

DESIGN AND PRACTICE OF EVAPORATION CRYSTALLIZER IN VACUUM PAN SALT MAKING

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Abstract: In the application by many factories, the backward forced circulation and axial discharge evaporation crystallizer with external heater has been proved to be successful and vigorous. This new equipment should be further researched, improved, popularized and perfected. This article elaborates the characteristics of this equipment on the bases of hydromechanics, crystallization mechanism, specific design parameters and the selection of materials.

Key words: Vacuum pan salt making; evaporation crystallizer; crystallization mechanism; structure of evaporator; design parameters; selection of materials.

1. INTRODUCTION

Evaporation and crystallization are important unit operation in the chemical process, which play a dominant role in vacuum pan salt making. The evaporation crystallizers being used are developed on the of the primitive evaporation facilities. The use of the present evaporators is not only to aquire product by intensifying the heat transfer and evaporation but to enhance the quality and grain size of the crystal product as the principal purpose. That is to say, the heat transfer and evaporation are the preconditions and environment for heat

Salt is made by means of a process in which brine is concentrated for crystallization of solid NaCl through heating and evaporation. With the social development and the progress of science and technology, the percentage of salt for human consumption is getting smaller and smaller while the large percentage of salt is used as raw material for basic chemical industry and other industries. Salt products have experienced a development from ancient flake salt, tube salt, cake salt to special salt that meets the special requirements of various uses. Salt making

transfer and mass transfer in which qualified product is made. In the process of heat transfer and evaporation, qualified crystal product can only be made with strict control of supersaturation of feed, formation of nuclei and the environment of crystal growth. This means a big step taken to combine the principles of evaporation and crystallization.

2. EVOLUTION OF EVAPORATION CRYSTALLIZERS

facilities are also developed from manual-operated kitchen round pan, inlaid pan, small square pan, small flat pan and large flat pan to internally-heated forced circulation (Calandria) evaporator, externally-heated forced circulation (with tangential inlet or axial inlet) evaporator and externally-heated reversed circulation (with radial discharge or axial discharge) evaporator. (See Figure 1). Oslo, DTB or inverted cone crystallizers can be added to the above-mentioned evaporators if larger crystal size ($\geq 1\text{mm}$) of salt is required.

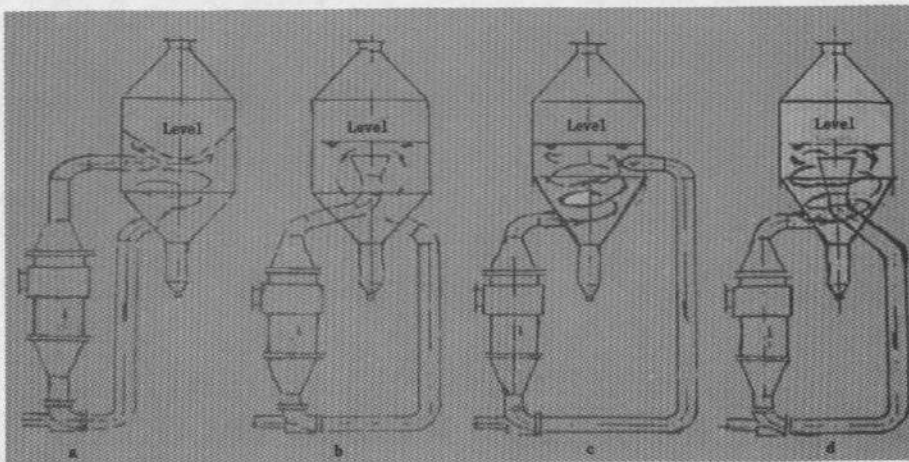


Figure 1 Schematic drawing of evaporation crystallizer

- a. Evaporator with external heating, normal forced-circulation and tangential inlet
- b. Evaporator with external heating, forced-circulation and axial inlet
- c. Evaporator with external heating, reversed forced-circulation and radial outlet
- d. Evaporator with external heating, reversed forced-circulation and axial outlet

3. BRIEF INTRODUCTION OF MECHANISM OF NaCl CRYSTALLIZATION

3.1 Crystallization of NaCl from feed brine requires ceaseless heat which evaporates the water content so that the feed brine becomes saturated or supersaturated. See Figure 2.

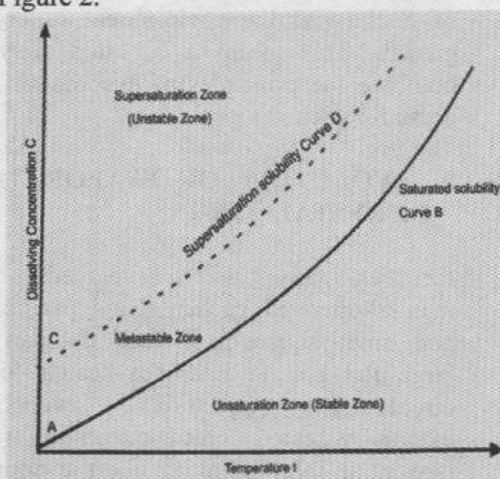


Figure 2 Solution temperature vs solubility curve

3.1.1 NaCl will not crystallize when brine is not saturated and NaCl crystals will dissolve in such unsaturated brine, as indicated by the unsaturated zone (stable zone) at the lower part under curve A-B in

the figure.

3.1.2 Evaporation of brine continues and NaCl reaches saturation, as indicated by the curve A-B which shows that the equilibrium solubility enters metastable zone. At this stage, the crystallization and dissolution of NaCl are in a state of dynamic balance and the solute NaCl will not crystallize out as nuclei. If NaCl nuclei enter, they will grow by themselves, as is shown in the metastable zone between curve A-B and curve C-D in the figure.

3.1.3 More NaCl nuclei will spontaneously form when NaCl content exceeds supersaturation curve C-D and enter supersaturation zone (unstable zone) with continuous evaporation of brine.

Among the three zones, the most important is the metastable zone. Under the conditions of crystal existence in feed, the formation of nuclei will take place in the metastable zone. The metastable zone is apt to be affected by such factors as crystal existence, size of crystal, number of crystals, agitation, vibration and impurities. The

growth of crystals should be controlled in this zone. Compared to other salts, the range of NaCl metastable zone is rather narrow. So, it is difficult to get larger crystal size. Supersaturation ΔC of the solution is the key factor and the driving force for the crystal to grow, which is defined by

$$\Delta C = C_2 - C_1 \quad (\text{g/L}) \quad (1)$$

Where: C_1 —equilibrium saturation of solution at the same temperature (g/l)

C_2 —actual saturation of solution (g/l)

The growth of crystals requires supersaturation of the solution and must be controlled in the metastable zone. Supersaturation is consumed by crystal growth. During the actual operation, the actual supersaturation of the solution is far lower than the maximum supersaturation. According to literature, the maximum allowed supersaturation depends upon the nature of the system, which is normally 0.5~5 g/l. Generally, the actual supersaturation ΔC is controlled at 1.50g/l, which is 10~30% of the maximum supersaturation ΔC_{max} .

3.2 NaCl crystal nucleation—crystal growing

In accordance with the analysis of the general diffusion theory of unit operation, crystal growth is related to the following factors.

3.2.1 The driving force for crystal growth is the difference of supersaturation of the solution and velocity of mass transfer. The solute in the supersaturated solution diffuses to the static liquid layer adjacent to the nuclei, pierces the liquid layer and reaches the surface of the crystals in such a way that the crystals grow larger, and crystallization heat is liberated and transferred by diffusion into the solution. See Figure 3. The supersaturation of the solution can be found by the following equation.

$$\text{Supersaturation} = \frac{\text{salt production}}{\text{circulation amount}} \quad (\text{g/h}) / (\text{l/h}) \quad (\text{g/l}) \quad (2)$$

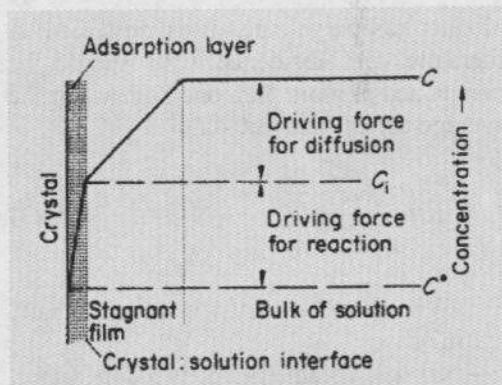


Figure 3 Concentration driving forces in crystallization from solution according to the simple diffusion-reaction model

3.2.2 Temperature of solution

Under the conditions of the same time and the same supersaturation difference, the higher temperature of the solution is, the smaller the viscosity of the solution is, the faster the velocity of the solute diffusion is and the quicker the crystal growth is. Therefore, it is easier to get crystals of larger size when temperature of the solution is higher. See Figure 4.

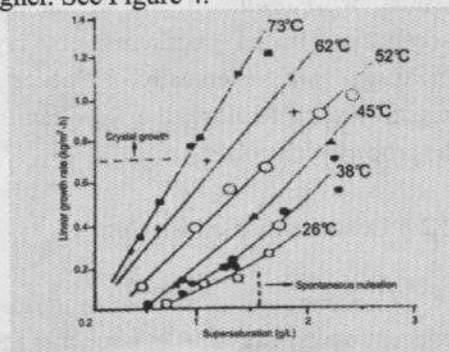


Figure 4 Salt crystal growth rate vs supersaturation

3.2.3 Concentration of impurities in solution and suspended substance

At the same temperature, concentration of the solution increases with the increasing of the content of impurities and suspended substance in solution. The diffusion velocity of the solution and the velocity of crystal growing decrease with increasing of solution viscosity.

3.2.4 Crystal residence time in crystallizer

Crystal residence time is determined by the requirement of NaCl crystal growth rate and crystal size, when NaCl crystal nucleation rate is basically the same as the

product discharge rate. It is described in literature that residence time should be maintained at more than one hour when the average crystal size ca.0.4mm.

$$Ra = \frac{6\alpha}{\beta} \rho \bar{V} \quad (3)$$

Where: R— crystal growth rate, kg/(m²·s)

α— crystal volumetric conversion factor, calculated as a sphere: α=1/6

β— surface area conversion factor, calculated as a sphere: β=π

ρ— crystal density, kg/m³

V— average crystal growth coefficient, m/s

3.2.5 Circulation flow

Circulation flow, which determines the local flow rate in the crystallizer, is inversely proportional to the supersaturation of solution when steam is fixed. High speed will lead to fierce collision among crystals, between crystals and wall of the vessel, which will result in the formation of secondary nuclei because of crystal breakage, and eventually influence the crystal size. Therefore, the flow rate must be properly controlled.

3.2.6 Concentration of salt slurry

Concentration of salt slurry means the concentration of crystals in circulating feed, or the ratio of solid to liquid. Under the same condition, high concentration of salt slurry is higher in the crystallizer, the amount of crystals are larger. Longer residence time is better for the elimination of supersaturation and the growth of crystals. However, if the concentration of salt slurry is too high, collision among crystals and between crystals and wall of vessel tends to increase. Hence the possibility of formation of secondary nuclei due to breakage increases, which is disadvantageous to crystal growth. So, concentration of crystals must be controlled at a proper level. Ideal ratio of solid to liquid is controlled at about 20%.

4. DESIGN AND PRACTICE OF CONTEMPORARY EVAPORATION CRYSTALLIZERS

Design is the bridge and the link between the scientific experiment and productive practice. Engineering design is by no means a blind scale-up or scale-down and copy of drawings, data and results of the predecessors. Design must be combined with the actual conditions. It is a creation job. Creation is the soul and driving force for design. Creation requires one to meet the challenge and risks. Designers must seek truth from facts and be good at discovery, improvement and enhancement by summarizing the experiences of the predecessors so that the designed project can be of advanced technology with good utilization of resources, clean operation, energy saving, reduction of consumption, reasonable economy and safety.

Most commonly used types of evaporators in China's salt making industry are shown in Figure 1. They are composed of evaporator, heat exchanger, upper and lower circulation pipes, circulation pump and salt leg. Such evaporation systems are required to be rational in structure, comply with the fundamentals of hydrodynamics with small resistance, low energy consumption, high efficiency of heat transfer, high evaporation intensity, good separation of steam and water, and meet the requirement of crystal growth with qualified products. Dimensions and parameters of the components of the crystallizer are determined by results of the calculation of material balance, heat balance and related empiric data, which are described as follows.

4.1 Diameter of evaporator and height of separation chamber

The design of relevant dimensions of the heater must meet the following three requirements:

a. Supersaturation of the feed can be effectively reduced and eliminated so that

crystals can grow under fine condition and in excellent environment

b. The reduction of short-circuit loss of feed favors flash and separation of vapor from liquid so that entrainment is minimized

c. The internal surface of the evaporator must be polished and clean so that salt incrustation is prevented and normal continuous operation is ensured

4.1.1 Evaporation volumetric intensity method

This means the volume of the vapor discharged from each cubic meter of evaporating space per second. Given the height of separation space, diameter of the evaporator is calculated as the following equation.

$$D = \sqrt{W / (V \pi H)} \quad (\text{m}) \quad (4)$$

Where: D— diameter of evaporator (m)

W— volumetric flow of vapor (m^3/s)

V— allowed evaporation volumetric intensity: $1.1 \sim 1.5 \text{ m}^3/\text{m}^3 \cdot \text{s}$

(Others suggest $1.8 \sim 2.5 \text{ m}^3/\text{m}^3 \cdot \text{s}$)

H— height of steam and water separation space: $1.8 \sim 2.5 \text{ m}$

(Others suggest $2.5 \sim 33.0 \text{ m}$)

4.1.2 Mass and speed method

This means water allowed to be evaporated per unit surface area per unit time.

$$D = \sqrt{4W / (\pi V)} \quad (5)$$

Where: W— water evaporated kg/h

V— allowed mass speed: $2500 \sim 800 \text{ kg}/\text{m}^2 \cdot \text{h}$ (lower limit for last effect)

4.1.3 Approximate proportion method

Taking the separation space as a steam and water separator, its diameter is calculated as

$$D = \sqrt{U_{\text{load}} / (0.541 R_d)} = \sqrt{U_{\text{load}} / (0.541 \times 0.44)} = 6.47 \sqrt{U_{\text{load}}} \quad (6)$$

where: $U_{\text{load}} = W_{\text{sec}} \sqrt{r_{\text{vapor}} / r_{\text{liquid}}} \cdot r_{\text{vapor}}$
(m^3/s)

W_{sec} — vapor volume (m^3/s)

r_{vapor} — vapor gravity (kg/m^3)

r_{liquid} — feed gravity (kg/m^3)

R_d —ratio of actual steam speed to basic speed (normally 0.44, but 1.15 without demister)

4.1.4 Cross section speed of vapor method

Speed of vapor (or speed in empty vessel) in evaporator is specified as $4 \sim 7 \text{ m/s}$. The author suggests that it should be controlled at 4 m/s in the last effect of a multiple-effect evaporation system. Its diameter is calculated as

$$D = \sqrt{4GV / (\pi W)} \quad (\text{m}) \quad (7)$$

Where: G—vapor flow (kg/h)

V—specific volume of vapor (m^3/kg)

W—flow rate of vapor (m/s)

π —ratio of circumference of a circle to its diameter

4.1.5 Height of vapor separation space

Height of vapor separation space means the effective height of the steam and liquid separation section above the feed level in evaporator. Feed which enters into the evaporator boils by heating. Bubbles go upward and break at the surface of the feed and forms vapor. The effective height is that at which most of the droplets and mist entrained in vapor can fall and settle down. This height stated in literature is $2.0 \sim 3.0 \text{ m}$ in most cases. However, the height in China is more than 3 m without demister, and even tends to increasing.

4.1.6 Diameter of secondary steam pipe

Specific volume of vapor varies with pressure. In order to reduce the pressure drop in secondary steam pipe and temperature loss, vapor speed in the secondary steam pipe is controlled at

10~40m/s for calculation.

4.2 Determination of heating area, diameter and length of heating tube

4.2.1 Heating area

Based on the calculation of material balance and heat balance and the parameters chosen, heating area is calculated as

$$F=Q/(k\cdot\Delta t) \quad (\text{m}^2) \quad (8)$$

Where: F —heating area (m^2)

Q —heat transferred in unit time (Kcal/h)

k —total heat transfer coefficient (Kcal/ $\text{m}^2\cdot\text{h}\cdot^\circ\text{C}$)

Δt —effective temperature difference ($^\circ\text{C}$)

4.2.2 Diameter and length of heating tube

Given heat load is set, the correlation of Δt with d , L and W can basically be determined when heating area is set. We can calculate as

$$Q=k\cdot F\cdot\Delta t=k\cdot n\cdot\pi\cdot d\cdot L\cdot\Delta t \quad (\text{Kcal/h}) \quad (9)$$

$$Q=\pi/4\cdot d^2\cdot n\cdot w\cdot\gamma\cdot c\cdot\Delta t\cdot 3600 \quad (\text{Kcal/h}) \quad (10)$$

Substituting (9) into (10), it follows

$$\Delta t_c=k\cdot\Delta t\cdot L/900\cdot\gamma\cdot w\cdot d \quad (^\circ\text{C}) \quad (11)$$

Where: k —total heat transfer coefficient (Kcal/ $\text{m}^2\cdot\text{h}\cdot^\circ\text{C}$)

Δt —effective temperature difference ($^\circ\text{C}$)

Δt_c —feed temperature rise ($^\circ\text{C}$)

d —calculated diameter of heating tube (m)

L —effective length of heat transfer of heating tube (m)

w —feed flow rate in heating tube (m/s)

γ —gravity of circulating feed (kg/m^3)

c —specific heat of feed (kJ/kg $\cdot^\circ\text{C}$)

n —number of heating tubes

It can be seen from the equation above that Δt_c is proportional to L and inversely proportional to d and w when heat load and heating area are determined. Δt_c is an important parameter for design because it is closely related to the supersaturation of feed, speed of crystal growth and quantity and quality of the salt product. Generally speaking, the value of Δt_c is determined before d , L and w are determined.

According to literature and experiences, in most cases, $\Delta t_c=3^\circ\text{C}$, 5°C is highest, d (outside)=32~45 mm, $L=5000\sim 7000\text{mm}$, 12000mm is the longest, $w=1.2\sim 2.5\text{m/s}$ (1.8m/s is preferable).

4.2.3 Number of heating tubes

Number of tubes is calculated as the following when heating area is determined.

$$N=F/(\pi\cdot d\cdot L) \quad (12)$$

Where: F —heating area (m^2)

d —calculated diameter of heating tube (m)

L —effective heat transfer length of heating tube (m)

π —ratio of circumference of a circle to its diameter

It is specified in the Chinese standards governing the calculation of shell-and-tube heat exchanger that outside diameter is taken for calculation of diameter of heating tubes. In salt industry, average value of inside and outside diameters is conventionally applied. According to the author's design practice and data from literature, the value of total heat transfer coefficient is influenced by α_1 (heat supply coefficient outside the tube) and α_2 (heat supply coefficient inside the tube). When $\alpha_1<\alpha_2$, outside diameter is taken for calculation. When $\alpha_1=\alpha_2$, average value is taken and when $\alpha_1>\alpha_2$, inside diameter is taken for calculation. In the exchangers used in Chinese salt plants, α_1 is far higher than α_2 , at least by 2 to 3 times. Therefore, the author suggests that taking the value of inside diameter is suitable for calculation of numbers of heating tubes.

4.2.4 Diameter of shell body of heat exchanger

When diameter and number of the tubes are set, tubes are commonly arranged in an equilateral triangle pattern. The diameter of the shell of the exchanger can be calculated with the following empiric equation.

$$D=1.15Pt\sqrt{N} \quad (m) \quad (13)$$

Where D— diameter of shell of exchanger (m)

Pt— clearance between tubes (mm)

N— number of tubes

Clearance between tubes—center to center distance between tubes— $Pt=1.3\sim1.5d$ (outside) when expansion method is used. In quite a long period of time, same clearance was applied to the exchangers of the multiple effect facilities, hence the same diameter of the shell body of exchangers. The author does not think it's a proper practice. We know that there is large difference between specific volume of steam entering the first effect and that in the last effect. In order to reduce the loss of pressure and temperature to favor heat transfer, different clearances must be applied according to different specific volume of steam. At a higher vacuum, the clearance for the last effect should be larger. So, $Pt=1.3\sim1.8d$ (outside)

is a better choice.

4.2.5 Steam inlet arrangement

In order to prevent tubes from erosion and vibration caused by steam, dam board or guide vane should be used at steam inlet. When dam board is used, the distance h between the board and inside of the shell should be 0.25 larger than inside diameter d of steam inlet pipe, diameter D of the board should be larger than diameter d of steam inlet pipe and cross-sectional area of the steam passage must be larger than that of steam inlet pipe, as is shown by a in Figure 5. Guide vane is another ideal arrangement, which is commonly used in salt making industry. It leads the steam of comparatively high flow rate into the jacketed annular channel for redistribution. The correlation of width h of annular passage to diameter d of steam inlet pipe is $h\geq0.3d$, as is shown by b in Figure 5.

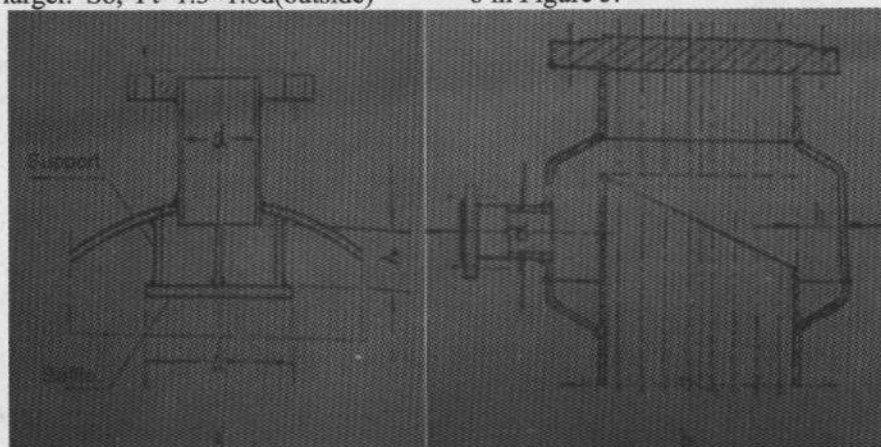


Figure 5 Schematic drawing of anti-surge device at steam inlet

4.2.6 Baffle arrangement

Baffles were not used in most of the Chinese salt plants in early times until in 1980s when material was improved with enhanced corrosion resistance, cycle of changing tubes was elongated and complete set of salt plant was imported from abroad, the Chinese designers began to use them for the purpose of intensifying the process of heat transfer. In most cases, notched round plate are used. The notching rate of $0.25D$ is

normally used in design. Distance between baffles at the upper section is larger than that at lower section with the largest distance less than the diameter of the exchanger shell. For baffles of condensing type, the author suggests that the notching rate be increased to about $0.45D$. The reason for this is the gradual condensation of steam and gradual decrease of the steam volumetric flow. It is the same for the distance between baffles. Distance at the upper section should be larger than that at

the lower section. However, it is stated in some literature that there is no need to use baffles because baffles have little impact on heat supply coefficient when the space of the shell body is used for condensation of steam. But the installation of baffles for increasing rigidity of tube string, preventing tube vibration and discharging condensate is an exception.

4.3 Diameter of circulation pipe

Empiric data is normally the basis for calculation of diameters of the upper and lower circulation pipes. Data in literature has it that the ratio of cross-sectional area of lower circulation pipe to the total cross-sectional area of heating tubes is 0.8~1.1 for externally-heated forced circulation evaporation crystallizer. Cross-sectional area of upper circulation pipe is the same as that of lower pipe or the diameter of upper circulation pipe is 0.2~0.3 times of diameter of exchanger. In the long period of practice, the head of circulation pump is reduced by enlarging the diameter of circulation pipe in an attempt to reduce feed resistance in circulation pipe. In the design in recent years, the ratio of cross-sectional area of circulation pipe to the total cross-sectional area of the heating tubes has been controlled at 1.0~1.5, which tends to increase at present while the diameters of upper and lower circulation pipes tend to be the same. However, the elbow connecting upper circulation pipe to the upper cone of the vessel is of the same diameter. The author changed it into a reducing type, which has been proved to be effective in practice.

4.4 Distance between the upper tube plate and the level in evaporator

In order to prevent the decrease of total heat transfer coefficient caused by feed boiling and scale plugging in tubes, enough height of liquid column must be maintained above the upper tube plate. This height of liquid column can be roughly calculated as

$$H = \frac{P_1 - P_2}{r} \quad (\text{m}) \quad (14)$$

Where: H —height of liquid column (m)

P_1 —pressure (at) of saturated steam at the temperature of feed outlet temperature minus feed boiling point rise

P_2 —pressure (at) of vapor from evaporator— average gravity of steam, liquid and solid (kg/m³)

4.5 Circulation pump

Circulation pump is an important component of an evaporation crystallizer with externally-heated forced circulation. Its quality directly influences the energy consumption of the system, product grain size, smooth operation of the system and operation cost. The flow, the head and the efficiency of the pump must meet the requirement of the easy, long time and safe operation of the system.

Circulation pump used in salt plant is of axial flow type with large flow, low head and high specific speed. Its flow, head and efficiency are proportional to the first power, second power and third power of speed respectively, and to the third power, second power and fifth power of the diameter of pump impeller respectively. And the specific speed is a principal parameter which determines the form of impeller, characteristics of performance parameters and cavitation performance. At present, pump speed is calculated as

$$C = \frac{5.62n\sqrt{Q}}{NPSH^{3/4}} \quad (15)$$

Where: Q — optimum working flow (m³/s)

n — rated speed of pump (r/min)

$NPSH$ — required net positive suction head designed or at optimum working condition

C — cavitation specific speed

Given similar geometry and movement of the pump, it follows $Q=K_2 \cdot n \cdot D^3$, $NPSH=k_1 \cdot n^2 \cdot D^2$. Substituting Q and $NPSH$ into Equation (15), it follows $n \cdot D = \text{constant}$.

For pumps with similar geometry and

movement, the value of $n \cdot D$ is the same and cavitation is similar. At present in China a model axial flow pump with $D=300\text{mm}$, $n=1450\text{r/min}$ and $n \cdot D=435$ can operate without cavitation. Therefore, $n \cdot D=435$ (for large capacity axial flow pump made in foreign countries, $n \cdot D=200$) is taken as a principle to select pump. The value of $n \cdot D$ should be less than 435 no matter how large the diameter of the pump is. The less the value is, the less the possibility of cavitation is. Accordingly, pump with larger diameter of impeller and lower speed should be selected when flow is set. The similar geometry tells us that pump flow is proportional to the first power of speed and the third power of diameter of impeller. The reduction of flow rate decreases the hydraulic loss and raises the pump efficiency.

4.6 Feed volume

This means the volume of feed filling the whole system of evaporation, crystallization and circulation, where feed is evaporated, the solute NaCl reaches saturation and crystallizes, and crystals grow to the required size. In order to ensure the required environment and conditions, the volume should meet the requirement of about 30 seconds for which feed finishes a cycle in the the circulation system.

4.7 Diameter and length of salt leg

Salt leg is a vessel where NaCl crystals settle down and become thickened. The amount of slurry discharge controls the ratio of solid to liquid in the circulating feed and ensures normal operation of the evaporation crystallizer. In order to enhance the quality of product and reduce steam consumption, elutriation brine can be used to remove fine salt crystals and dissolvable particles of impurities.

Diameter of salt leg

According to scientific experiment and productive practice, the diameter of salt leg

is determined by the settled amount of salt crystals per unit cross-sectional area per unit time, normally $14\sim 20\text{t/m}^2\text{h}$. When elutriation brine is used, its rising speed is determined by the required crystal size and the ratio of solid to liquid in slurry. Literature suggests $1\sim 10\text{mm/s}$.

Length of salt leg

In most cases according to the experiences of both at home and abroad, 5 meters or so is a common practice, and length of 3 meters is also seen. Better results can only be obtained when correct length is taken in accordance with the actual conditions such as the scale of the plant and process applied.

4.8 Selection of material

4.8.1 Material that is smooth on surface, easy to fabricate and maintain, corrosion and erosion resistant can be selected for evaporator, upper and lower circulation pipes and upper and lower cones of exchanger. In 1980s and 1990s, B_{30} copper-nickel-clad plate, 316L-clad plate, duplex stainless steel (18-5)clad plate, full titanium and titanium alloy clad plate were used in salt plants. Practice has proved that all these plates are feasible in use. However, under the conditions of dense concentration of Cl^- , pit corrosion and transcrystallization and even transcrystalline rupture occur on 316L influenced by pH value and sulfides. Therefore, when 316L is used, great attention must be paid to the environment and conditions, such as adjusting the pH value of the feed and removing sulfides including organic sulfides. At present environment and conditions, it is better to select duplex stainless steel-2205 which is superior to 316L in terms of anti-corrosion, anti-erosion, easy fabrication and economic aspects. No matter what material is selected, the surface of the vessel wall and welded joints contacting feed must be ground, polished and treated with acid washing and passivation so that a smooth and dense film is formed to prevent salting up by the

adherence of the induced nuclei.

4.8.2 Tube, tube plate and shell of heat exchanger

Heat exchanger is a critical component of the evaporation crystallizer. Selection must be based on careful comparison. In 1980s and 1990s, seamless carbon steel tubes, low alloy (E2) steel tubes, copper tubes, B30 copper-nickel alloy tubes, titanium alloy tubes and full titanium tubes were commonly used with coordinated tube plate or clad tube plate. Carbon steel plate or stainless steel clad plate was used to fabricate the shell. In consideration of reasonable economy, titanium alloy or full titanium are the best choice for making tubes because they are characteristic of smooth surface without hydrophilicity, and of high rate of heat transfer, anti-corrosion, anti-erosion, light specific gravity, small wall thickness and long life of operation. Tube plate is made of plate clad with the same material as that of tube. For the shell, stainless steel or duplex stainless steel clad plate is used.

5 CONCLUSION

Evaporation crystallizer is a key unit of vacuum pan salt making system, to which great attention has always been paid by the designers and salt producers. In this paper, approaches are made on the crystallizing mechanism and hydrodynamics. Based on the data provided by some salt producers, the selected technology and economy and the product quality are analyzed. Advantages and disadvantages of different types of evaporation crystallizers are discussed. The crystallizer designed by the author, which is indicated by d in Figure 1, has been used in over 10 newly-built or modified salt plants with great success in China.

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