Multiple Effect Thermal Vapor Compression

Overview
The Multiple Effect Thermal Vapor Compression Seawater Desalination Plant described here is designed to meet the following requirements:

- Provide an output of YYYY m3/day (XXX USGPM)
- Operate at a Gain Output Ratio of X kg of distillate/kg of steam input to thermocompressor
- Minimize carryover of solids into the distillate for purity of not more than X ppm TDS.

Process Selection
Aqua-Chem ICD's Multiple Effect (MED) Thermal Vapor Compression design is a 4 effect unit which incorporates SPRAY-FILM® technology. Aqua-Chem ICD's MED design is the result of over 20 years of experience in the design, manufacture, start-up and operation of MED evaporator systems worldwide.

For this system, steam or water vapor condenses inside horizontal tubes. Seawater is sprayed over the outside of the horizontal tubes and acts as a heat sink for the condensing vapor. The latent heat of vaporization transfers from the water vapor through the tube wall to the thin seawater film on the outside of the tubes. For every kilogram of water vapor that condenses, approximately one kilogram of water evaporates from the seawater film once the seawater has reached the saturation temperature.

SPRAY-FILM® technology offers superior quality seawater distribution via spray nozzles over the tubes. The spray nozzles ensure that the seawater flows uniformly and generously over the heat transfer surface. The seawater feed flow rate in this system is conservatively designed to keep the heat transfer surface well wetted.

The vapors evaporated from the seawater will contain significant quantities of noncondensables, specifically CO_2 and air. There will also be air leakage. These noncondensables will flow with the vapor into the steam chest of the next effect. As the steam condenses, the non-condensables will stay in the vicinity of the tube wall unless swept away by high velocities. Having this vapor on the inside of the tubes is an advantage of the SPRAY-FILM® design. SPRAY-FILM® evaporators maintain high vapor velocities within the tubes without the need for expensive and complicated baffling. Splitting the tube bundle by approximately 90% in the first pass and 10% in the second pass, ensures that the noncondensables flow continuously to the vent line. This technique maintains high heat transfer coefficients and prevents loss of driving force (differential temperature) by minimizing excessive subcooling of the heating vapor.

The system operates under a vacuum with a top brine temperature of YY°C (XXX°F). By operating at low temperatures, the heat transfer surface is less likely to scale, and the amount of heat required to bring the incoming seawater to its boiling point is minimized.

This Multiple Effect plant incorporates the use of a thermocompressor to improve the thermal performance of the plant. The thermocompressor is driven by high pressure steam which entrains and boosts lower pressure vapors from the last effect to the moderately higher pressure condition required in the first effect to operate the process. By recycling the lower pressure vapors from the last effect with a thermocompressor, less steam is required from an external source than if there were no thermocompressor.

Process Flows - Feed and Brine
As the seawater feed enters the main condenser, the cooler seawater condenses vapor from the last effect and is preheated as a result of the latent heat of condensation. Of the heated seawater leaving the condenser, a portion is the make-up feed for the evaporator, and when the seawater temperature is high, the remainder is cooling water that is rejected from the system.

After the seawater leaves the condenser, a constant make-up feed flow to the evaporator goes to a strainer. The make-up feed flow is split equally to each of the four effects with the flow to the first effect being preheated by using it as cooling water to the vacuum system condensers. Within each effect, the seawater is sprayed over the tube bundle. The heating vapor inside the tubes condenses, releasing latent heat causing the feed on the outside of the tubes to evaporate.

Hot brine collects below each tube bundle and flows, via a brine loop, to the next effect. Since the next effect is at a lower pressure, flashing occurs, releasing additional vapor. This flow continues through each of the effects until the flashed brine collects in the last effect. A portion of the brine from the last effect may be recycled to the make-up stream when seawater temperatures are low to maintain the plant temperature profile.

Process Flow - Heating Vapor

The vapor produced in the first effect serves as heating steam in the second effect, the second effect vapor serves as heating steam in the third effect, etc. Of the vapor produced in the last effect, a portion is entrained by the thermocompressor and the remainder flows into the main condenser. In the main condenser, the vapor is condensed by cooler seawater on the tubeside. The system uses a controller to maintain a steady condensing condition in the condenser. This is done by controlling the amount of seawater in/cooling water rejected from the system.

The vapors produced in each vessel will carry over very small brine droplets. These droplets are removed by mist eliminators installed in each effect. This gives rise to high purity distillate.

Process Flow - Steam

Motive (supply) steam entering the thermocompressor entrains low pressure vapor from the last effect. The motive steam thermally compresses the entrained vapor in the diffuser of the thermocompressor, and the higher enthalpy mixture condenses in the first effect tube bundle driving the process.

External steam is also required to maintain a vacuum in the system. With the release of noncondensable gases from the seawater and air leakage, the use of a two stage steam jet ejector/surface condenser vacuum system provides the means for removing the noncondensable gases to atmosphere and maintaining the system vacuum.

Process Flow - Venting

Venting is extremely important in an evaporator operating under a vacuum. In the SPRAY-FILM® type evaporator, the tubes are arranged in multiple passes to get the best possible removal of noncondensables from the heat transfer surface.

Noncondensables vent from the last pass of each tube bundle to the vent manifold that discharges to the main condenser. From the main condenser, the noncondensables are entrained by the first stage ejector of the vacuum system. In two stage ejector/condenser vacuum system, the noncondensables are expanded to atmospheric conditions for removal from the evaporator.

Process Flow -Distillate

The vapor condensed in the tubes of each effect and on the outside of the tubes in the condenser is distillate. Via distillate loops, the distillate flows from the first effect steamchest to each of the succesive effects' steamchests and finally into the main condenser. The distillate flow is level controlled in the main condenser and pumped out of the system with the distillate pumps.

Steam Control and Turndown

The temperature difference between the first effect and the main condenser basically dictates the evaporator production rate for a given steam flow. The condenser temperature is fixed by the system controllers, however, the first effect temperature can vary depending on the steam flow rate (heat input) at the thermocompressor inlet nozzle. The production of distillate can be altered via control of the steam flow to the thermocompressor. Reducing this steam flow will automatically cause the output to drop, for example, when the steam flow is approximately 70% of full capacity, the plant production of distillate will be approximately 70% of full capacity as well.

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