International Journal of Engineering & Technology, 7 (3.7) (2018) 448-451

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design of a Closed Air Open Water Humidification Dehumidification Desalination System

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Abstract

Desalination is the processes used to generate pure water from seawater. Humidification-Dehumidification (HDH) desalination is a low temperature thermal desalination process where the required thermal energy can be obtained from low quality sources. This paper details the design, analysis and fabrication of a Closed Air Open Water (CAOW), Saline Water Heated HDH equipment, capable of producing 50 litres of water in 6 hours. The main components, i.e. the humidifier, water heating chamber and dehumidifier were constructed from SS 3048 in order to resist corrosion. Multiple designs for sparger were considered, and keeping in mind the pressure drop experienced by the air, spider type spargers were chosen. The equipment is capable of studying the effect of operating parameters, such as liquid column height, superficial gas velocity, etc. on dehumidifier and humidifier effectiveness. It is also proposed to use different carrier gases in place of air, and a mechanism consisting of multiple valve-pipe arrangement was designed and fabricated in order to facilitate removal and filling of carrier gas in the equipment.

Keywords: *CAOW, Carrier gas, Desalination, Sparger.*

1. Introduction

Different types of water desalination processes have been developed. Mainly desalination processes can be classified into the following two categories: phase change (thermal processes) and single phase (membrane processes). HDH is a thermal desalination process which uses air as a carrier gas to desalinate seawater. The seawater is heated by some thermal source and humidifies the air. This air goes into a dehumidifier, where pure water is produced. The HDH cycle consists of three components: (i) air or brine heater, which uses heat from solar, geothermal or other sources, (ii) humidifier or evaporator, (iii) dehumidifier or condenser. HDH systems are suited for small scale applications, since they have no high maintenance equipment like membranes or high temperature steam lines

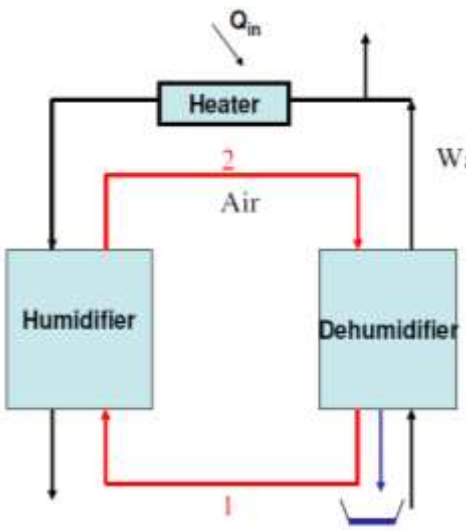

Figure 1: CAOW water heated system

1.1 Closed-Air Open-Water (CAOW) Water Heated Systems

A schematic of the CAOW system is shown in Figure-1. Air enters the humidifier, where it is heated and humidified. This air flows to the dehumidifier where it loses heat and moisture. Water is supplied to the cycle into the dehumidifier, and excess water is drained at the humidifier. Since the air recirculates between the humidifier and the dehumidifier, it is known as the Closed Air Open water cycle.

2. Design Methodology

2.1 Humidifier

Most commonly used humidifiers are spray towers, wetted wall towers and packed bed towers. When water is brought into contact with unsaturated air, some amount of water evaporates and humidifies the air. The humidifier used here is of packed bed type (Figure-2(a)). Heated water is sprayed at the top of the packed bed. Air flows from the bottom, through the packed bed and exits at the top.

2.2 Dehumidifier

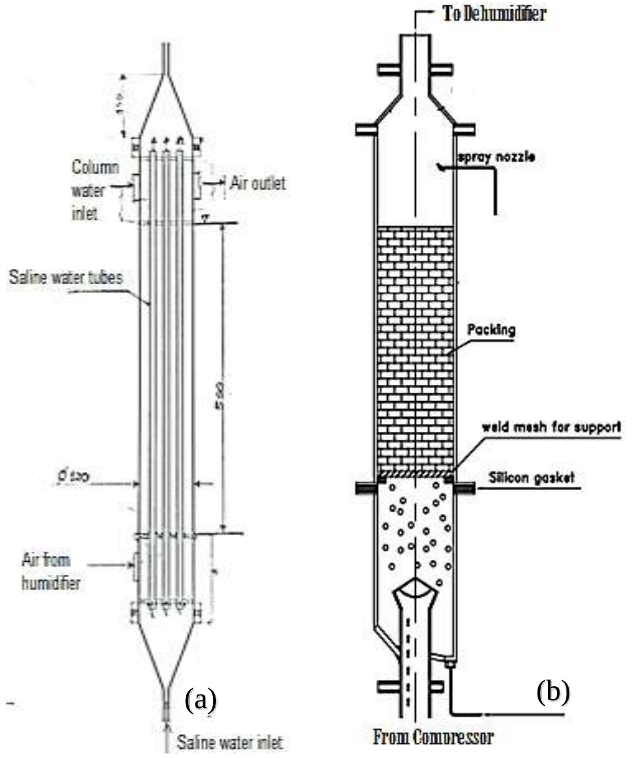

Figure 2: (a) Packed bed humidifier (b) Bubble column dehumidifier

The dehumidifier is a bubble column, constructed similar to a shell and tube heat exchanger (Figure-2(b)). On the shell side, the column liquid is present, through which the air is bubbled. On the tube side, saline water flows to absorb the latent heat of condensation and maintain the column liquid at constant temperature.

2.3 Air Sparger

The design is a spider type sparger with multiple arms (Figure-3). The arms are made from ½ ” pipe with 3 mm holes drilled. The sparger arms are placed between the saline water tubes. This sparger is placed at the bottom of the dehumidifier column.

2.4 Packing material

Packed bed column with pall rings (random packing) is being used. The gas-liquid contact in a packed column is continuous. The liquid flows down in the column over a packing surface and the vapour (or the gas) moves counter-currently, up the column.

2.5 Material selection

SS3048 pipes, Class B, were chosen for their corrosion resistance. As per IS 1239, Class C pipes are to be used for steam only. Class A does not have the required diameter for the humidifier column. Hence we use Class B 140mm OD pipes.

3. Process Description

3.1 Saline Water Flow

Saline water is drawn by the pump from the saline water tank and sent to the dehumidifier through the internal tubes. The column liquid pre-heats the saline water from the recovered latent heat of condensation. The saline water then flows into the heating chamber through the coil. Then it is sprayed through the liquid distributor inside the humidifier. Excess water is collected at the bottom and drained into a collecting tank.

3.2 Air Flow

Air is pumped by the compressor into the humidifier at the bottom, where it comes in contact with drops of hot water. Packing material is used to increase the surface area of heat and mass transfer. The air is humidified and heated as it travels upward through the humidifier. The air then goes to the bottom of the dehumidifier through a no-return valve. It is bubbled through a sparger into the column liquid. As the air bubbles rise, they get cooled and condensation occurs. The dehumidified air leaves the dehumidifier from the top and enters the carrier gas removal mechanism.
Condensation in the dehumidifier leads to increase in the column liquid level. This extra liquid is the pure water produced.

3.3 Carrier Gas Removal

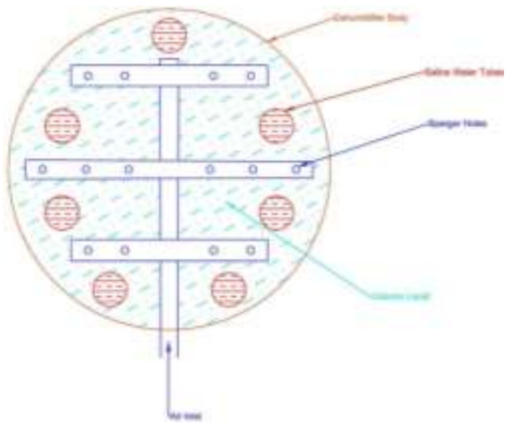

Figure 3: Schematic of finalised air sparger

An arrangement to facilitate removal of carrier gas was fabricated using multiple ball valves (Figure-5). This arrangement is placed in the air stream leaving the dehumidifier. During normal operation (indicated in blue), all the valves except Valve 4 are open and the gas flows towards the air receiver tank. When flushing out the existing gas (indicated in red), Valve 2 is closed, and others are open. To ensure complete removal (indicated in green) Valves 1 and 3 are closed, with Valves 2 and 4 open.

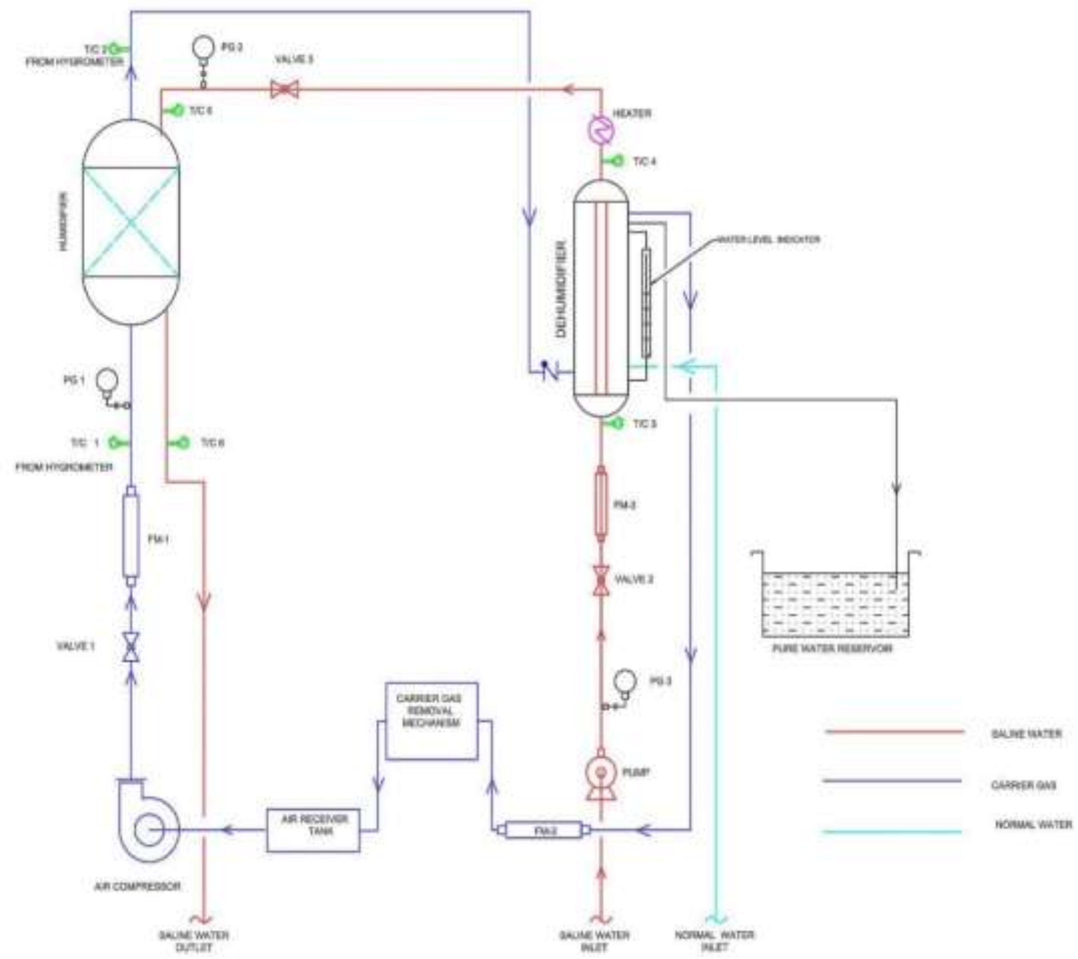

Figure 4: Process flow diagram of the desalination system

4. Calculations

4.1 Humidifier Design

To estimate the column diameter, the following data are assumed:
Pure water production rate: 50 litres in 6 hours.
Recovery ratio = 0.1.
Entry to humidifier: saturated at 30 °C
The correlations are taken from Treybal (1980). For our case, the value from the graph is 0.045.

$$\frac{\acute{G}^2 C_f f {\mu_L}^{0.1}}{\rho_G(\rho_L-\rho_G)} = 0.045 \qquad (1)$$

4.2 Dehumidifier Design

The gas holdup is predicted using relations from Akita and Yoshida (1973).

a. Diameter of bubble:

$$d = 0.0071\, Re^{-0.05} \qquad (2)$$

b. Gas Holdup:

$$\frac{\varepsilon_G}{(1-\varepsilon_G)^4} = 0.2\left(\frac{gD^2\rho_L}{\gamma}\right)^{\frac{1}{8}}\left(\frac{gD^3}{\upsilon_L^2}\right)^{\frac{1}{12}}\left(\frac{U_G}{\sqrt{gD}}\right) \qquad (3)$$

$$k_L a = 0.6 D_L^{0.5} v_L^{-0.12}\left(\frac{\gamma}{\rho_L}\right)^{-0.62} D^{0.17} g^{0.93} \varepsilon_G^{1.1} \qquad (4)$$

c. Volumetric mass transfer coefficient:

4.3 Sparger Design

The methodology for sparger design was adopted from Kulkarni(2010).

a) Critical velocity:

$$V_{o\,critical}^2 = 1.25\left(\frac{d_0\, g(\rho_L-\rho_G}{\rho_G}\right)\left(0.37 + 140H_L\left(\frac{\Delta x}{d_0}\right)^{-1.6}\left(\frac{t}{d_0}\right)^{0.75}\right) \qquad (5)$$

b) Number of holes:

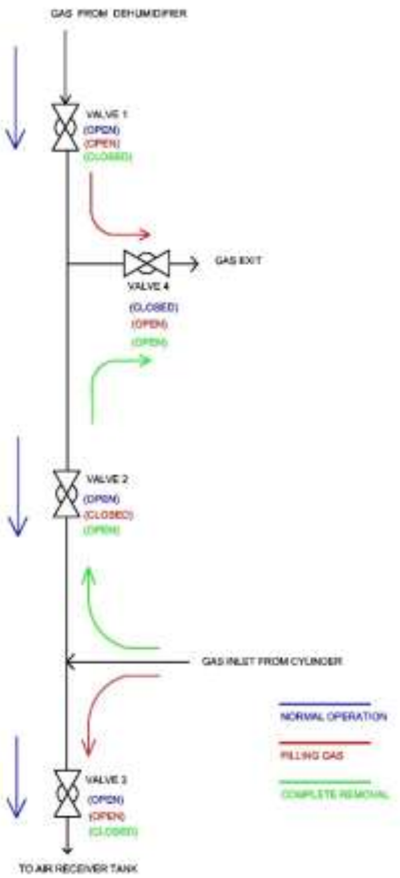

Figure 5: Carrier gas removal

$$N = \frac{D^2 V_G}{V_0 d_0^2} \quad (6)$$

3.4 Computed Dimensions

A. Water pipe sizing:
   a) Velocity = 0.18 m/s
   b) Diameter = 0.5 in
B. Air pipe sizing:
   a) Velocity = 8.28 m/s
   b) Diameter = 0.5 in
C. Humidifier:
   a) Column diameter = 12.8 cm
   b) Column height = 52 cm
   c) Packing height = 47.3 cm
D. Dehumidifier:
   a) Column diameter = 12 cm
   b) Column height = 72 cm
   c) Liquid height = 50 cm
   d) Sparger hole diameter = 3 mm
   e) No. of holes = 14
   f) Gas holdup = 0.336
   g) Volumetric mass transfer coeff = 10.52 s^{-1}

4. Conclusion

From literature review, it was found that CAOW water-heated HDH desalination is best suited for water production in terms of Gained Output Ratio and energy requirements. The dimensions for the various components of the desalination system were calculated using the relevant correlations from literature and the components were fabricated.

Acknowledgement

We would like to thank the Department of Science and Technology, Government of India, for funding this project. We would also like to thank the Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, for the support and encouragement extended by them during the course of this project.

List of symbols

d_0	Hole diameter
D	Diameter of the bubble column
$\acute{G}$	Mass flux
H_L	Clear liquid height
k_L	Volumetric mass transfer coefficient
$\dot{m}_{pw}$	Mass flow rate of produced water
$\dot{m}_w$	Mass flow rate of feed water
h_{fg}	Enthalpy of vaporisation
$\dot{Q}_{in}$	Heat input
t	Thickness of the pipe
U_G, V_G	Superficial gas velocity
V_0	Hole velocity
Δx	Pitch
μ_L	Dynamic viscosity of column liquid
ρ_G	Density of gas
ρ_L	Density of liquid
ε_G	Gas holdup
γ	Surface tension
$\boldsymbol{v_L}$	Kinematic viscosity of liquid

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