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Studies on open loop and closed loop systems of humidification and dehumidification techniques for water desalination

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ABSTRACT

The humidification and dehumidification technique is an interesting one adopted for production of fresh water when the demand is centralized. This technique presents several advantages such as flexibility in capacity, installation and operating costs. Feasibility of the process can be justified economically because of the requirement of low heat energy by the process which can be obtained from various alternative energy sources like geothermal, solar, wind etc.

The present work is a study of both theoretical and experimental approach to desalination with humidification and dehumidification which is a promising technique of production of fresh water at small scale (few liters/hr). A general model based on heat and mass transfer balances in each component of the system was developed and used to optimize the system's characteristics. The production of fresh water depends on the ratio between the salt water and the air mass flow rates. In this paper it is discussed that, if the ratio is continuously adjusted for optimum performance, it is possible to produce some quantity of fresh water daily per square meter of chamber surface on a typical time. The performances for open and closed air loop systems are presented.

The installation consists of two compact units containing a closed loop which is an air cycle and the other is an open loop in which the air is taken from the atmosphere and heated. Air is heated and passed through sprinkled raw hot water chamber counter currently (humidifier), so that the air humidifies and the water vapour along with non-condensable air is dehumidified. Further it is passed through a refrigerator and condensed to recover fresh water.

KEYWORDS

Desalination;
Humidification;
Dehumidification;
Fresh water production.

INTRODUCTION

Water, known as the universal solvent is a very vital commodity for the sustenance of human activities and as the immortal of nature. Water has a deep influence on the development and progress of mankind. But, today there is an acute dearth in the water resources. Almost two thirds of the rain water in its transit travels through the earth rendering itself brackish. So a special technique that is based on the production of fresh wa-

ter using humidification and dehumidification is used for making the water potable.

Desalination refers to a process where salt water is converted to fresh or drinkable water. Different methods used for this purpose are Multi stage flash distillation, multiple effect distillation, vapour compression distillation, electro dialysis, reverse osmosis, freezing, solar humidification and membrane distillation. Each process has its own advantages and disadvantages as discussed later.

In nature, desalination occurs by water cycle. Evaporation of water from the surface of the sea and from the surfaces of water bodies on the earth takes place using solar energy, form as clouds. The rain from the clouds falls partly on sea and partly on earth. As it moves over and through the earth it dissolves minerals and other materials, becoming salty. During its transit to the sea a part of the water is evaporated by sun's energy. This evaporated water leaves behind the salts and the resulting water vapour forms clouds, which produce rain, continuing the cycle.

In this present projects are tried to mimic this natural cycle by using a humidification and dehumidification cycle in both the models. The present models are used to take input as both raw water and saline water. The main objectives of developing the closed cycle model and open cycle model is to heat the unsaturated air using air heater and humidify the air making contact with raw water, later dehumidify the condensable water vapour by passing through a refrigerated cold surface, finally recovering the fresh water.

It was found that the performance of the system was strongly dependent on the temperature of inlet salt water to the humidifier, the mass flow rate of salt water, and the mass flow rate of the process air. There existed an optimum rotation speed for the fan corresponding to an optimum mass flow rate of air with respect to both thermal efficiency and water production. The unit worked perfectly and the thermal efficiency was above 80%. Other low-grade heat resources such as waste heat can also be utilized to drive the desalination process. It was expected that the unit would be of great potential for use in desalination in arid areas and isolated islands.

MATERIALS AND METHOD

Closed loop system

Desalination of Water using humidification & Dehumidification Techniques is an experimental analysis. The marine or surface water is taken in the tank and air was circulated throughout the system as shown in figure below. The system was equipped with humidifier, dehumidifier, compressor, pump, spray chamber,

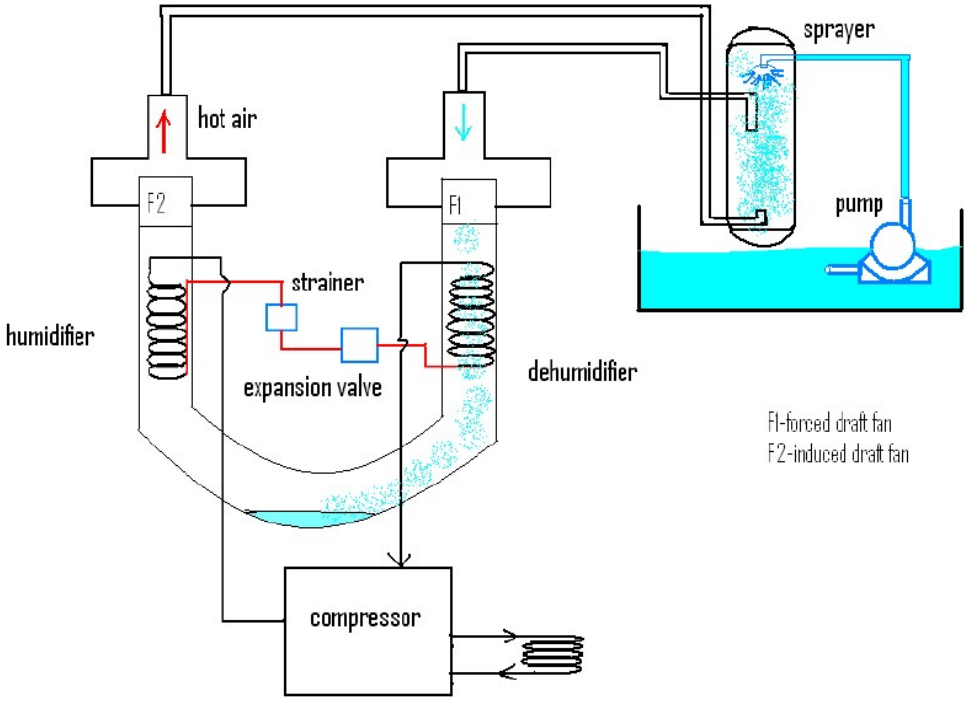
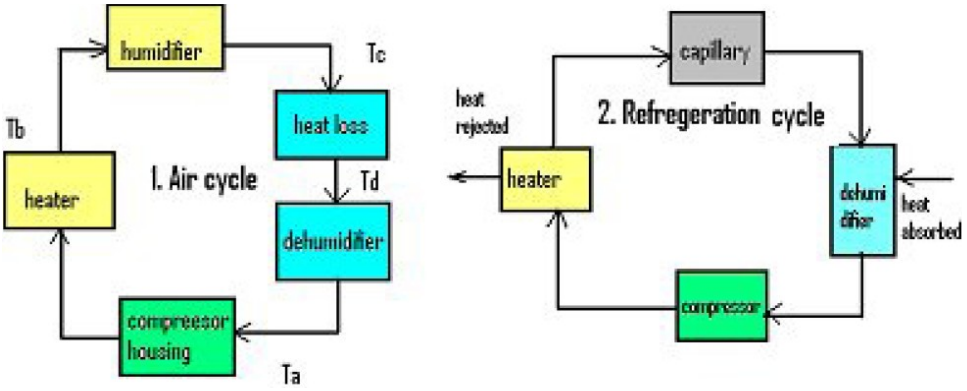


Figure 1 : Diagram of closed loop system

sprayer, coils, forced fan, induced fan and valves, electric power. Initially, in the system, air was passed through the humidifier by the induced draft fan and heated with the help of hot coil continuously, and then the hot air was passed through the humidification / spray chamber. Here the sprayer which was sprayed the water from top to bottom, the hot air was passed from bottom to top in the humidification chamber, means it is a counter current flow. In the humidification chamber the hot air flows in counter current and contact with sprayed water flow, then the mass transfer is taking place between them. Then water phase changed to vapor phase partially, then remaining water flows down.

The water vapor humid air is passed through condenser / dehumidifier and condensed on the cooling surface in dehumidifier chamber. Then the pure water collects from the bottom of the U-tube. Here, the main concept of this technology has been to design of the humidifier and dehumidifier to improve the heat and mass transfer rates by increasing the gas liquid contact area and achieve multi stage effect. These technologies are mainly classified as closed air cycle, closed water cycle systems, and the refrigeration cycle for absorption and rejection of heat as shown in figure 1.



Open loop system

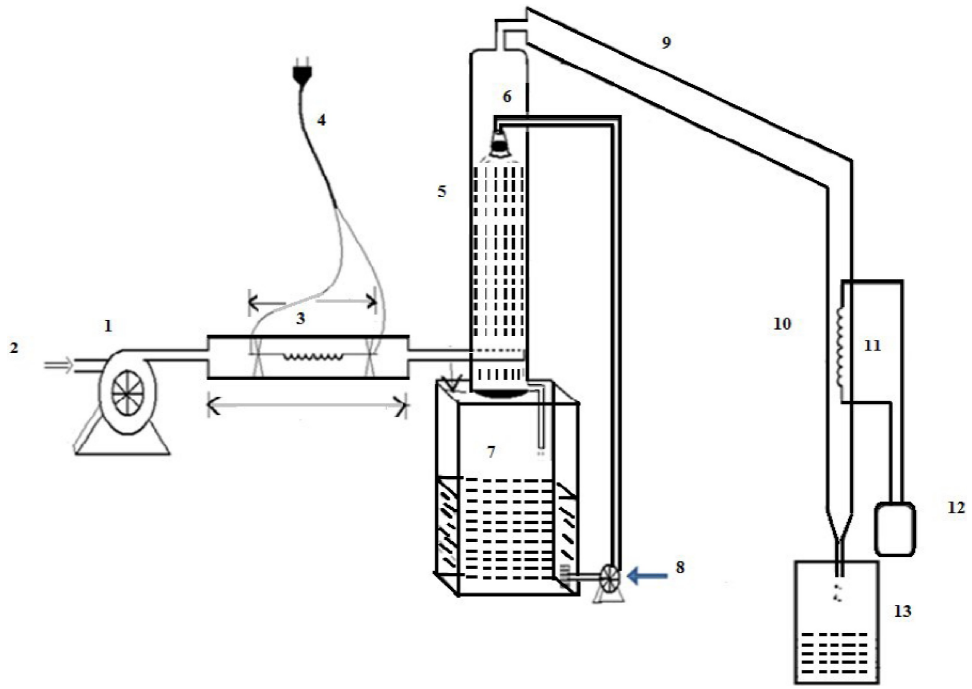
Desalination of Water using humidification & Dehumidification Techniques is an experimental analysis. The marine or surface water is taken in the tank and air was circulated from the atmosphere through the system as shown in figure below. The system was equipped with humidifier, dehumidifier, blower, compressor, pump, spray chamber, sprayer, coils, and valves, electric power. Initially, in the system, air was passed through the humidifier by the induced draft fan and heated with the help of hot coil continuously, and then the hot air was passed through the humidification / spray chamber. Here the sprayer which was sprayed the water from top to bottom, the hot air was passed from bottom to top in the humidification chamber, means it is a counter current flow. In the humidification chamber the hot air flows in counter current and contact with sprayed water flow, then the mass transfer is taking place between them. Then water phase changed to vapor phase partially, then remaining water flows down. The water vapor humid air is passed through condenser / dehumidifier and condensed on the cooling surface in dehumidifier chamber. Then the pure water collects from the bottom of the U-tube. Here, the main concept of this technology has been to design of the humidifier and dehumidifier to improve the heat and mass transfer rates by increasing the gas liquid contact area and achieve multi stage effect. These technologies are mainly classified as closed air cycle and closed water cycle systems. And in the other case also considered that the open cycle of air flow and closed cycle of water flow.

Humidifier:

Material of construction	= PVC
Air blower, ID	= 8cm
Connection pipe of air blower, ID	= 7cm
heater pipe, ID	= 10.5cm
Length of the air heater zone	= 60cm (Copper)
Height of humidifier column	= 76.5 cm
Inner diameter of humidifier	= 15.5cm

A humidifier has been provided where an unsaturated hot air is sent and the air is humidified by making contact with sprinkling raw water in counter- current fashion. The air is maintained at specific temperature using air heater and unsaturated air is sent through humidifier and made saturated.

Dehumidification:



1-blower, 2-air inlet flow, 3- air heater, 4-electric plugin, 5-humidifier, 6-water sprinkle, 7-raw water tank, 8-pump, 9-air carrier, 10 -dehumidifier, 11-refrigirator coil surface, 12-compressor, 13-treated water.

Figure 2 : Schematic diagram of open loop system

Material of construction	= Copper coil
Length of Copper coil	= 400cm (4meters)
Capillary tube length	= 304.8 cm
Capillary diameter	= 0.5 cm
Height of humidifier column	= 90 cm (PVC)
Inner diameter of humidifier	=10.5cm

Dehumidification is the technique in which saturated comes in contact with a cool surface where the excess moisture present in the air corresponding to saturation at that particular temperature gets condensed.

The above two principles are used to desalinate water. An experimental set up has been fabricated to produce pure water. In the present process the raw tap water contact with heated air in a humidifier where mass transfer takes place from water phase to vapour phase. When the humid air subjected to cooling which results in condensation of water.

Humidity influence on air temperature

Humidity is defined as the amount of moisture in the air. Air contains a certain amount of water vapour. The amount of water vapour any mass of air can contain depends on the temperature of the air: the warmer the air is, the more water it can hold. A low relative humidity means that the air is dry and could hold a lot more moisture at that temperature.

For example,

At 20 ^{0}C (68^{0}F), 1 m^3 of air can hold a maximum of 18 grams of water.

At 25 ^{0}C (77^{0}F), 1m^3 of air can hold a maximum of 22 grams of water.

At 0 ^{0}C (32^{0}F), 1 m^3 of air can hold a maximum of 5 grams of water.

Above conditions shows relative humidity is 100%, if it contains 11 grams of water, the relative humidity is 50%, if 0 grams of water, relative humidity is 0%.

Formulas and model calculations

Humid volume: The humid volume VH is defined as the volume of unit mass of 'dry' air with accompanying water vapor at given temperature and pressure. If Y' is the absolute humidity of a sample of air at atmospheric pressure and temperature T1^{0}K.

Humid volume can be calculated from the following equation assuming ideal gas behavior (volume of 1Kmol of a gas at 1atm and 0 ^{0}C=22.4m^3).

VH = [1/28.97 + Y2 /18.02] ×22.4× [(T1+273)/ 273], in m^3 per kg dry air.

Humid heat: The humid heat CH is the heat energy required to the temperature of unit mass of dry air with

the accompanying water vapor by one degree. At ordinary temperature and pressure heat capacity of dry air, water vapor may be 1.005kJ/kg^{0}k, 1.88kJ/kg^{0}k. Humidity of a sample of moist air is Y', it can be calculated from following equation. CH=1.005+1.88 Y', in kJ/ (kg dry air) (k)

Enthalpy

Enthalpy of a sample of air appears in the energy balance equation of water cooling and many similar operations. It is expressed on the basis of unit mass of dry air. Thus the statement "the enthalpy of the sample of air is H' kJ/kg" means that 1kg of dry air with accompanying water vapour has a heat content of H' kJ with means respect to the specified reference states of air and water. An equation for the calculation of enthalpy of stream of moist air at 1atm pressure and of humidity y' and temperature T1 is given below. It is assumed that y' kg water is vaporized at reference temperature (T^0C) and mixed with 1kg of dry air at same temperature, T^0C, to get (1+y×) kg moist air. If λ is the latent heat of vaporization of water at the reference temperature, the enthalpy is given as

H' = y' λ + CH (T1-T)

(Enthalpy) (Latent heat) (Sensible heat)

Where CH is the humid heat of the air.

If the reference temperature is 0^{0}C, we take λ=2500kJ/kg; so the enthalpy is

H' = 2500 y' + (1.005+1.88 Y') (T1-T), in kJ per kg dry air, the basis of above equation is schematically shown below

Sample calculation

At dry bulb temperature (T1) = 50^{0}C (323.15^{0}k)
Wet bulb temperature (T) = 23.5^{0}C (296.5^{0}k)
Absolute humidity(Y') = 0.01

Humid volume (VH): Humid volume can be calculated from formula

VH = [1/28.97 + Y2 /18.02] ×22.4× [(T1+273)/273]
VH = [1/28.97 + 0.01/18.02]×22.4× [(50s+273)/273]
=> VH =0.930m^3/kg dry air.

Humid heat (CH): Humid volume can be calculated from formula

CH = 1.005+1.88 Y', in kJ/ (kg dry air) (k)
CH = 1.005+1.88(0.01) => CH = 1.0238 kJ/ (kg dry air) (k)

Enthalpy: An equation for the calculation of enthalpy is H' = 2500 y' + (1.005+1.88 Y') (T1-T), in kJ per kg dry air

H' = 2500(0.01) + (1.005+1.88 ×0.01) (50-35) => H2'= 39.166 kJ per kg dry air.

Practical observation

Influence of wet bulb depression on relative humidity at various dry bulb temperatures

At dry bulb temperature (T_1) = 50^{0}C (323.15^{0}k)
Wet bulb temperature (T) = 23.5^{0}C (296.5^{0}k)
Absolute humidity(Y') = 0.01
Wet bulb depression = 50^{0}C - 23.50 ^{0}C = 26.5^{0}C

The above observation of wet bulb depression is obtained when the process is run at 50^{0}C dry bulb temperature.

CONCLUSION

The present open loop method of water desalination produced pure 100 ml of water in 10 minutes when maintained the air flow rate = 4.318m^3/hr, Room temp. = 25^{0}C, Water flow rate = 0.3272 m^3/hr. The present model is used for the production of fresh water taking raw tap water as input in the humidifier and made contact with hot air. Raw tap water can be replaced with the saline water in order to make potable water. The present system of humidification and dehumidification technique of fresh water production can be used for desalination process. It can be replaced with the other contemporary methods, also scale up the present model to improve the efficiency in near future. This technique presents several advantages such as flexibility in capacity, moderate installation and operating costs, simplicity, possibility of using low temperature and low energy (geothermal, solar, recovered energy or cogeneration), etc.

REFERENCES

[1] A.E.Kabeel; Humidification and Dehumidification process of desiccant solution by air injection, Mechanical Power Department., Tanta University, Egypt.

[2] S.A.El-Agouz; A new process of desalination by air passing through seawater based on Humidifica-

tion and Dehumidification process, Mechanical power Engg, Egypt.

[3] Cemil Yamale, I.smail Solmusf; A solar desalination system using Humidification and Dehumidification process: Experimental study and comparison with the theoretical results, Mech. Engg, Middle East Technical University, Ankara Turkey, **220**, 538–551 **(2008)**.

[4] S.A.El-Agouz; Desalination based on Humidification and Dehumidification by air bubbles passing through brackish water, Chemical Eng. Journal, **165**, 413–419 **(2010)**.

[5] Hisham Ettouney; Design and analysis of Humidification and Dehumidification desalination process, Santa Margherita Ligure, Italy, **183(1–3)**, 341–352 1 November **(2005)**.

[6] Rihua Xiong, Shichang Wang, Zhi Wang; A mathematical model for a thermally coupled Humidification and Dehumidification desalination process, Desalination, **196(1–3)**, 177–187 5 September **(2006)**.

[7] www.Elsevier.com.

[8] Perry's Chemical Engineer's Handbook, the McGraw-Hill Companies, Inc.