Aquatech

aqua-chem ICD
Industrial Concentration & Desalination

Zero Liquid Discharge System

Overview

The Aqua-Chem ICD Zero Liquid Discharge System is a fully integrated automated system incorporating a mechanical vapor compression brine concentrator, a forced circulation crystallizer, and solids dewatering. High purity distillate produced in this system can be used for cooling tower or boiler makeup water.

The Aqua-Chem ICD Zero Liquid Discharge System typically follows a reverse osmosis (RO) preconcentrator. High TDS and saturation in low solubility scaling salts such as calcium sulfate ($CaSO_4$) and silica (SiO_2) limit the percentage of water which can be recovered by an RO system. Feedwater saturated in $CaSO_4$ and/or SiO_2 is also very difficult to concentrate in a normal evaporator but can be handled in the Aqua-Chem ICD brine concentrator. The process, also called seeded slurry evaporation, involves establishing and maintaining a slurry of calcium sulfate seed crystals in the circulating brine in the evaporator. With careful thermal and mechanical design, the SiO_2 and $CaSO_4$ will precipitate preferentially on the recirculating crystals instead of on the tubes. The brine concentrator is capable of concentrating the wastewater to near saturation in the sodium salts without scaling the heat transfer tubes.

The remaining water is evaporated in the forced circulation crystallizer. This evaporator easily handles the crystallization of the remaining salts regardless of the exact chemical analysis. The salts are removed as a cake by a (filter press, centrifuge).

The Aqua-Chem ICD Zero Liquid Discharge System is designed for automatic steady state operation and will require little operator attention. The materials of construction have been selected to resist corrosion and ensure a long plant life. The system is very reliable. The pumps and compressor typically operate years without significant problems, given periodic maintenance typical for rotating equipment. Almost any problem can be fixed in a day. The system is designed to minimize scaling of the heat transfer surfaces; however, it is also designed to operate in a slightly fouled condition, so normal fouling or scaling will not affect the design capacity of the unit. Chemical cleaning of the system is typically required once or twice per year.

Process Description

The feed is acidified with H_2SO_4 to a pH of 5.5 which converts bicarbonate to dissolved CO_2 for removal in the deaerator. The bicarbonate is removed to prevent scaling of the brine concentrator tubes with calcium carbonate ($CaCO_3$). A small amount of scale inhibitor is metered into the feed to avoid scaling in the feed/distillate plate heat exchanger. Depending on the amount of calcium in the feed, the anti-scale may be reduced or eliminated.

The feed/distillate heat exchanger, a plate and frame type with titanium plates, preheats the feed with outgoing hot distillate. The heated feed flows to the deaerator to remove dissolved carbon dioxide and oxygen, to minimize corrosion in the system. Aqua-Chem ICD uses a flashing deaerator which does not utilize packing, thereby avoiding plugging problems. The feed is sprayed into the pressurized, barometric half of the deaerator which further heats the feed with low pressure evaporator vent vapors. The feed then flashes into the low pressure portion of the deaerator. A small fraction of water from the feed is vaporized, along with the dissolved carbon dioxide and oxygen, which are virtually eliminated by this step. Typical dissolved oxygen content in the deaerated feed is 10 ppb.

The feed then flows to the brine concentrator vessel. Calcium sulfate scale is managed in this vessel by proper feed pretreatment and by providing adequate seed crystal surface area dispersed homogeneously in the brine slurry. The seed crystals prevent supersaturation extremes and promote crystal growth rather than scaling on the heat transfer surface.

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The seed crystals are added as gypsum to the seed makeup tank at startup to establish the circulating slurry. As the brine is concentrated and some is pumped to the crystallizer, seed crystals are replenished by natural generation from calcium and sulfate ions in the incoming feed water. A seed thickening tank is provided to recycle seed crystals back into the brine concentrator if the natural seeding level is too low. A $CaCl_2$ injection system is provided to add Ca+2 directly into the feed line if the incoming Ca+2 concentration is too low. Both of these systems are used to maintain adequate seed crystal concentration in the brine concentrator.

The brine concentrator vessel is designed with a long bottom channel to provide sufficient residence time for crystal growth. A vapor separator with mist eliminators is used to remove entrained droplets of brine from the vapor before it flows to the compressor. The mist eliminators are periodically sprayed with hot distillate to dissolve any accumulated solids.

Vapor generated in the brine concentrator flows to a mechanical compressor, which increases its saturation pressure and temperature. Then the compressed vapor flows to the shell side of the brine concentrator in lieu of external heating steam. The vapor is condensed on the outside of the tubes, transferring heat to the circulating brine on the tubeside. Condensed vapor (distillate) is pumped out of the system. Some of the distillate is sprayed into the compressor discharge duct to desuperheat the compressed vapor.

The brine concentrator is designed with a very low delta-T (temperature difference between the heating medium and the boiling brine) and a high recirculation rate. The two main benefits are reduced scaling rate and a lower compressor power requirement. Energy economy is maximized by utilizing distillate and vent stream heat. The system is designed for low make-up steam at steady state operation.

The brine is concentrated to approximately 25% total solids in the brine concentrator. To maintain a solids balance in the system, part of the concentrated brine is continuously pumped from the brine concentrator to the forced circulation crystallizer.

Recirculated brine is pumped through the forced circulation heat exchanger where it is heated with steam from the brine concentrator to above its normal boiling temperature. Boiling of the brine in the heat exchanger is suppressed due to sufficient static head. Boiling in the heat exchanger would cause scale formation on the heat transfer surface. The heated brine then enters a flash tank operating at a slightly lower pressure, causing flash evaporation of water and formation of salt crystals in the brine. High recirculation rates are used to keep the contact time on the heated surface low, reducing the scaling rate of the heat transfer surface.

Once every eight hours the a batch of slurry is discharged from the crystallizer to the filter press feed tank. This slurry is fed to the filter press, which separates out the salt crystals as a cake. The liquid portion, saturated in dissolved salts, is returned to the forced circulation crystallizer. The salt cake is dumped at 8 hour intervals into a hopper for disposal. This sequence is manually initiated, and requires an operator to be present to assure that the plates have properly released the salt cake.

Vertical Tube Falling Film Evaporator (Brine Concentrator)

Falling film vertical tube evaporators use vertical tube bundles with brine evaporating from a thin film on the inside of the tubes. Brine is distributed in a thin film down the inside of the tubes. The brine absorbs heat from condensing water vapor on the outside of the tubes. The latent heat of vaporization transfers from the water vapor through the tube wall to the thin brine film on the inside of the tube. For every kilogram of water vapor that condenses, approximately one kilogram of water is evaporated from the brine film.

The vapor condensing on the tube bundle is primarily water vapor but can also contain air and other non-condensables. These non-condensables will stay in the vicinity of the tube walls and impede heat transfer unless swept away by sufficiently high vapor velocities. A vent on the evaporator body continuously removes the non-condensables to maintain high heat transfer coefficients and to prevent loss of driving force (differential temperature) through excess subcooling of the heating vapor.

The brine is introduced at the top of the vessel and flows in a downward direction as a falling film. The brine is uniformly and generously directed to the full circumference of each tube as a thin film. Because the recirculation rate is many times greater than the evaporation rate, only a small change in concentration occurs down the tube length as evaporation takes place. The recirculation rate is chosen conservatively to ensure that the heat transfer surface is well wetted and localized drying is not encountered.

A proprietary dual perforated plate distributor ensures that the liquid is evenly distributed to the tubes. The plates have holes larger than 13 mm and have been proven to be much less susceptible to plugging than other designs including individual weir inserts or swirler inserts.

Careful design eliminates areas where the solids and impurities may collect and impede liquid flow and heat transfer. Design features include large holes in the distribution system, sloped bottoms, and smooth entrance to pump suctions.

Mechanical Vapor Compression (VC)

Vapor compression is a highly efficient process using mechanical energy input to achieve evaporation and condensation. The fundamental difference between the vapor compression unit and the conventional evaporator is that the latent heat of vaporization is fully utilized in the VC evaporator. Since the evaporator also serves as the condenser, essentially all of the latent heat is recycled, with no rejection of heat to cooling water.

The evaporated vapor flows through the mist eliminator to the suction of the compressor. The compressor does work on the water vapor increasing the saturation pressure of the water vapor so that when it condenses, it does so at a higher temperature. The compressed vapor flows to the heating side of the evaporator. As it condenses, it transfers the latent heat of vaporization back to the liquid film on the tubeside.

The compression process produces discharge vapors that are superheated (i.e. hotter than the corresponding saturation temperature). Scaling, excessive fouling, and stress corrosion can occur if the superheated vapor is allowed to condense on the evaporator tube bundle. This scaling would occur as the sensible heat is transferred through the tube. To remove the superheat in the compressed vapor discharge, desuperheating water (in the form of distillate) is sprayed into the vapor stream. This distillate is very near the saturation temperature so latent heat is not removed from the vapor stream and can be used for the evaporation process.

A multi-stage centrifugal blower is used for the brine concentrator. It is coupled to a motor-driven gearbox. This type of compressor is very simple and easy to maintain. System turndown is achieved by the adjustment of the blower discharge damper valve. Turndown to 65% of rated capacity can be attained in this manner.

Control

The system is designed for automatic cascade control. Evaporation rate in the brine concentrator is based on an operator setpoint. The damper valve at the compressor discharge controls vapor flow to the brine concentrator based on the distillate flow rate out of the system. All other flow rates automatically adjust based on this setpoint. The feed rate is based on distillate outflow and brine level in the brine concentrator. Pressure (and indirectly temperature) in the brine concentrator is controlled by venting excess steam to the atmosphere or by allowing external steam into the system. The concentrated brine flow rate is remotely set based on feed and distillate flows. Operational parameters of system pressure, sump level, distillate level, and concentrate flow will be automatically controlled based on changes to the desired evaporation rate.

Operation

The system is designed for manual start-up and automatic operation. The feed chemistry should be monitored periodically. Sufficient safeguards and interlocks to prevent unsafe conditions or equipment damage are included in this design. When the system is shut down it is important to either keep the system pressurized with steam to keep oxygen out or drain and flush the system to remove the chlorides. Chlorides in the presence of oxygen will accelerate corrosion and reduce equipment life.

Maintenance

The required maintenance for this Aqua-Chem ICD Zero Liquid Discharge System is typical for commercial process equipment containing high quality industrial duty components. The unit's rotating equipment, such as pumps and compressors, require periodic adjustment, lubrication, and servicing of components such as seals. Instrumentation was specifically chosen to be durable and trouble free, but will require periodic adjustment and recalibration. If recommended spare parts are kept on hand and a preventative maintenance program is implemented, then the net availability (operating factor) can be expected to exceed 95%. The required maintenance procedures, recommended spare parts, and recommended preventative maintenance program will be provided by Aqua-Chem ICD.

Washing

The heat transfer surface has been designed to operate at capacity with lightly scaled heat transfer surfaces. An occasional manual adjustment of the compressor valve will maintain the system capacity as the evaporators slowly scales and loses performance. When this valve has been fully opened and the necessary capacity can no longer be maintained, a chemical wash will be required to restore performance. A complete chemical cleaning procedure will normally take between 12 and 24 hours. The evaporators are normally cleaned by recirculating a hot 10% EDTA solution (diluted Nalco 760 for example) with the recirculation pumps. The cleaning solution is injected into the recirculation line. The solution is maintained hot (70°C) by using a small amount of steam flow through existing controls. Cleaning frequency for an evaporator of this type is typically once or twice per year.

It may be economical to hydroblast prior to cleaning with EDTA. This reduces the amount of EDTA required. We recommend a professional hydroblast crew do this work. Two 600 mm manholes on the top channel facilitate easier distribution plate removal and tube blasting.

Materials of Construction

Due to the relatively high chloride content the major vessels wetted materials are 6% molybdenum stainless steel such as 254 SMO or AL6XN. Tubes are titanium grade 2. Other materials used for brine service include fiberglass, CD4MCu, Hastelloy C, and 316L Stainless Steel as applicable. Use of these materials will assure equipment life beyond 20 operating years.

Spare Parts

Installing spare pumps in brine service would lead to stagnant areas and potential corrosion. Considering the high reliability of these pumps, it is better not to install spares but keep shelf spares. In the event a pump replacement is necessary, the feed storage tank would be used to collect the feed flow as it would be when the unit was shut down for cleaning. Upon startup the excess capacity designed into the unit will process the stored feed.