DBT of atmosphere = 35□C
WBT of atmosphere = 32□C
Relative humidity = 78%
The graph showing the amount of water collected by varying the humidifier inlet water flow rate is shown below.

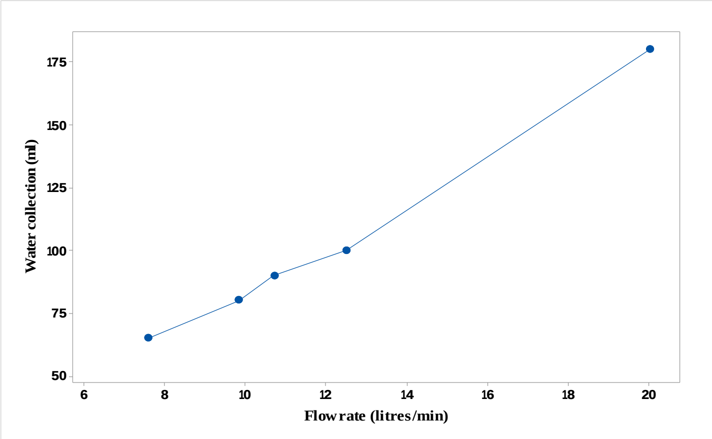

Fig. 14. Mass flow rate of humidifier inlet water VS water collection

Based on the above result it can be noted that the water production increases by increasing the flow rate of inlet feed water. It can be done by using higher capacity pump. The reason behind above result is that as the flow rate increases, the rate of evaporation of water in humidification chamber increases there by producing more water vapour and this vapour condense in dehumidification chamber to give more water.

D. Effect of relative humidity of atmosphere on quantity of fresh water

The experiments are carried out by keeping following parameter constant.
Humidifier inlet water temperature = 60□C
Dehumidifier inlet water temperature = 29□C
Flow rate of feed water = 10.71 litres/minute
The graph showing the amount of water collection at different value of atmospheric air relative humidity is shown below.

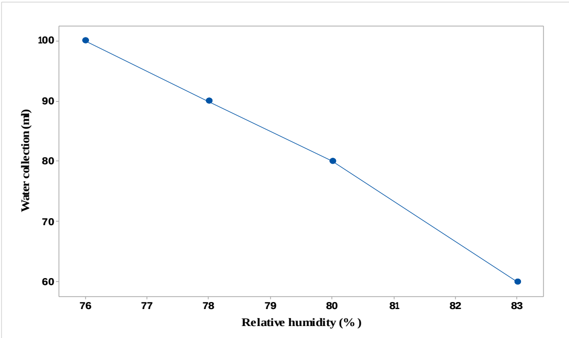

Fig. 15. Relative humidity VS water collection

Based on the above data we can conclude that the fresh water production will be more if relative humidity of atmosphere is low. It is because with low relative humidity holds only a small percentage of the total possible quantity of water vapour that it is capable of holding at the same temperature. In this case the potential of evaporating an extra amount of water is very high. Relative humidity is generally less in afternoon.

V. CHEMICAL ANALYSIS OF WATER

Table 2: Experimental Results

S.no	Parameter	Result	Remarks	Standards
1	pH	6.8	A	6.8-8.5
2	Ammonia(NH4) (total ammonia nitrogen)	0.23	A	<1
3	Calcium	4	NA	>23
4	Magnesium	51	NA	2×calcium
5	Total hardness	220	A	150-400 ppm
6	Alkalinity(HCO_3)	36	NA	120-200
7	Nitrite	0	A	<0.1

From the result of water testing, it is evident that the calcium content in the water is remarkably low than the required content. Other parameters are observed to be almost well within the range.

VI. CONCLUSIONS

Following conclusions are made from the present work on fabrication and experimental investigation on thermal desalination system by using humidification and dehumidification technique:

1) A prototype of thermal desalination system for producing fresh portable water from saline water is successfully fabricated and installed with humidification and dehumidification technique using low cost materials.
2) From the experimental investigation it is found that the temperature of humidifier inlet water plays very crucial role for the production of dehumidifier fresh water. The higher the temperature of the hot feed, the higher the temperature of the hot feed, the higher the rate of evaporation and thus higher will be the amount of fresh water output. For different experiments carried out by varying humidifier inlet water temperatures (60□C, 70□C, 80□C), water yield in dehumidifier section is found to be maximum i.e. 170 ml at a temperature of 80□C for 30 minutes of time.
3) The fresh water collection in dehumidifier section is found to be maximum if we use dehumidifier inlet water having less temperature. Out of all the experiments carried out at 20C, 25C and 29C of dehumidifier inlet water temperature more water production is found to be at 20C and the amount collected is 125 ml for 30 minutes.
4) The flow rate of humidifier inlet water is also major parameter to decide amount of fresh water collection. Out of 5 experiments carried out at flow rate of 7.59 liters/min, 9.83 liters/min, 10.71 liters/min, 12.5 liters/min, and 20 liters/min, more water of 180 ml is found to be produced at higher flow rate i.e. 20 liters/min of the humidifier inlet water temperature.
5) The quantity of water collected in dehumidification section is found to be maximum at low relative humidity of atmospheric air. Out of 4 experiments carried out at 76%, 78%, 80% and 83%, more water i.e. 100 ml is found to be collected at 76% relative humidity value. The relative humidity (RH) of atmospheric air is found to be low at afternoon sessions, hence more production of fresh water quantity is achieved.
6) According to the water testing result all the parameters like PH, ammonia (NH_4), hardness, alkalinity (HCO_3) and nitrite is found to be adequate expect calcium and magnesium. Some post treatment should be done in order to make it perfectly potable.

VII. FUTURE SCOPE

1) By doing pre-treatment for feed water before admitting to humidification chamber using filters, corrosion and scale formation on dehumidifier coil and on whole set up having pipes, chambers etc. can be diminished. This leads to the high efficiency of desalination system.
2) By using desalination in different stages (not more than 3) through more number of desalination chambers, productivity can be improved.
3) This system is more useful if we employ low grade renewable energy sources. Like solar, geothermal etc. as heating source for feed water. Even waste heat from industry can also be utilized for heating feed water.
4) Instead of water heating, if we heat air then performance can be enhanced. But heating cost is high for air. Solar air heater is best suited for this type of desalination system.
5) By doing post treatment for water we can make it perfectly potable.
6) The concept of humidification and dehumidification technique can be used in coastal and arid area in order to do farming by utilizing solar green house for water desalination.

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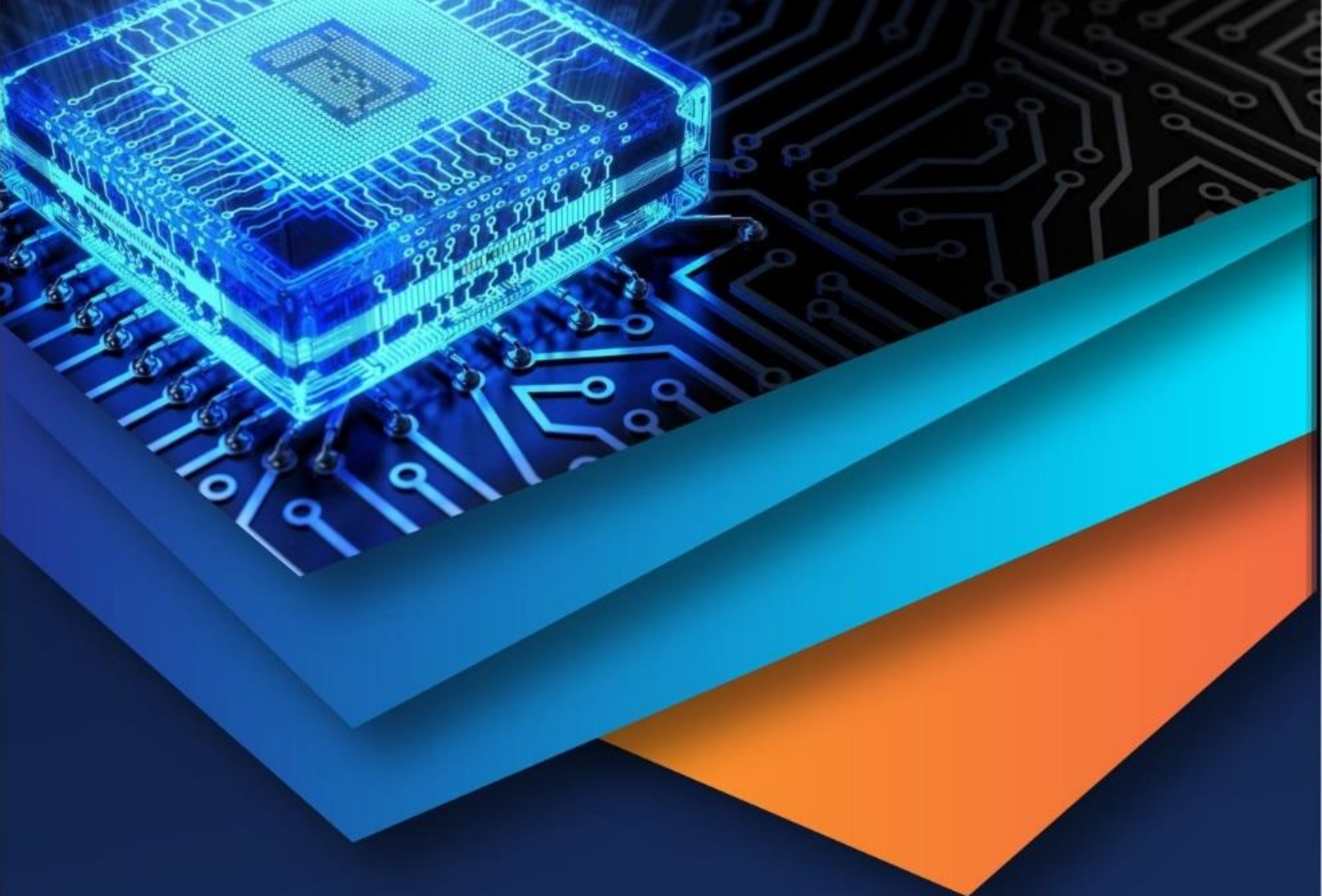

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