# Description and Operation of a High Capacity Evaporator for the Production of a very Pure Chemical Grade Salt

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**ABSTRACT**

A very pure salt is required for caustic production in mercury cells. In order to cover their need, Montedison decided in 1968, to build a salt plant with solution mining in Ciro Marina-Calabria-Italy. The evaporation unit was installed by Whiting Fermont, Paris (Swenson Evaporators). In combination with a new type of brine treatment at ambient temperature designed by Montedison, it produces more than 3,000 metric tons per day of salt with a minimum of 99.94 percent NaCl and less than 1 ppm heavy metals. The evaporation plant is a combination of a quadruple effect evaporator and a mechanical recompression evaporator. The vessels have been designed for a capacity of 1,500,000 metric tons per year and heating surfaces for the first step i.e. 1,000,000 metric tons per year. The installation is certainly one of the greatest of its kind. To give an indication of its size one can note that the recompression vessel is twelve meters in diameter, the heaters installed are 2,5 and 3,0 meters in diameter and more than 12 meters long. The vapor compressor which is an axial type can handle up to 250 metric tons per hour of vapor. A man can walk inside the recompression evaporator vapor piping. The plant is using 60 bar, 480°C steam in two back pressure 10,000 kW turbines running respectively an alternator and a compressor. All the back pressure steam is absorbed by the first effect heater of the quadruple effect evaporator. The alternator produces all the electricity required by the plant. The specific consumption is below 700 kg of steam per metric ton of salt. The plant began operation in the winter 1970.

## INTRODUCTION

Caustic production in mercury cells requires very pure salt (NaCl) with an extremely low heavy metal content. Montedison's requirement for a large quantity of salt meeting this purity and stringent specifications, as well as operation and increasing energy costs resulted in a methodical search and evaluation of existing proven technology in the field of salt crystallization, in order to arrive at the most economical design. This search and evaluation of the many offers submitted to Montedison resulted in the choice of an evaporator of Swenson design. Whiting Fermont, at the time a minority owned company of Whiting Corporation and an exclusive Common Market licensee of the Swenson Division of Whiting Corporation, was entrusted with the detail engineering and supply of the required evaporation plant.

## EVAPORATOR DESIGN

Swenson approached the problem of design from the point of view of the minimum energy requirement per ton of salt produced, consistent with low capital investment. A study of conventional multiple effect evaporator designs and the associated energy requirements made it very obvious that this path alone would hardly meet the needs and challenge of a salt plant design built from scratch. The opportunity for Swenson's creative thinking was unique in that there was no existing plant on the site and all auxiliary services such as steam and electrical energy supply could be designed specifically to meet the needs of the overall chosen plant design. After many heat and material balances based on using conventional multiple effect evaporators, thermorecompression and mechanical recompression design, it became obvious that energy consumption and cost considerations dictated the choice of a combination, multiple effect evaporator operating in conjunction with a mechanical recompression unit. In the final arrangement chosen, steam is generated at high pressure and used to drive two turbines. One of these turbines is connected to an alternator which provides the necessary electric current for the plant, and the other is connected to a compressor which recompresses the vapor from the single effect evaporator so that it can be re-used in the heating elements of the single effect. The exhaust steam from both turbines is used to drive the quadruple multiple effect evaporator.

The mechanical design of the evaporator required careful study because of the size of the unit. The consideration of multiple trains of evaporators was quickly eliminated on the grounds of cost comparisons with a single train unit. The design of each specific element making up an evaporator has requirements which differ considerably for a large evaporator from those for a small evaporator. This subject of mechanical design of large evaporators is covered in detail in a paper presented at the Third Symposium on Salt by H. Newman (1970) now retired but at that time Assistant Manager of Swenson.

The complex relationships of the many possible designs made the use of a computer indispensable in determining the equilibrium operating conditions. A computer program was also used to determine the optimum vessel wall thicknesses, spacing and size of reinforcing bars. Without the availability of a computer program the myriad of calculations necessary to arrive at the optimum design and minimum cost would never have been completed in time to meet proposal deadlines.

## PROCESS FLOW DESCRIPTION

Figure 1 outlines the principle of evaporator feed brine purification. Figure 2 represents the flow sheet of the evaporation plant.

The raw brine is saturated with calcium sulphate. It is mixed with a recycle stream containing a high amount of sodium sulphate coming from the evaporation plant (the ratio is 100/40 b.w.). About half of the calcium sulphate is precipitated in this first step. The remaining calcium sulphate is chemically treated in the second step using sodium carbonate. The resultant calcium carbonate formed and the heavy metals in the form of hydroxydes are precipitated in this step. The pH is controlled using caustic.

The purified brine is clarified in a settler with final clarification accomplished through sand filters. The recycle stream for the first step calcium precipitation comes from the overflow of the fourth effect hydrocyclone $HC_4$ where the sodium sulphate concentration is maximum.

A small amount of water is injected in the recycle line in order to dissolve salt fines. Part of the recycle stream is

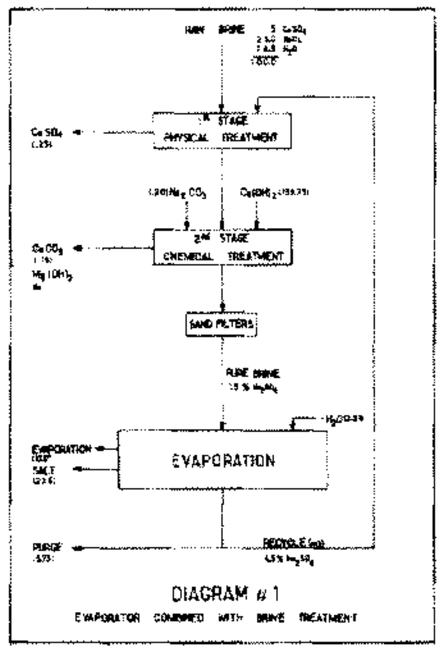


**Figure 1.** Evaporator combined with brine treatment.

dumped in order to purge the system of excess sodium sulphate build up.

The evaporation plant consists of 1) a mechanical recompression evaporator, 2) a quadruple effect evaporator, and 3) pusher type centrifuges to dewater the salt slurry.

The recompression evaporator produces 40% of the total salt capacity of the plant. The plant uses high pressure steam at 60 ATA superheated to 480°C. It is introduced in parallel into two identical 10.000 kW turbines each driving respectively the axial compressor of the recompression evaporator and the generator producing electrical energy for the complete plant.

The steam discharged from the turbines at a pressure of about 3 ATA is desuperheated and used in the first effect heater HE1 of the quadruple effect evaporator and as make-up steam to the recompression evaporator. A pressure reducing station gives more flexibility to the system.

The turbine exhaust steam condenses in the quadruple first effect heating element and supplies all the heat required to evaporate the brine in the quadruple effect evaporator. The vapors of the fourth effect are condensed in a direct contact condenser using seawater as a cooling medium. The vacuum is obtained with steam ejectors using high pressure steam. The water vapors generated in the recompression evaporator are treated in a scrubber, compressed from 1,5 ATA to 3 ATA in the axial type compressor and condensed together with the make-up steam in the two heaters of the recompression evaporator.

The fresh purified brine is sent to the feed tank and part of it is used to wash the salt produced which is collected in the wash leg. From the feed tank the brine is fed in parallel

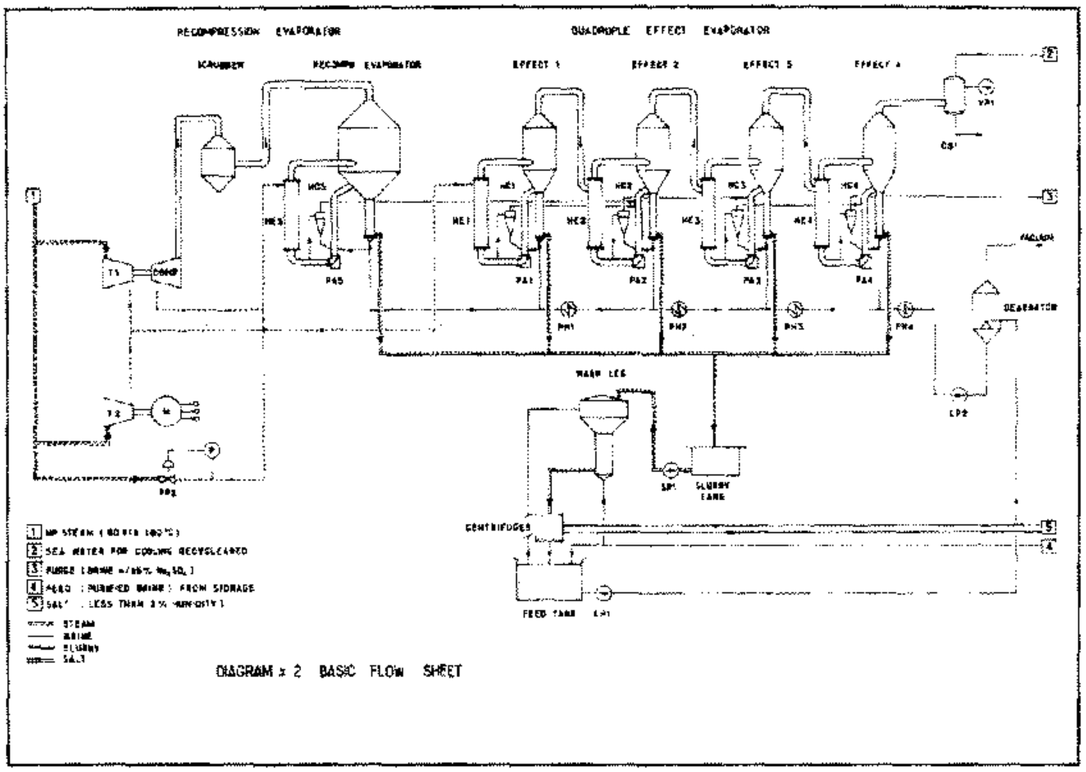


**Figure 2.** Basic flow sheet.

to the evaporators and reheated by preheaters using hot condensate and vapors as heating medium.

In each effect, the feed brine required to maintain a proper operating level in each effect is introduced through a level control valve into the circulating loop. A constant flow of feed brine is introduced at the bottom of each elutriation leg to fluidize and partially wash the salt produced prior to discharge.

The salt is discharged in the form of a thick slurry from each vessel into the slurry tank and sent to the wash leg where it is counter-currently washed with fresh brine and then to the centrifuges for separation from the brine. In the centrifuges the washing is completed using condensate sprayed on the cake.

Figure 3 shows a typical Swenson forced circulation evaporator used to crystallize salt. The brine is recirculated by means of an external axial pump and heated in an external one pass vertical tube heat exchanger. A mesh demister is installed in each vessel in order to minimize entrainment and produce a very pure condensate.

## PLANT DESCRIPTION

This plant is exceptional in size. The vapor head diameters in the range of 8 to 12 meters are of monel-clad steel construction. The vapor piping is in carbon steel. The diameter of the vapor pipe connecting the fourth effect to

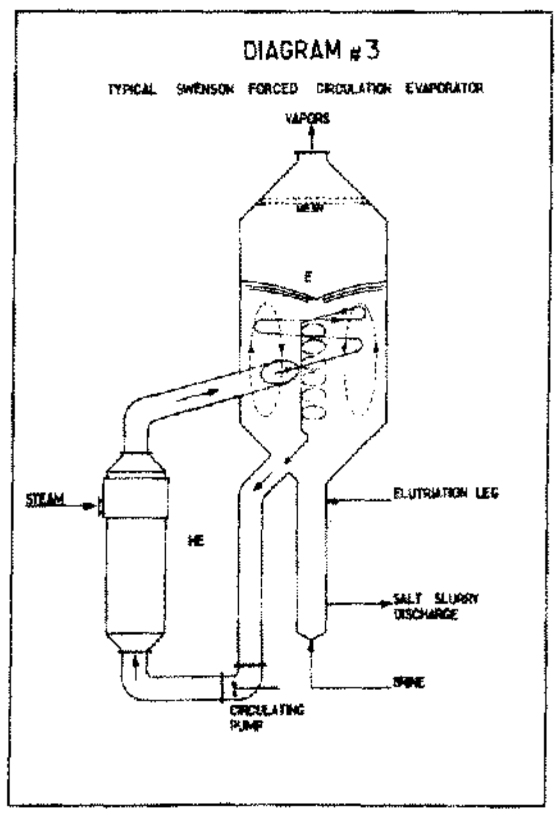


**Figure 3.** Typical Swenson forced circulation evaporator.

the condenser is 3000 mm and the diameter of the pipe connecting the recompression vapor head and the suction flange of the axial compressor is 2,000 mm. The circulation pumps have a diameter of 1,100 mm and can give a flow rate of about 15,000 $m^3/h$.

The heaters are about 3 m in diameter and 12 m long. They contain a total of 112 kilometers of 70–30 cupronickel tubes. The compressor is an 11 stage axial type. At the time of plant construction it was the largest unit ever built for a vapor recompression application.

The centrifuges are two stage pusher type. Five centrifuges are installed. One centrifuge is used as a spare. The basket diameter of each centrifuge is 1,400 mm in diameter. The seawater cooling line to the direct contact condenser is about 1000 mm in diameter.

## OPERATING AND DESIGN CAPACITY

The plant was designed for a capacity of 1,500,000 metric tons per year of salt. Only sufficient heating surface was installed to realize an immediate production capacity of 1,000,000 metric tons per year equivalent to a daily production of 3,000 metric tons of salt (NaCl). There are plans to add additional heating elements and circulating loops to increase the production capacity by 50% to the design rate. The following figures represent present average hourly plant production capabilities.

| | | |
|---|---|---|
| Production of salt | : | 125 t/hr |
| High pressure steam (60 ATA) | : | 88 t/hr |
| Seawater | : | 4000 $m^3$/hr at 30°C |
| Electricity | : | 4500–5000 kW |
| Condensate | : | 350 $m^3$/hr |

## QUALITY OF THE PRODUCTS

The centrifuged salt produced has a moisture content of about two percent by weight and is 99.94% pure on dry basis. It has less than 8 ppm of calcium, less than 120 ppm $SO_4$ and does not contain more than 1 ppm of metals (Cu, Ni, Cr, Fe and Mg). There is no additional drying of the salt prior to shipment. The vapor condensate contains less than 50 ppm of salt.

## PLANT OPERATION

The plant is producing 3,400 t of salt daily when commercially clean, this is 13% over-design capacity. The plant is chemically cleaned every 6 months. A 20 day shut-down is scheduled once a year for general maintenance purpose. This down time is used also to chemically clean the entire plant. In addition to the semi-annual chemical cleaning of the evaporators a complete water boil out is scheduled once every three months on a routine basis.

## CHEMICAL CLEANING

Semiannual chemical cleaning is accomplished by filling the bodies with water which contains a small amount of corrosion inhibitor. The circulating stream is maintained slightly on the acid side by the addition of hydrochloric acid. A sudden drop in pH is an indication that the acid reaction with the carbonate scale is complete. Acid addition is immediately interrupted, the bodies are drained and then rinsed with plant water.

Water boil outs scheduled every three months are accomplished by first cutting off all steam to the evaporators and discharging the accumulated salt in the bodies at the fastest rate permitted by the capacity of the centrifuge station. When the salt slurry density has dropped to below 5% apparent settled volume, water is added raising the level in each body several feet making sure all salt build up areas are submerged. The diluted brine is circulated until all the build up of salt accumulated on the walls is dissolved. This procedure takes approximately six hours and the production loss due to the brine dilution is approximately 10 hours.

## OPERATING PERSONNEL

Three people are required per shift to operate the plant. This does not include maintenance people, salt loading or shipping personnel. Of the three persons, one is assigned to the central control panel, one is an assistant who takes samples, clears plugged lines and is generally in the evaporator area to check any problems or malfunction indicated on the control panel. The third man is assigned specifically to the operation of the centrifuges. This third man is necessary because of the remote location of the centrifuges. Locating the centrifuges next to the control room could possibly eliminate this third man. His duties would be added to the chief operator located in the control room.

## PLANT FLEXIBILITY

The plant can be operated at 75 to 115% of design capacity without any serious operating problems. Further capacity reduction can be realized by shutting down the mechanical recompression unit and operating only the quadruple effect.

## CONCLUSIONS

1. Seven years of operation have proven that the choice of a single train of evaporators was justified. No serious production losses because of plant malfunction or maintenance requirements have been experienced.
2. Planned and careful maintenance as well as proper stocking of critical parts have proven that the on-stream time of a mechanical recompression unit compares very

favorably with a conventional multiple effect. No disasters were encountered although it is recommended that a spare rotor for the compressor be available.

3. The energy crisis has justified the choice of this combination of mechanical recompression and multiple effect. Energy requirements for a straight quadruple effect are 510,000 Kcal/t of salt. Energy requirements for the recompression and quadruple combination are 372,000 Kcal/t of salt.
4. The mechanical recompression unit should be considered when adding capacity to an existing plant whose boiler capacity has reached maximum output.
5. The addition of a mechanical recompression evaporator to improve fuel economy should be studied in existing plants.
6. In areas of low and moderate electrical costs, conversion of existing multiple effects to mechanical recompression should be studied to determine whether energy savings can justify such a conversion.

## REFERENCE

Newman, H.H. 1970. Design factors in large salt evaporators. Third Symposium on Salt, 2:13–19. Northern Ohio Geological Society, Cleveland, Ohio.