STEADY-STATE SIMULATION

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Contents

Summary

The results of steady-state simulation, calculated by using the TDM algorithm and SPEEDUP flow sheeting package, are presented for two MSF plants of different capacities. These are compared either with the vendor simulation results or performance test data showing excellent agreement. TDM is found to be faster and more robust.

1. Process Constraints

State-of-the-art multistage flash (MSF) plants have a stable range of operation between loads corresponding to 60 and 110 per cent of their nominal capacities. The lowest load limit is determined by the capacities of the pumps and the performance of the flow control valves, while both limits depend on the permissible minimum and maximum tube-side brine velocities, respectively.

The seawater temperature in the Gulf, where most MSF plants are located, varies from 18°C in the winter to 35°C in the summer. At the highest temperature the flash range will be the lowest; therefore, the brine recycle flow and the heat transfer areas are to be designed for these conditions. At a temperature lower than the maximum, the situation for the whole evaporator changes from the thermodynamic point of view, since the pressure values inside the evaporator decrease in accordance with the decrease in saturation temperatures. This, in turn, affects the interstage brine flow because the pressure drop between the adjacent stages changes. Moreover, due to a decrease in the vapor density with decreasing pressure, the vapor velocity increases. As a rule of thumb, at constant load the vapor velocities are doubled when the temperatures of the individual stages decrease by 15°C.

In order to limit deviations from the design conditions, the MSF plants operate during the winter season with a recycle of cooling water in the heat rejection section to raise the seawater intake temperature. However, the recycled heated seawater flow is not sufficient to keep the intake seawater temperature constant throughout the year. Therefore, all the plants are designed in such a fashion that a certain temperature drop is acceptable during the winter mode of operation. For example, when the seawater temperature reaches 18°C, a cooling water temperature of not more than 24°C is acceptable to a particular vendor compared to the maximum summer temperature of 35°C. This way of operating minimizes the operation time of the cooling water recycle system as well as the total electrical energy demand.

In choosing the operation setpoints for full or partial loads of a particular plant, the following aspects must be given due consideration.

(a) Stable operation of the evaporator including ancillaries.
(b) Minimum energy consumption, both thermal and electrical.
(c) Low fouling rates.
(d) Minimum consumption of chemicals.
(e) Avoiding mechanical or material damage to process units or their components.

From the simulation point of view, the first two aspects are of major interest and will be discussed further in the context of the following operation variables.

(a) Top brine temperature (TBT) to which the brine is heated in the brine heater before it starts flashing.
(b) Brine recycle flow rate from the last flash stage used as coolant in the recovery section.
(c) Rejection section coolant entrance temperature and its rate.
(d) Make-up feed flow rate entering the last flash stage.
(e) Pressure and temperature of steam supplied to the brine heater.

1.1. Top Brine Temperature

The TBT plays a crucial role in determining the performance of an MSF plant. It is usually expressed in terms of a performance ratio (PR), which is approximately equal to the ratio between the flow rates of the distillate produced and the steam supplied to the brine heater. By increasing the TBT, both the distillate production rate and the PR increase. The production rate goes up because the flashing range increases at a higher TBT. At the same time, a higher TBT leads to greater scale formation; however, there are anti-scale chemicals available which permit the TBT to rise to as high as 120°C. To achieve the best performance as well as a high production rate, the maximum possible TBT should be maintained. If, on the other hand, the production rate is to be reduced by reducing the brine flow rate, while maintaining a higher TBT the vapor vented along with the released non-condensables may be higher than desired. However, this is certainly a better alternative with respect to operation stability, corrosion aspects, and energy demand than reducing the TBT to a low limit. In the latter case, the pressure difference to the vented condenser may become insufficient with the result that non-condensable gases are not adequately extracted, followed by instability and possible vapor side corrosion problems.

1.2. Brine Recycle Rate

An increase in the brine recycle rate increases the distillate production, but adversely affects the PR. The upper limit of the recycle rate is normally determined by the recycle pump capacity, which is usually chosen as 110 per cent of the nominal flow. At this capacity the permissible tube velocity limit (approximately $2.2\ m\ s^{-1}$) will not be exceeded. The limit for reducing the tube-side velocity is partly set by considerations of fouling and sedimentation of solids on the metallic surface, particularly in the brine heater. The performance of the ball cleaning system also has a bearing on this limit. The minimum permissible limit (approximately $1.8\ m\ s^{-1}$) therefore depends upon the TBT as well as heat transfer considerations. However, in most cases, brine levels that are either too high or too low can place constraints on operation, even before the flow limits are reached. It is, however, desirable to operate with minimum permissible brine levels by adjusting both the TBT and the recycle flow. Operation with low brine levels results in high PR and the vapor velocities are also low.

According to the design specifications, a desalination plant must be capable of operating at maximum load at any time of the year. For a given TBT, the flash range is smallest when the seawater temperature reaches its peak; therefore, in this situation maximum recycle flow is required. The temperature and pressure profiles inside the evaporator will adjust themselves in accordance with the first law of thermodynamics and the mechanism of heat transfer.

1.3. Make-up Flow Rate

For a specified production rate, a high make-up flow rate results in lower salt concentration in the blowdown stream and also causes a decrease in the brine density, boiling point elevation (BPE), and other thermodynamic penalties. Consequently, some increase in PR can be expected. On the other hand, larger make-up requires more anti-scale chemicals for treatment. The maximum permissible limit of salt concentration in the blowdown is 65 000 p.p.m.

1.4. Seawater Flow Rate and Temperature

The same upper and lower limits of velocity apply for the seawater flow rate in the cooling tubes of the heat rejection section as for the recycle flow through the heat recovery section. Higher seawater flow rates will increase the heat loss for the system in the seawater rejection stream, while lower rates will affect the heat-transfer coefficients.

For the specified seawater temperature, simulation indicates that its flow rate has a marginal effect on PR or the distillate production rate. However, keeping the proper seawater flow rate and its temperature are important for a proper flashing temperature in the last stage.

For the reduced production rate, a high seawater temperature has a favorable effect on interstage brine transfer. In the case where the brine flow rate is reduced in favor of a higher TBT, it will improve the thermal efficiency of partial load operation.

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Biographical Sketch

Asghar Husain received Master of Science degree in Applied Chemistry from the Osmania University, Hyderabad – India in 1948, Bachelor of Chemical of Engineering from the University of Michigan – U.S.A. in 1950 and Doctor of Science from the University of Indonesia in 1958 on submission of a thesis on batchwise distillation. This work has been abridged in Chemical Engineers Handbook by Perry in 4^{th} to 6^{th} edition, a McGraw Hill publication.

He taught at the Technical Faculty of the University of Indonesia at Bandung (1952 -1959) and at the Delhi Polytechnic, Delhi University (1959 – 1961). Then he joined as the Research Scientist in the Regional Research Laboratory (now known as IICT) in his hometown Hyderabad – India, a constituent of the Council of Scientific and Industrial Research (CSIR – Delhi).

He retired from the CSIR in 1984 with the title of Distinguished Scientist. The he served as the Professor of Chemical Engineering at Al Fatah University, Tripoli – Libya (1984-1988). Since 1991, he is associated with ICWES at Abu Dhabi, U.A.E.

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