Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2016.1145601

57 (2016) 24705–24715
November

Taylor & Francis
Taylor & Francis Group

Water quality improvement studies in LTTD plant

D. Balaji*, K. Jayaraj, S.V.S. Phani Kumar, M.V. Ramana Murthy

Department of Ocean Structures, National Institute of Ocean Technology, Chennai, India, Tel. +91 66783349; email: dbalaji@niot.res.in (D. Balaji), Tel. +91 66783362; email: jayarajk@niot.res.in (K. Jayaraj), Tel. +91 66783353; email: phani@niot.res.in (S.V.S. Phani Kumar), Tel. +91 66783586; email: mvr@niot.res.in (M.V. Ramana Murthy)

Received 11 August 2015; Accepted 13 January 2016

ABSTRACT

Low-temperature thermal desalination plant (LTTD) is a process which involves evaporation of warm surface seawater at 28–29˚C inside a vacuum flash chamber, which is maintained at a subatmospheric pressure of around 24–27 mbar [abs] and the resultant vapor is condensed in the shell and tube heat exchanger using cooling water drawn from deep sea, which is available at 12–13˚C. Two configurations have been used to conduct experiments, namely bare spout and elevated demister configuration. During the operation of LTTD plant located at Agatti Island, an increase in the salinity of product water from 110 ppm during low tide to 570 ppm during high tide is observed in the bare spout configuration. Increased tide level leads to increased flood level inside flash chamber. Increased flood level results in reduction in the separation distance between the brine liquid level and the de-mister. As a result, the salinity level of product water is increased beyond an acceptable limit. In order to bring down the salinity level, a modification is performed on the geometry of the spout pipe and elevation of demister inside flash chamber which is named as elevated demister configuration. The mechanism, which improves water quality by implementing elevated demister configuration and drawbacks of bare spout configuration are discussed in this paper. Necessary experiments are conducted for studying the effect of both the configurations on the product quality. Results based on the experimental studies show a significant improvement in the water quality ranging from 4 to 45 ppm between low and high tides when implementing the elevated demister configuration.

Keywords: LTTD; Pool evaporation; Demister; Spout pipe; TDS; Flash chamber; Entrainment factor

1. Introduction

Low-temperature thermal desalination plant (LTTD) uses a unique technology in which the surface seawater (28–29˚C) is flash evaporated inside a vacuum flash chamber maintained at a pressure of 0.027 bar (abs) at 10.8 m barometric level. The generated vapor from flash chamber reaches the shell and tube condenser through the vapor duct where it gets condensed to form product water. The deep-sea cooling water at 12–13˚C is drawn from a sea depth of around 350–400 m using a long high density poly (ethylene) (HDPE) pipe of 630 mm OD. The length of the pipe varies between 800 and 1000 m depending upon the depth profile from the seashore. Two submersible seawater pumps are being used to supply

*Corresponding author.

1944-3994/1944-3986 © 2016 Balaban Desalination Publications. All rights reserved.

warm surface seawater and cold deep-sea water to the flash chamber (2.8 m dia) and condenser (1.2 m dia), respectively. Seawater pumps are erected inside a concrete rectangular sump of size 8 m × 12 m with 9 m height located in 4 and 5 m water depth. The cooling water pipe is flanged to the sump through a flexible hose for supplying cooling water to the condenser. Vacuum pumps are being used to create and maintain vacuum inside flash chamber and condenser, which is very much essential for continuous production of product water. During the high tide, the difference in height between sea surface level and delivery point (spout tip) of feed water inside flash chamber gets reduced, thus a reduction in the static head of the system occurs that in turn affects the flow rate of feed pump. The bottom of the flash chamber is erected at +10.8 m level from the chartered datum (CD) in view of complete removal of brine discharge water by gravity flow and the spout pipe fixed at chamber bottom whose tip of the mouth is protruded up to +11.17 m from CD. This protruded height comes to around 0.37 m, which is provided for removing the brine discharge water from the chamber without disturbing the flashing of incoming feed water at the spout tip. However, during high tide of 1.6 m level, the brine water level inside the chamber rises up to +11.4 m from CD that completely submerges the spout tip below brine level since the spout tip comes only at +11.17 m level from CD. During high tide, the distance between brine surface and demister face is decreased which enables the carryover saline droplets to reach the demister easily and re-entrainment occurs. Fig. 2 shows the external view of the flash chamber with truncated cone shape integrated deaerator at the bottom. See Fig. 1.

Quality of product water depends on the amount of entrainment/carryover of saline water particles in the vapor stream that escapes from flash chamber to condenser through demister. Carryover depends on factors such as velocity and size of droplets, nature of forces acting on droplet that is moving relative to vapor phase, fluid properties such as surface tension, viscosity, density, bubble dynamics at and below the separation interface (Bagul et al.) [1]. Garner et al. [2] studied the mechanism of droplet formation and its quantification to analyze the carryover. Aiba and Yamada [3], Spiel [4], Rozen et al. [5] performed experiments of droplet size and velocity distribution. Kataoka Isao and Ishii Mamoru [6] developed a correlation for the pool entrainment based on the simple mechanistic modeling and a number of data. According to them, there exist three different regions of the entrainment in the vertical direction from a pool surface. In the first region near to the free surface, the amount of entrainment is independent of height and gas velocity. In the second region, the amount of entrainment decreases with increasing height from the free surface and increases with increasing gas velocity. In the third region, the entrainment increases with increasing gas velocity and decreases with increasing

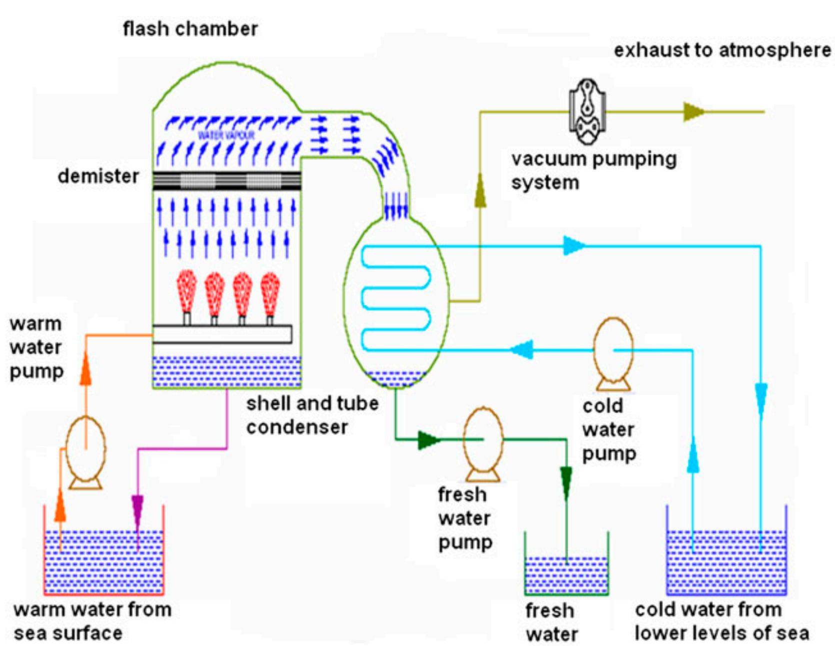


Fig. 1. Schematic View of LTTD plant.

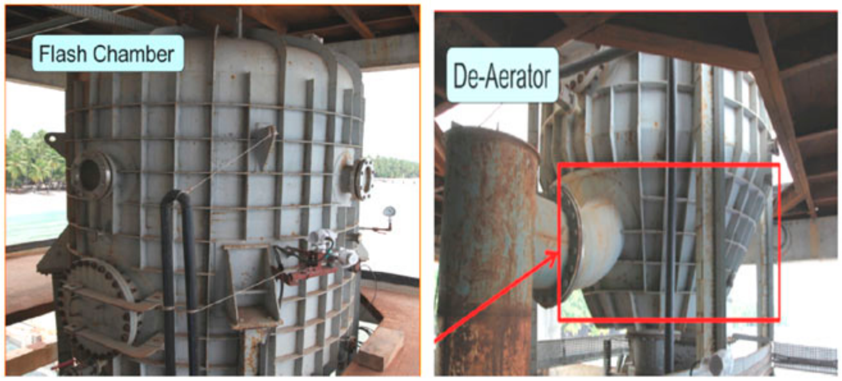


Fig. 2. A view of flash chamber and deaerator.

height due to deposition of droplets. The factors such as size of carryover saline droplets, density of the water vapor, density of the feed water, vapor velocity, vapor viscosity, clearance between the water surface and demister location in flash chamber, and type of demister used, are affecting the quality of product water in desalination plant Kataoka Isao et al. [6]. Rognoni et al. [7] presented a spray system in which the product water quality increased to a remarkable level. In this paper, he suggested a technique in which distilled water will be sprayed over the water vapor traveling in upward direction that hits the saline carrying water droplet away from vapor to avoid increase in salinity. Abdullah et al. [8] suggests that product quality can be improved by increasing droplet separation efficiency with increased demister specific area and packing density, whereas the technique discussed in the present paper shows that the product quality improvement could be achieved by increasing the elevation of demister location.

2. Influence of vapor velocity on carry over droplet size and vapor drag force

The higher the vapor velocity, the greater will be the size of droplet that it could be able to carry. Fig. 3 is plotted using the estimated droplet size and drag force based on the observed plant data such as flash chamber pressure and product water flow rate. Fig. 3 indicates that increase in vapor velocity results in an increase in the size of the water droplet. The diameter shown is the critical diameter i.e. when the droplet size increases more than this diameter, at that particular velocity, then the water droplets settle down under gravity to brine liquid inside flash chamber. If the bigger droplet hits the demister before it settles down from vapor then it would break into very fine particles. These particles could not be captured by the demister because these particles do not have sufficient inertial energy for making an impact with demister and it just follows the vapor passage and reaches the condenser [9]. Decrease in particle size results in reduced capturing efficiency of demister [10].

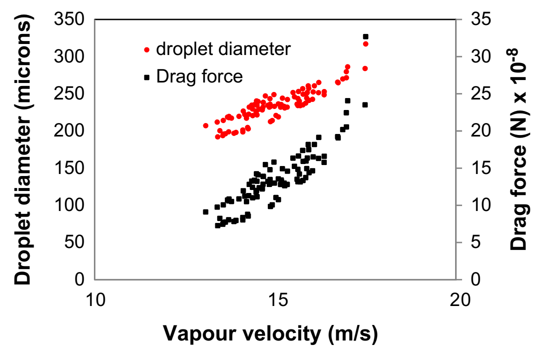


Fig. 3. Vapor velocity vs. droplet diameter/drag force.

The critical diameter of the water droplet is estimated using correlation-(1) suggested by Ettouney [11] in his paper. This correlation is based on the balancing of forces between the vapor and water droplet.

$$\frac{\pi d_d^2}{4} C_d \rho_v V_v^2 = \frac{1}{6}\pi d_d^3(\rho_l - \rho_v)g \tag{1}$$

$$C_d = \frac{24}{Re} + \frac{3}{Re^{0.5}} + 0.34 \tag{2}$$

where d_d is the droplet diameter (m), ρ_L and ρ_v represent liquid and vapor density (kg/m^3), respectively, V_v is vapor velocity (m/s), k is entrainment rate (m/s), C_D is the drag coefficient, and Re is the Reynolds number of vapor.

Fig. 3 shows the estimated values of drag force required to balance the droplet diameters of various sizes at different vapor velocities. Muthunayagam et al. [12] suggested an Eq. (3) for estimating the upward drag force acting on the droplet.

$$F = \frac{\rho V^2}{2} C_D 4\pi r^2 \qquad (3)$$

where d_d is the droplet diameter (m), ρ represents liquid droplet (kg/m^3), V is the vapor velocity (m/s), r is the radius of droplet (m/s), and C_D is the drag coefficient.

Using Eq. (3) the drag force is estimated and shown in Fig. 3. From Fig. 3 it is observed that the required drag force (F) (in Newton for balancing the water droplet) increases with an increase in the droplet diameter as well as the vapor velocity.

3. Effect of vapor velocity on entrainment rate (*k*)

In most of the MSF plants, the vapor velocity varies between 1 and 10 m/s depending mainly on the size of its stages [13]. In the present work, the velocity of vapor is fixed at 16 m/s in order to keep the size and cost of the equipment to an optimum. The following Eq. (4) [14] is used to estimate the entrainment rate (k).

$$V_{\max} = k\left(\frac{\rho_l - \rho_v}{\rho_v}\right)^{0.5} \qquad (4)$$

where $V_{\max}$ is the maximum vapor velocity (m/s), ρ_L and ρ_v represent liquid and vapor density (kg/m^3), respectively, and k is the entrainment rate (m/s).

An experimental study has been carried out for an elevated demister configuration (Fig. 14) for different warm feedwater flow rates and resultant output variables such as total dissolved solids (TDS) of product water; chamber pressure and mass flow rate of product water are observed. Vapor velocity is estimated based on the measured mass flow rate of product water and flashing area. With this value, the entrainment rate for different vapor velocity at different flash chamber pressure is estimated. It is observed from the experiment that when the feedwater flow rate increases, the chamber pressure shows an increasing trend (Fig. 4). This is because, when more amount of feedwater enters the chamber, correspondingly the amount of vapor released from the feed water also increases (Fig. 4), which in turn raises the local pressure. Increase in the amount of release rate of vapor

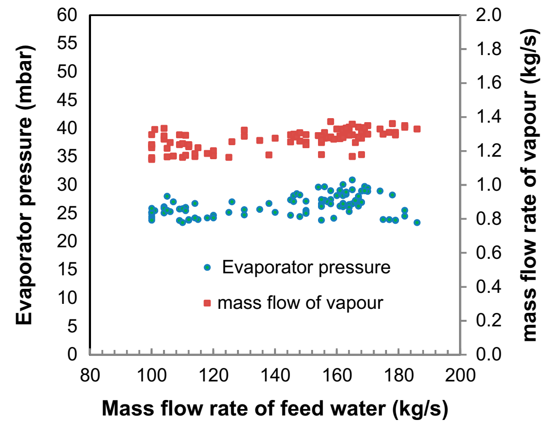


Fig. 4. M_{feed} vs. M_{vap}/P_{fc}.

in seawater inside a flashing chamber results in increase in the vapor velocity. As the vapor velocity increases the entrainment rate increases, which varies between 0.06 and 0.07 m/s corresponding to the vapor velocity of 13.4–17.5 m/s. Entrainment mainly depends on vapor velocity, droplet size, density of vapor and feedwater flow rate. Density of water vapor depends on flashing pressure maintained inside vacuum chamber. It is depicted in Fig. 5 that even though the entrainment rate shows an increasing trend with increase in the vapor velocity, still the measured TDS follows a scattered pattern that varies between 4 and 35 ppm. This could be due to an uneven size distribution of carryover droplets in the clearance available between brine pool and demister. Splashing of seawater in this zone through spouts could rearrange the droplet size distribution in such a way that the fine droplets would grow in size to become bigger and heavier that could not be carried over further by

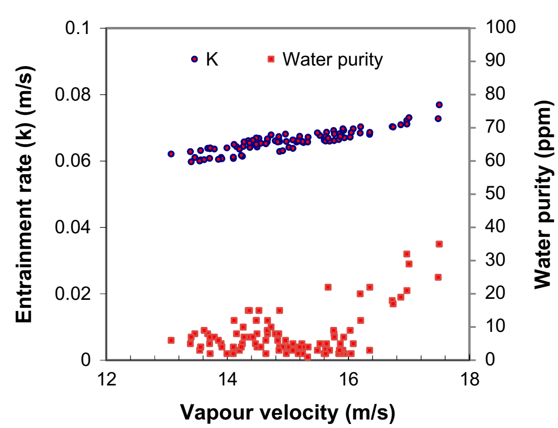


Fig. 5. $V_{\max}$ vs. k/water purity.

upstream vapor. Amount of TDS in this condition mainly depends on the following factors such as how much quantity of bigger droplets shedded from vapor, how much quantity of bigger droplets hits the demister to break into fine particles, and finally how many fine particles re-entrains the demister. For the present study, TDS varies between 4 and 35 ppm, which is favoring the condition in which most of the bigger droplets could have shedded from vapor before reaching demister leaving only few quantity of fine droplets to reach demister that could have given very less TDS to product water.

4. Terminal settling velocity (U_T)

Drag force and buoyancy of vapor acting on carryover water droplet becomes equal to the gravity force of the droplet at a certain velocity known to be the terminal velocity. Falling of droplet at an accelerated velocity becomes slow and reaches constant speed when it reached terminal velocity. As the droplet moves faster under gravity influence, the drag force of vapor acting on droplet increases. At certain speed, both the opposite forces balance each other that made the droplet to fall at constant settling velocity.

The following Eq. (5) [15] is used to estimate the terminal velocity (U_T).

$$U_T = \sqrt{\frac{4gD_p(\rho_L - \rho_V)}{3C_D\rho_V}} \tag{5}$$

where D_p is the droplet diameter (m), ρ_L and ρ_v represent liquid and vapor density (kg/m^3), respectively, and C_D is the drag coefficient.

Terminal velocity depends on the size of droplet and amount of resistance it experiences as a result of upward moving of water vapor and also due to buoyancy offered by the vapor fluid over the droplet. Increase in droplet diameter lead to an increase in the terminal velocity as shown in Fig. 6. In order to settle down the carryover droplet from the vapor, it should be noted that the droplet terminal velocity should be greater than the vapor velocity [15]. The value of the vapor velocity is calculated to be varying between 13 and 17 m/s during the experiment (Fig. 7), whereas the corresponding terminal droplet velocity is estimated to be varying between 18 and 25 m/s (Fig. 7). Increased droplet diameter leads to an increased terminal velocity and increased amount of droplet shedding. This condition is expected mostly when splashing of water takes place through spouts. During splashing, most of the heavier droplets fall back before reaching demister except fine droplets. As a result, the quality of water can be maintained within an acceptable limit.

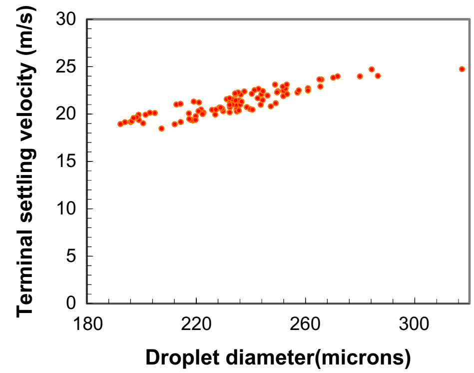


Fig. 6. D_p vs. U_T.

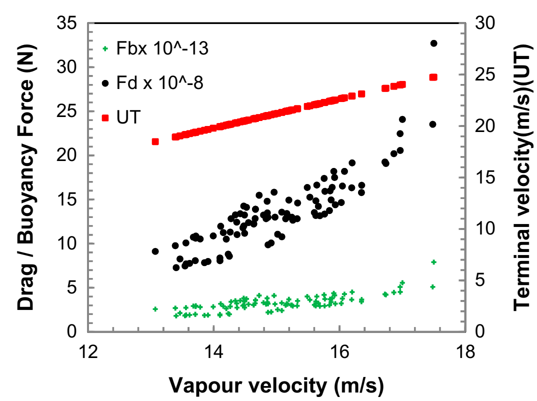


Fig. 7. V_{vap} vs. $F_D/F_B/U_T$.

5. Effect of tidal variation on FC flood level and resultant product water quality

The tidal level measurements are taken directly from the reference scale provided inside the rectangular concrete sump placed at 5 m water depth in the sea, from which the surface warm feedwater is being supplied to the flash chamber using submersible feed water pump. When the tidal level increases, the level of water column, i.e. flood level inside flash chamber also increases. In the above Fig. 8, it is shown that for bare spout configuration (Fig. 10), as the tide level reaches to 1.2 m, the flood level inside chamber is increased to 0.28 m and TDS of product water is measured to be 287 ppm. As the tide level increases to 1.4 m the chamber is flooded with 0.48 m water level with spout tip completely submerged below water level. During this time the TDS is measured as

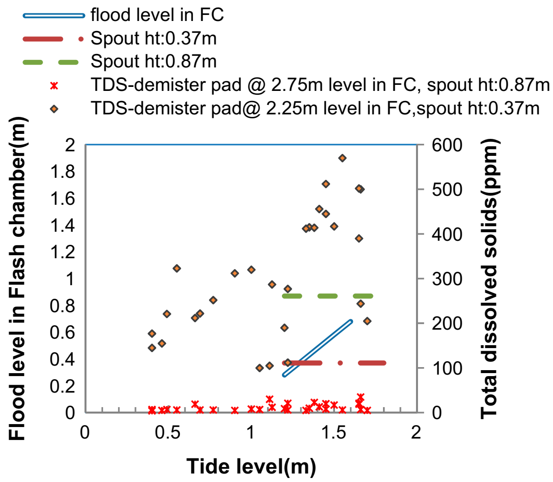


Fig. 8. Tide level vs. FC flood level.

425 ppm. When the highest tide is reached (i.e. 1.6 m) the water level increased up to 0.68 m inside the chamber and corresponding TDS value shows 570 ppm. The decrease in clearance as the tide level increases is depicted in Fig. 9. But in the demister elevation configuration (Fig. 11), the TDS scatters between 4 and 45 ppm for the varying tide level and flood level (Fig. 8). The mechanism that controls the quality of water in these two configurations is discussed in Section 8.

6. Droplet generation mechanism in pool entrainment [16,17]

In pool evaporation systems, droplets are entrained by the mechanisms of bubble bursting, splashing, and foaming near the top of the pool. Bubble bursting generally occurs under the situations where the surface vapor flux rate is very low and when churning action of water on surface is very small. Splashing and foaming occurs, when the pool of liquid under goes violent agitation, as a result of turbulent churning action on surface of water.

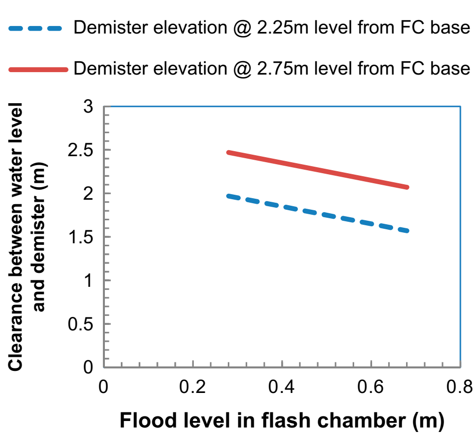


Fig. 9. FC flood level vs. clearance.

Generation of droplets from the free surface of pool of liquid, based on bubble burst mechanism is explained in this segment. In this mechanism, the formation of bubble occurs on the surface as a result of liberation of vapor due to vacuum maintained above pool surface. This bubble will continue to grow until it bursts into fine film droplets.

Bubble bursting happens when the internal pressure inside the bubble exceeds the surface tension offered by the liquid film. These fine film droplets will be easily carried away by the vapor stream in vacuum space as long as their droplet diameter is smaller than critical diameter for the corresponding vapor stream velocity. Entrainment of fine droplets from pool of liquid in large quantity certainly leads to a drastic increase in the salinity of the water especially when the separation distance to the demister filter is short. Prediction of the droplet size distribution above the free surface is highly difficult because the droplet size will vary depending on the vapor release velocity and the bubble bursting size.

Bursting of fully grown spherical big size bubble results in the formation of fine film droplets. Bursting of big size bubble leads to a disintegration of its dome into fine film droplets. Before bursting, full portion comes out of liquid surface in big size bubbles. But in small size bubble, half of its spherical portions are below the liquid surface. During bursting of small size droplet, a small depressed portion is formed on the liquid surface. Due to the surface tension, the surrounding water rushes into that depressed portion simultaneously from all the direction and resulted in collision. This collision lead to rising of water from the center of the depressed portion and ejected into the vacuum space above the pool of liquid. Top portion of the ejected water jet spouted out into a small droplet. This droplet will be carried away by the vapor stream if its diameter is less than critical diameter for that corresponding velocity of vapor, otherwise the droplet will settle back into the pool of liquid. This mechanism is called as momentum exchange droplet ejection mechanism. Detailed drawings related to bubble dome bursting into fine particles and momentum exchange droplet ejection mechanism are available in literatures [16,17].

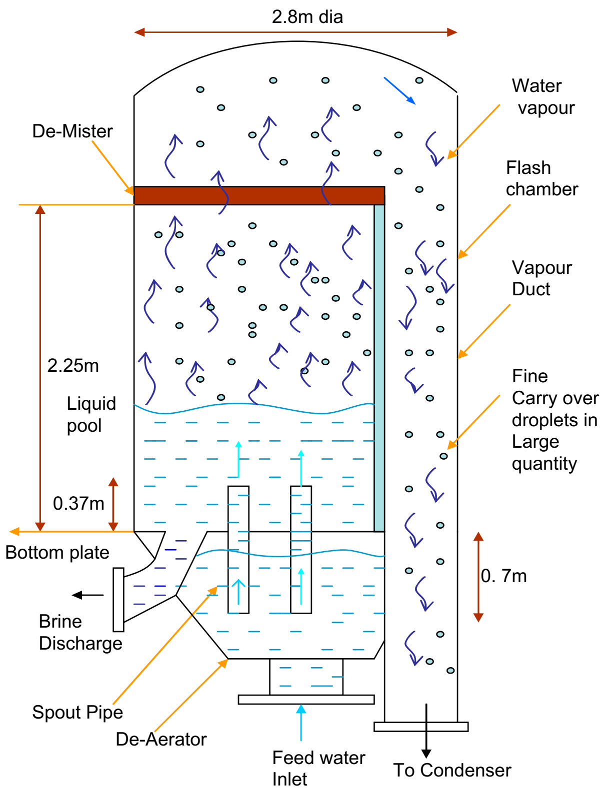


Fig. 10. Bare spout configuration.

7. Experimental setup and measurement procedure

7.1. Bare spout configuration

In this configuration (Fig. 10), the spout pipe is projected into the flash chamber to a height of 0.37 m above flash chamber base with an internal diameter of 0.1 m and it is projected downward to 0.7 m into the deaerator in downward direction. Totally, 24 spouts are fixed inside the flash chamber with a pitch distance of around 0.25 m. Spout pipe possess dual purpose, one for sustaining differential pressure between flash chamber and the deaerator, and other for creating flashing to increase water surface area which helps in enhancing the evaporation rate. During high tide, the flood level rises inside flash chamber in order to develop a water column required for discharging the brine water out of the chamber under gravity flow against the maintained vacuum. Because of raise in flood level, the water surface approaches closer to the demister face. During this time, the TDS of product water is observed to be in the range of around 570 ppm average, as a result of entrainment from pool of liquid. When low tide level reached, the gap between demister and water level increased. During this time, the TDS is reduced to a low value of 110 ppm average. Salinity of product water varied from 110 to 570 ppm between low and high tide during the experiment.

7.2. Elevated demister configuration

Since bare spout pipe in the original configuration is unable to keep the TDS level under control, a modification is executed on the existing spout pipe. In this configuration (Fig. 11), the spout pipe height increased to 0.87 m from 0.37 m and a PVC cone expander of 100NB to 250NB is fixed at the spout tip. The expander cone fitted with a 0.01 m thick and 0.1 m diameter low density poly(ethylene) (LDPE) round disk positioned concentrically in the middle of expander (Fig. 12). Due to increase in spout height to 0.87 from 0.37 m, the flooding of water above spout tip did not occur during high tide, whereas it happened when spout height was kept at 0.37 m. Effect of putting divergent cone at spout tip actually reduces the velocity of water leaves from the spout and end stopper

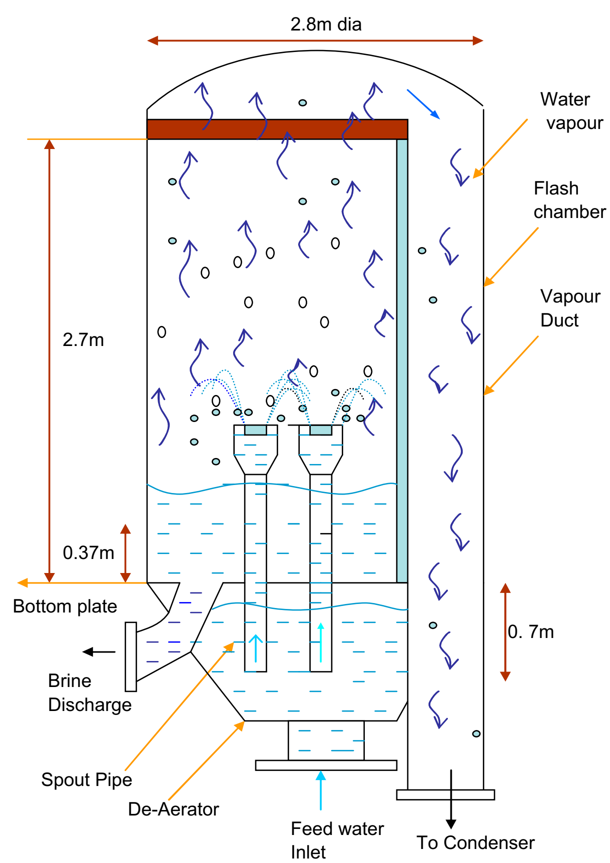


Fig. 11. Elevated demister configuration.

Fig. 12. Increased spouts pipe height with cone expander at spout tip inside chamber.

plate provided at spout tip reduces the velocity head. Therefore, the water jet touching demister directly is avoided. Demister location is elevated to a new level by extending vapor duct height to 0.5 m as shown in Fig. 13. The duct height is increased using SS 304 plates made accurately to the dimensions of the existing vapor duct with 0.01 m thickness pre-welded with supporting angles and with drilled holes for easy installation of plates inside the flash chamber.

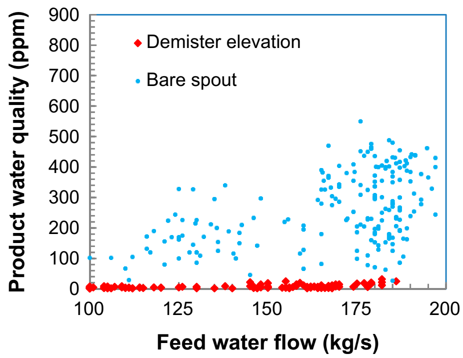
Stainless steel fasteners and long stud rods are used for assembling the extended vapor duct with the existing portion. Any welding activity inside chamber is avoided as it may create holes in the tubes of the heat exchanger directly below the vapor duct. The extended plate of 0.5 m height provided with angle frame for easy installation of *C*-type demister over it (Fig. 13). After keeping this demister at the elevated region, the TDS level of the product water comes down below 50 ppm during high tide.

8. Results and discussions

Experimental study has been carried out for the demister elevation configuration for improving the quality of the product water of LTTD plant and resultant values are plotted in the Fig. 14. Water quality analyzer is used to check the TDS values of product water. Flow rate of condensate is measured using vortex type in-line flow meter with an accuracy of ±1%. Saturation pressure of the flash chamber is measured using vacuum transmitters (±0.2% accuracy). Flow rate of warm feed water is measured using insertion type flow meter with an accuracy of ±1%. Because of the tidal variation, the consistency in the purity level of water could not be achieved. During high tide, the available pump head changes and flow rate varies proportionately. Tide level varies between 0.2 and 1.6 m above mean sea level.

Fig. 14 indicates the purity of the product water that scattered between 110 and 570 ppm at different flow rates in the bare spout configuration (Fig. 13) between low and high tide. Water level inside flash chamber is varying between 0.28 and 0.72 m with respect to tide levels. The flash chamber flood level shown in the Fig. 15 is inclusive of tide level, head due to friction loss in discharge pipeline and wave action on pipe exit end. Discharging of brine water at outlet pipeline creates certain friction loss that leads to rise in water inside chamber to certain extent for enabling gravity flow to take place, in addition to tide

Fig. 13. Demister pad elevation with extended vapor duct.



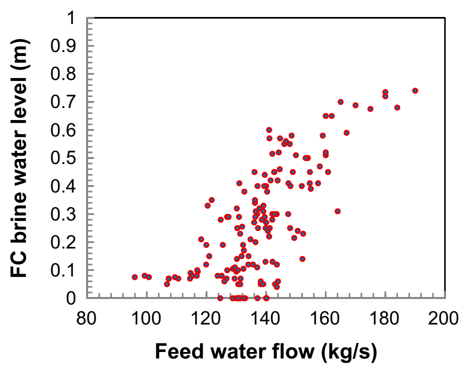


Fig. 15. WW flow vs. FC water level.

level. Moreover, periodic hitting of waves at the exit end of brine discharge pipe would disturb the free fall of outgoing water from chamber that could also have slight effect on the increase in the flood level. Therefore, the flood level inside flash chamber at any time could be due to the combined effect of flow rate, wave action at pipe exit end and tide level, where the latter one dominates more.

In bare spout configuration, the fine particles bursting out from bubble dome [16] that is generated from pool of liquid could have entrained the demister, as it do not have enough inertia force to make an impact over demister. Moreover, high vacuum in the downstream of demister immediately sucks these droplets and sends it to condenser where it contaminated the condensed product water. Small particles would be settled down under gravity influence only by coalescence action, when feedwater splashed via spouts. Coalescence action promotes growth in droplet size, which resulted in increased terminal velocity (as it depends on droplet diameter). Gravity settling of droplet happens whenever the terminal velocity of droplet exceeds the upward vapor stream drag force; otherwise vapor stream carryover the droplets along with it. The mechanism by which entrainment occurs during flooding from pool of liquid surface is already discussed in Section 6.

In order to control the flooding and the TDS of product water, a modification is performed on bare spout configuration and converted to demister elevation configuration, which is shown in the Fig. 11. In this configuration, the spout pipe height is increased up to 0.87 from 0.37 m. This is done to avoid submergence of spout tip below liquid level and enable splashing to take place during high tide. Splashing of water through spouts increases surface area that results in increased vapor velocity. High velocity vapor could lift big size droplets. As discussed earlier that when the big droplets move upward their weight increases by coalescence action that would certainly lead to the shedding of most of droplets from the water vapor leaving only fine particles to reach demister that resulted in improved water quality. This could be possible only when the vertical travelling distance of droplet against gravity is sufficiently high. As a trial experiment, the demister elevation is increased to a maximum limit to observe its effect on quality of product water. With this setup, the experiments are conducted for different feed water flow rates and a remarkable improvement in product water quality was observed that varies between 4 and 45 ppm. As discussed above, the idea behind this concept is that, increase in the vertical traveling distance (up to 1.88 m from spout tip) of the water vapor against gravity helps to reduce the salt carryover droplet by way of increasing the droplet weight. The weight of the droplet increases as a result of coalescence action when moving in the vapor space i.e. neighboring droplets combine together to form big droplet. Coalescence of droplets with each other increases the size and obviously the weight. Hence, the droplets, which are heavier than the drag force of the vapor for that particular velocity, will settle back into the brine water. This would control the salinity of the product water considerably.

In order to confirm that, an increase in flood level (above spout tip and consequent reduction in separation distance) leads to an increase in the product water salinity (as observed in original bare spout configuration), a separate experimental study has been carried out in the demister elevation configuration. During this experiment, the brine discharge valve of flash chamber is closed purposefully by 25% and flood level is increased artificially in order to simulate the high tide condition. As the water level rises above the spout tip, the TDS of product water gradually increased from an average value of 25 ppm to above 1,000 ppm, as a result of decreased clearance between

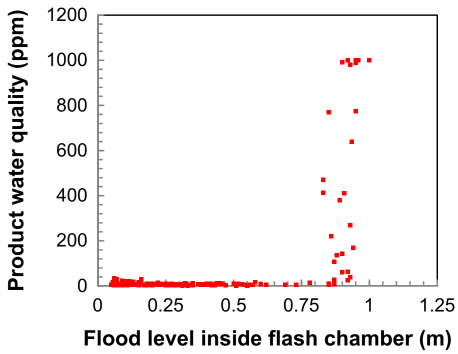


Fig. 16. FC flood level vs. water quality (elevated demister configuration).

liquid surface and demister (Fig. 16). High TDS value is observed in the product water as long as the flood level maintained more or less at 990 mm from flash chamber base i.e. nearer to demister face with spout completely submerged below water. As the flood level decreased below 800 mm, the TDS is observed to be reduced again to a value lower than 50 ppm and spout tip exposes again. This experiment clearly indicates that raise in flood level above spout tip and subsequent reduction in separation distance inside flash chamber apparently increases the salinity level of product water.

9. Conclusion

For bare spout configuration, it is observed that as long as spout tip is exposed above the flood level inside flash chamber, the TDS showed scattered value in the range between 110 and 320 ppm for different flood level, tide level, and feedwater flow rate. This could be due to uneven size distribution of carryover droplets in the space available between brine pool and demister. Once the liquid level increased above the spout tip, the TDS reached to a value of 370 ppm average and with further rise in flood level i.e. at the highest tide the TDS reached to a maximum value of 570 ppm. As the brine liquid level raises the separation distance between demister and liquid surface gradually decreases, which enables the saline particles to the reach demister easily. Moreover, high vacuum in downstream of demister sucks those saline droplets quickly to condenser, resulting in high TDS of product water. In order to improve the quality of product water, an experimental study is carried out using elevated demister configuration. From this study, it is observed that the TDS of product water showed a remarkable improvement with values varied between 4 and 45 ppm. Scattered pattern is observed for TDS of product water for different flood level, tide level, and feedwater flow rate, with exposed spout tip. Improvement in product quality is achieved by increasing demister elevation that resulted in increase in the separation distance between the brine level and demister. This, in turn, reduces the droplet entrainment by increasing the travel distance and promoting droplet coalescence that leads to shedding of most of droplets from vapor before reaching demister. This configuration will be implemented in future LTTD plants.

Abbreviations

LPD	—	liters per day
PPM	—	parts per million
TDS	—	total dissolved solids
cd	—	chartered datum
FC	—	flash chamber
MSL	—	mean sea level
WW	—	warm water
F_B	—	buoyancy force
F_D	—	drag force
U_T	—	terminal settling velocity

References

[1] R.K. Bagul, D.S. Pilkhwal, P.K. Vijayan, J.B. Joshi, Entrainment phenomenon in gas-liquid two-phase flow: A review, Indian Acad. Sci. 38(6) (2013) 1173–1217.
[2] F.H. Garner, S.R.M. Ellis, J.A. Lacey, The size distribution and entrainment of droplets, Trans. Inst. Chem. Eng. 32 (1954) 222–235.
[3] S. Aiba, T. Yamada, Studies on entrainment, AlChE J. 5(4) (1959) 506–509.
[4] D.E. Spiel, The sizes of the jet drops produced by air bubbles bursting on sea and fresh water surfaces, Tellus B 46B (1994) 325–338.
[5] A.M. Rozen, S.I. Golub, I.F. Davydor, Some laws governing drop carryover, Sov. Phys. Doklady 14(7) (1970) 648.
[6] M. Ishii, I. Kataoka, Mechanistic modelling of pool entrainment phenomenon, Int. J. Heat Mass Transfer 27(11) (1984) 1999–2014.
[7] M. Rognoni, Alessandro trezzi, pierolucchi, spray enhanced demisting, [SED] Desalination 152 (2002) 185–190.
[8] A.S. Al-Dughaither, A.A. Ibrahim, W.A. Al-Masry, Investigating droplet separation efficiency in wire-mesh mist eliminators in bubble column, J. Saudi Chem. Soc. 14 (2010) 331–339.
[9] http://www.amacs.com/wp-content/uploads/2012/09/AMACS-Mist-Eliminator-Brochure6.pdf.
[10] A. Buerkholz, Droplet Separation, VCH, New York, NY, 1989.
[11] H. Ettouney, Brine entrainment in multi stage flash desalination, Desalination 182 (2005) 87–97.
[12] A.E. Muthunayagam, K. Ramamurthi, J.R. Paden, Low temperature flash vaporization for desalination, Desalination 180 (2005) 25–32.

[13] R. Shafaghat, H. Shafaghat, F. Ghanbari, P. Sirousrezaei, R. Espanani, Design of a MSF desalination plant to be supplied by a new specific 42 MW power plant located in Iran, World Acad. Sci. Eng. Technol. 62 (2012) 515–521.
[14] M. Souders, G.G. Brown, Design of fractioning columns, entrainment and capacity, Ind. Eng. Chem. 38 (1) (1934) 98–103.
[15] W.Y. Svrcek, W.D. Monnery, Design two-phase separators within the right limits, Chem. Eng. Prog. 89(10) (1993) 53–60.
[16] E.L. Andreas, J.B. Edson, E.C. Monahan, M.P. Rouault, S.D. Smith, The spray contribution to net evaporation from the sea: A review of recent progress, Boundary Layer Meteorol. 72 (1995) 3–52
[17] R.F. Davis, The physical aspect of steam generation at high pressures and problem of steam contamination, Proc. Inst. Mech. Eng. 144 (1940) 198–215.