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Augmentation of Condensation of Water Vapour - a Review

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Abstract: It is well known that the need for drinking water is increasing day by day. There are two different types of seawater desalination procedures, namely Desalination by using Filters and the other using Thermal Methods. The different levels of filtration techniques are Particle Filtration, Micro-Filtration, Ultra-Filtration, Nano-Filtration and Reverse Osmosis (RO). Different thermal methods of desalination methods are Multi-Stage Flashing (MSF), Multi-Effect (ME), Vapor Compression (VC) and Solar Desalination (SD). This paper mainly deals with the MSF distiller and reviews the possible techniques to improve the productivity of MSF desalination by augmenting the condensation of water vapour.

Key words: Nano-Filtration and Reverse Osmosis · Multi-Stage Flashing · Productivity of MSF desalination

INTRODUCTION

In the Gulf countries and few other parts of the world, the Multi-Stage Flashing (MSF) distiller is very popular, due to its capacity to produce potable water in large volumes. As the thermal desalination systems require enormous amount of heat energy, they are usually attached to a thermal power plant, so as to produce electricity and water and aptly they are called 'Co-Generation Plants'. Schematic diagram of a traditional steam power plant and a desalination plants are provided in the Figs. 1 and 2. One can notice the major difference between the two line diagrams to be the replacement of the condenser and cooling tower by a brine heater and MSF distiller. In the MSF desalination plants, the brine solution get flashed into water vapor and later the vapor get condensed in the condenser to obtain desalinated water. The brine solution, which gets preheated, as it condenses the water vapour in each of the stages in the MSF distiller.

Improvement in productivity is always an attraction for any production industry. Depending upon the product, suitable method of improvement may be planned and designed. The techniques not only improve the quality of the product but also extend the life of a plant. They reduce the idling time of a plant. As far as the MSF desalination units are concerned, few methods to improve the production / productivity have been implemented already. They may be listed as (a) different additives (like anti forming agent and anti corrosion agents), (b) online spongy ball cleaning systems, (c) optimization of the operating conditions units and (d) material selection to have longer life of the components of the plant. Through literature survey, all the methods of augmentation techniques of condensation have been identified.

Multi-Stage Flash (MSF): There are three main thermal processes that take place in MSF distillation plants. The first is heating of pretreated seawater, second is flashing the heated seawater, in the flashing chambers, to produce water vapour and the third to condense the water vapour into product / desalted water. Figure 3 shows the schematic diagram of a MSF Flash Chamber. Main components of a desalination unit and different processes that are taking place in them are given below:

Pretreatment Unit: Here the seawater undergoes different chemical treatments and degasification processes. The seawater gets a dose of different chemicals like anti-scaling, anti corrosion agents and anti-foaming agents. To minimize the non-condensable gases and also other gases, which form compounds of corrosive nature like CO_2 gas into the system, de-aerator and de-carbonator units shall be provided in the distiller.

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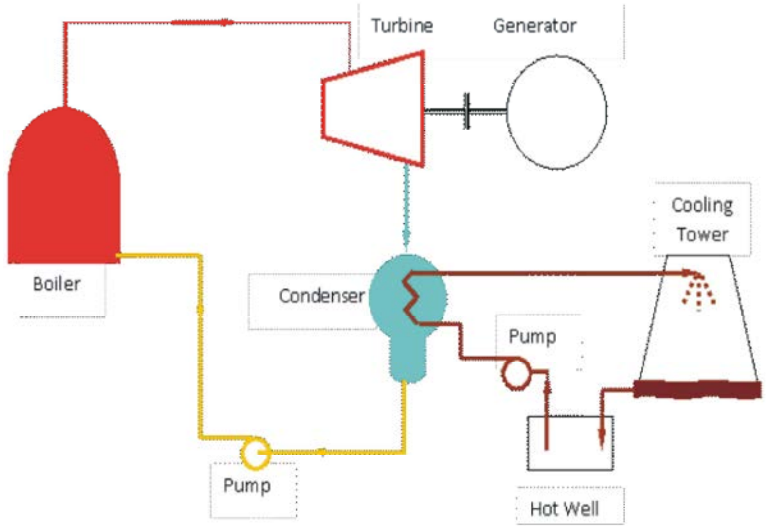

Fig. 1: Steam Power Plant with a Cooling Tower

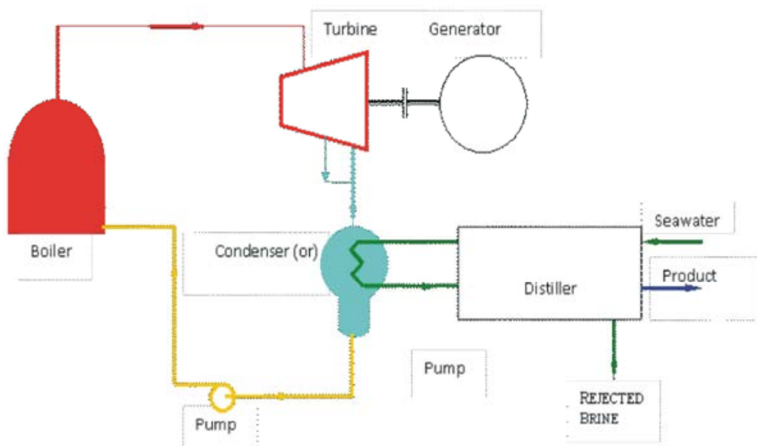

Fig. 2: Co-generation Steam Power Plant with a Distiller

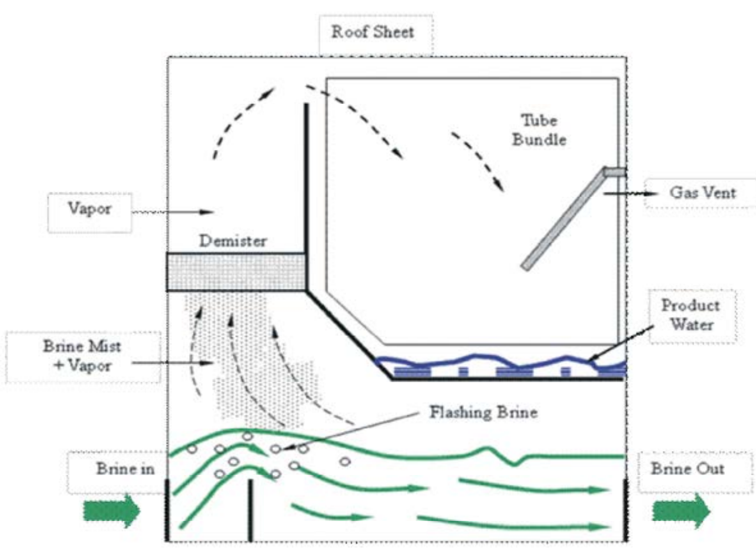

Fig. 3: Schematic diagram of a MSF Flash Chamber

Brine Heater: The brine heater shall be a shell and tube type heat exchanger with single pass arrangement. Exhaust steam from the turbine and the brine solution shall be the shell side and tube side fluids. It is a condenser and it act as a pre-heater of the brine solution. Temperature of the brine is increased to the maximum operating value, called the Top Brine Temperature (TBT). Due to the seawater pretreatment, the possibility of scale formation is very little.

Flash Chambers: The MSF unit is provided with a series of flash chambers. Depending on the design, the number of chambers in a distiller may vary from 19 to 21. Brine solution flows through narrow orifice and it flashes into steam due to pressure reduction. Steam thus produced will pass through a demister to the condenser tube bundle, placed top of the chamber. Brine solution flowing to the brine heater is the cooling fluid in the condenser. Condensate, the product water, gets collected in a trough.

Heat Recovery and Heat Rejection Sections: Depending upon the flow circuit, first 18 or 19 chambers and the last few chambers shall be called heat recovery sections and heat rejection sections respectively.

Post Treatment Unit: The product water at this point is very pure and free from minerals. In the post treatment unit water is added with certain salts / minerals to make it potable.

It is possible for the desalination plants to work more than the full design capacity with respect to the low temperature operations. To increase the production of water further, more quantity of steam at high temperature will be needed. Distillers can be operated at higher Top Brine Temperatures (TBT) values in the range of 98 to 105°C. This means that there will be a reduction in the electric power generation and the distillers will be exposed to adverse working conditions. Is there any method to increase the production of the distillers at the same temperature limits? It will lead to a higher productivity also. This paper is a product of thinking this line.

Scope for Productivity: The desalination process with MSF units requires vast heat transfer surfaces. If these surfaces are made more effective, it will have a direct effect on the performance of the desalination units. Many attempts have been made to improve the heat transfer coefficient by reducing the resistance to heat transfer. With steam condensing on a single tube with an improved surface, an improved heat transfer coefficient of 1.5 to 4 times more than that of smooth tubes have been reported by [1, 2]. According to Shigeru (1991) [3], a bundle of 30 horizontal tubes vertically placed had an enhanced heat transfer coefficient of 60 per cent. The cost of these modified tubes may be more, compared to a normal plain tube. However, the increase in the overall heat transfer coefficient will result in increased yield. This compensates the extra cost of these tubes. It is very important to note that the product water flow is directly proportional to the overall heat transfer coefficient.

In the existing plants if the augmentation techniques are implemented suitably, in the future, it can improve the yield and hence productivity. Prime aim of this paper is attached to the study of possible improvement in terms of condensation heat transfer. The experiment can also lead to a better design of MSF plants. Improved heat transfer performance reduces the number of tubes required. Therefore, compact plants can be designed.

Literature Review: Condensation is one of the three important thermal processes that take place in the MSF plants. Collier, (1981) [4], Hartnett *et al.*, (1973) [5] and Griffith, *et al.,* [6] have presented excellent reviews on the topic. Available literature in the field of augmentation of condensation heat transfer techniques has been presented in the following paragraphs.

Definition and Classification: Molecules of liquids and vapors move at random within the vessels containing them. When a liquid gets evaporated or boiled; the molecular gap between the molecules becomes very large. Now the medium is called vapor. When the vapor gets heated to a very high degree of superheat, then, the vapor is called gas. Condensation is the reverse process of boiling or evaporation. Collier, (1981) [4], defines condensation as the process of removal of heat from the system in such a way that vapor is converted into liquid.

Nucleation of condensation on a surface can be classified into two categories. They are listed below:

- Heterogeneous nucleation (condensation takes place on a foreign body).
- Homogeneous nucleation (base is of the same substance as that of the vapor)

Classifications and the factors affecting condensation process are listed below in brief. Basically condensation can be classified in terms of its modes of condensation into two ways:

- Drop-wise condensation (DWC)
- Film-wise condensation (FWC)

Condensation can also be classified further into two categories depending upon the base material on which condensation takes place as given below:

- Bulk condensation [as in cloud and fog]
- On a solid surface [as in a heat exchanger]

Marek and Straub, (2001) [7], analyzed the kinematics of condensation and factors affecting condensation. After studying the data from more than 100 sources, they gave the general guidelines on the factors, which have direct effect on the condensation coefficients. The data studied include the film-wise condensation on plain and special surfaces, drop-wise condensation, condensation in cloud chamber and condensation in the presence of different gases. Temperature, pressure, surface tension, effective removal of the condensate from the surface and presence of the non-condensable gases are affecting condensation of a vapor. Presence of CO_2 also reduces the condensation coefficients to 10 percent.

Techniques of Augmentation: The factors affecting the process of condensation are discussed in viewpoint of augmentation of condensation.

Drop-Wise Condensation: Very large increase in heat transfer coefficient will result if drop-wise condensation is initiated and sustained. Recently Alfred and Kyong, (2001) [8], have presented a report of an experiment in which many materials like copper, titanium, aluminum and high-grade steel were used as test materials. The measured individual coefficient of heat transfer has been reported as 17 times larger than that of film-wise condensation. In drop-wise condensation, the surface on which condensation takes place has to be prepared with chemicals and the drop-wise condensation sustains for a limited duration of time. Rifert *et al.*, (1989) [9], obtained a stable drop-wise condensation, which sustained for a very long time. With steam, an augmentation range of 2 to 9 times was obtained which decreased to 1.5 times after 700 hours of use. Thin layer of Teflon coating on the heat transfer surface, has been found to be very effective for condensation but it gets damaged after some use. Drop-wise condensation has been successfully tested over highly polished metal tubes. Electro plating of special metals like gold and silver also have good effect on drop-wise condensation. However, commercially viable enhanced tubes and procedures of using them are not available.

Use of External Forces: The idea of using an external force is to reduce the film thickness of condensate. Effects of the following external forces on condensation are reported.

- Forced convection - forced flow of vapor and the cooling fluid,
- Electrostatic field - AC or DC up to 7000V,
- Centrifugal forces - like rotating discs, pipes and spheres and
- Vibration - ultrasonic vibration of wires.

Hamed and Sorial, (1984) [10], covered the forced convective heat transfer of condensation of steam taking place over a horizontal tube. Heat transfer coefficient improvement of 2 to 3 times has been reported. Jones, (1978) [11] and Rohsenow (1985) [12], reviewed the use of electrostatic field in the heat transfer. Review covered both the single and two phase heat transfer systems. The electrostatic field is to be generated with the help of a power supply of nearly 7000V. This requirement makes this technique very expensive. The other two types of external forces namely, centrifugal and forces of vibration are not suitable for the MSF plants that commercially produce desalinated water for obvious reasons. The two main causes are the rugged design and the size of the plants.

Surface Geometry: For easy removal of condensate, a number of surface geometries have been tried and reported in the literature. Different methods used are listed below:

- Closed-pitch low fin surfaces (integral fins)
- Placing wires along the surface of the tube – surface tension makes the condensate to flow towards the wire.
- Rough surfaces
- Fluted tubes
- Roped tubes
- Spirally indented surfaces

Prabakar, (1989) [13], reported the results of an experimental work, with Freon 12 vapor condensing on enhanced surfaces made of copper tubes. Special surfaces

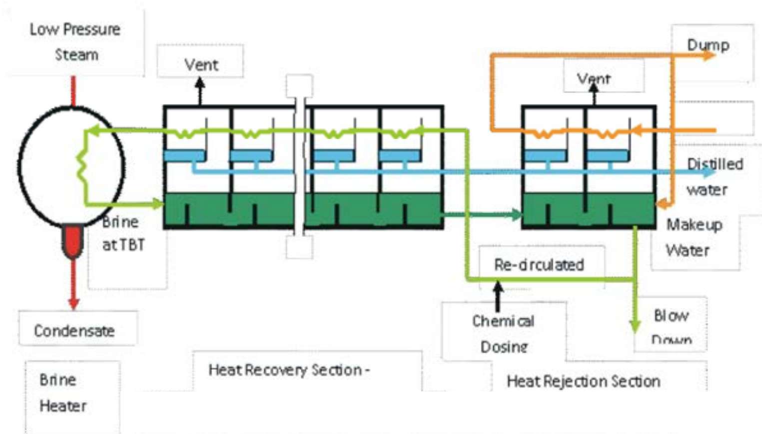

Fig. 4: Schematic Diagram Showing the Multi Stae Flash (MSF) distiller

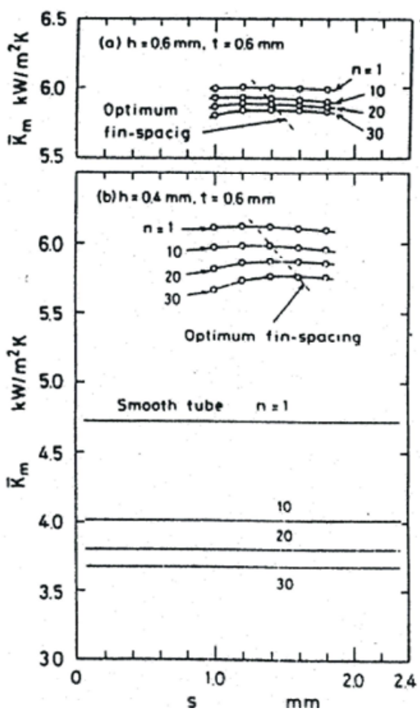

Fig. 5: Tube Bundle Experiments Results of Shigeru, N., 1991

Table 1: Approximate flow rates of different fluids in MSF plant

1.	Seawater flow.	≈ 7,500 tones / hr.
2.	Makeup water.	≈ 3,000 tones / hr.
3.	Dump water.	≈ 4,500 tones / hr.
4.	Blow off.	≈ 2,000 tones / hr.
5.	Chemical dosing.	≈ 100 to 200 kg / hr.
6.	Re-circulation brine.	≈ 10,000 tones / hr.
7.	Product water.	≈ 1,000 tones / hr.

were prepared on the outer surface of copper tubes while the inner surface was of commercially available surface finish. Copper tubes with the integral fins enhanced the condensation heat transfer by 10 times.

One of the most recent works on condensation is by Ravi, *et al*., (2002) [1]. Steam and Tetra Fluoroethane (refrigerant - R134a:- CH_2FCF_3) were used in the experiments. Different types of integral fins were used and the augmentation obtained was in the range of 0.2 to 2.9 times with steam and up to 6.54 times with R134a.

Also, Kalendar and Griffith, (2000) [14], have reported on the condensation augmentation in MSF plant. They had used commercially available fluted tubes like Korodence, Super-B, GEWA-SC, GEWA-TW, Thermoexecl-CC and Tred 26D in their experiments. These fluted tubes are being used in refrigeration and air conditioning equipment, to have compact designs of the heat exchangers. The heat transfer coefficient increased to a considerable value. Water was the cooling fluid flowing inside the tube. Tests were conducted with tubes of 19, 23, 29.5 mm ID. At higher velocities of flow, overall heat transfer was found to be in the range of 1.5 to 2.13. As the inner surfaces of these tubes are rough, it was reported that the pressure drop was higher than a plain tube in the order of nearly 90 percent.

Recently Samir *et al*. [15], who completed a KACST project, have performed tests with the help of indented tubes. Three single tubes of different enhanced surfaces were tried with single-phase liquid flow, double tube condensation and in a bundle of tubes arrangements. The best grove configuration on the surface of the tube was with a pitch of 2.54 mm (0.1") and with a depth 0.356 mm (0.014"). They also used one tube bundle consisting of 25 tubes (of which only 22 tubes where effective). The overall heat transfer was found to be increasing in the range of 1.6 to 4 times with Reynolds number and steam loading.

Table.1. Comparison of Experimental Results of Condensation Over Horizontal Tubes and Tube Bundles

S. No.	Name and Reference No.	Material	Tube Size	Fin height mm	Pitch	Tube Length mm	Operating Pressure	Enhancement Factor	Remark
1	Marto.P.J. [2], (1988).	Copper	21 mm. ID	1.0	1.0, .15, 2.0, 4.0, & 9.0 mm	133	85 mm of Hg	Up to 4	Review and experiment
2	Shigern,N. & Hiroshi, H. [15] (1991).	Copper	ID / OD 11.21 / 15.6 11.80 / 16.1	1.43 1.30	0.96 0.50		5.64 kPa ($t_{sat} = 35°C$)	Single tube =1.34 **Tube bundle =60 %**	Review and experiment **Tube bundles of 10, 20, 30.**
3	Ravi, K. et.al. [1], (2002).	CIFT SIFT PCIFT-1 PCIFT-2 CIFT (rectangular fins)	22.10 (OD) 24.97 -do- 24.98 -do- 24.94 -do- 24.94 -do-	1.10 1.06 0.96 0.96	2.57 2.56 2.58 2.58	310	10 to 110 kPa.	2.27 2.90 2.39 2.70 2.5 to 3.0	Review and experiments
4	Samir,S.A et.al. [14], (1989).	Aluminum Brass 1. Big pitch, single start. 2. Medium pitch, double start. 3. Small pitch, double start.	12 OD, 0.9144 mm thick	0.762, (0.030") 0.356, (0.014") 0.356, (0.014")	12.7,(0.5") 6.4,(0.25") 2.45,(0.1")	10.0 bar (150 psi)	1437 mm	Single phase: 70 to 90%, 70%, and 160%. Condensation: U increases with Reynolds number and steam loading	**Not Conclusive** with the condensation experiments.

ID = Inner Diameter, OD = Outer Diameter.

Recently, Shigeru and Hiroshi, (1991) [3], have performed tests with a single tube and a set of three tube bundle arrangements. Horizontal tubes with integral fins were placed one above the other to form three vertical bundles of 10, 20 and 30 tubes. Very encouraging result of 60 percent enhancement in heat transfer, with condensation of steam over a tube bundle of 30 tubes, was reported.

Homogenous Condensation Improvement by Nuclei Introduction: Collier, [4], has reported that over a rough surface, water collection in the existing cavities and scratches can act as the active nuclei for inception of condensation. Herman, [16], explains about a spray type of condenser to have a compact heat exchanger. Arshad, [17], has reported on the use of similar spray condensers in desalination plants. Minoru *et al*. [18], report the results of direct contact condensation experiments of steam and sub-cooled water spray. Pasandideh *et al.* [19], have a report on the cooling effectiveness of a water drop impinging on a hot surface with a temperature difference of 50 to 120°C.

CONCLUSION

It has been observed that many technical articles are found in the literature regarding the Augmentation of Condensation of vapors of different fluids, Ravi, 2002, Marto, 1988, Shigeru & Hiroshi, 1991 and Samir et al, 1989, which are applicable for a single tube and horizontal tube bundle with enhanced surfaces. A table has been provided to indicate the operating parameters and results of the experiments.

The refrigeration and air conditioning industry has started using the enhanced surfaces in their heat transfer equipment designs. However, for water vapor application, there is a large gap between the researchers and manufacturers. This attitude can be attributed to the tendency of the metal to get corroded. It is suggested to focus on the selection of materials and heat treatment methods to improve the corrosion characteristics of the heat transfer tubes.

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