Design Factors in Large Salt Evaporators

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ABSTRACT

This paper deals with the development of large salt evaporators within approximately the last decade. For the purpose of this paper "large" is defined as having an evaporative capacity of 500,000 #/hr and up.

Design factors relating to the principal elements of large salt evaporators are discussed, including vapor heads, heating elements, circulating systems, vapor piping, condensers and supporting steelwork.

Use of arrangements combining mechanical recompression with multiple effect evaporators are discussed, and economy compared with straight multiple effect evaporators.

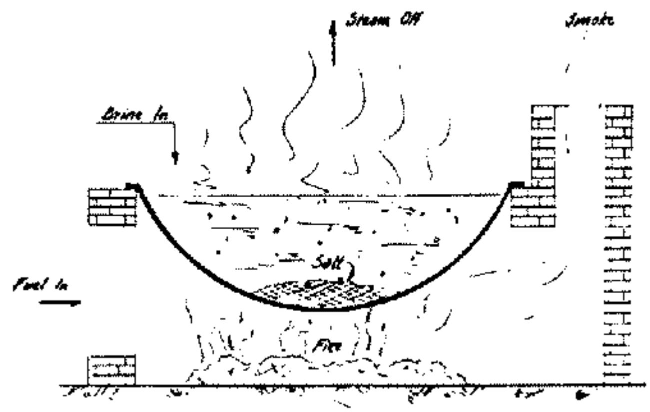


Figure 1. Direct-fired lead pan.

Evaporation of brine for the production of salt has a longer history than any other industrial evaporation process. Evaporation in direct fired open pans began before recorded history.

Figure 1 represents the sort of direct fired lead pans which were in use in the British Isles during the time of the Roman occupation.

Figure 2 is a reproduction of a wood cut by Agricola illustrating the well developed salt production which existed in medieval Germany. The operator or "master" is ladling salt from the direct fired pan into baskets for drainage and transportation. This was a continuous 24 hour per day operation shutting down only for feast days.

Figure 3 also by Agricola illustrates some of the details of the pans. They were of riveted iron construction, having joints sealed with a mixture of ox liver, ox blood and ashes. They were supported around the outside on a brick setting and the flat bottom was held up by means of hanger rods suspended from an overhead arrangement of cross beams.

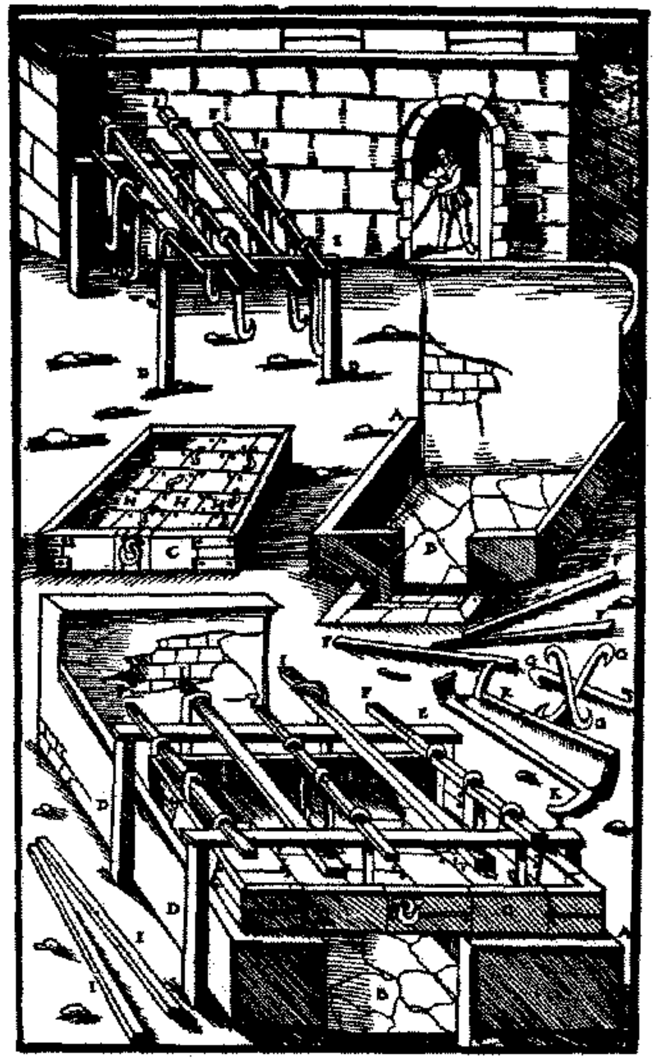
The life of one of these pans was about half a year.

There are no exact records of the production rates achieved, but assuming Agricola's drawing to be approximately to scale, the pans appear to be about 8 feet x 4 feet, and from this resulting area we can calculate the approximate production rate as roughly one half ton per hour of salt assuming the feed brine to be saturated.

Skipping over several hundred years to the twentieth century, we find evaporated salt being produced in multiple effect calandria type evaporators of cast iron construction, usually with copper tubes. The largest single trains of evaporators of this type had capacities of up to approximately 1000 tons per day of salt with body sizes ranging

A—Wooden dipper. B—Cask. C—Tub. D—Master. E—Youth. F—Wife. G—Wooden spade. H—Boards. I—Baskets. K—Hoe. L—Rake. M—Straw. N—Bowl. O—Bucket containing the blood. P—Tankard which contains beer.

Figure 2. Salt production in Medieval Germany.



A—Fireplace. B—Mouth of fireplace. C—Caldron. D—Posts sunk into the ground. E—Cross-beams. F—Shorter bars. G—Iron hooks. H—Staples. I—Longer bars. K—Iron rod bent to support the caldron.

Figure 3. Pan details.

up to 26 feet in diameter. A typical evaporator of this type is shown in Figure 4.

Within the last two to three decades, a further radical increase in the size of salting evaporators has taken place with the development of installations having evaporation rates approaching 1,000,000 PPH in a single train corresponding to salt production rates of approximately 4200 tons per day. Still larger installations are already under construction and there would be no difficulty in designing and building an evaporator having a capacity of over 2,000,000 PPH evaporation, as will be discussed further on. These large evaporators have generally been of the outside heating element, forced circulation type, such as shown in Figure 5.

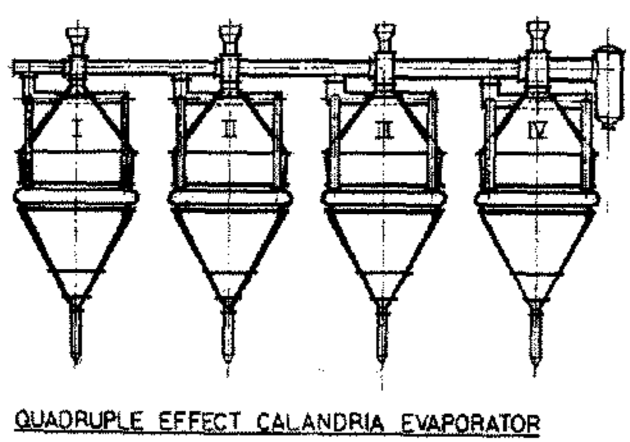


Figure 4. Calandria type evaporator.

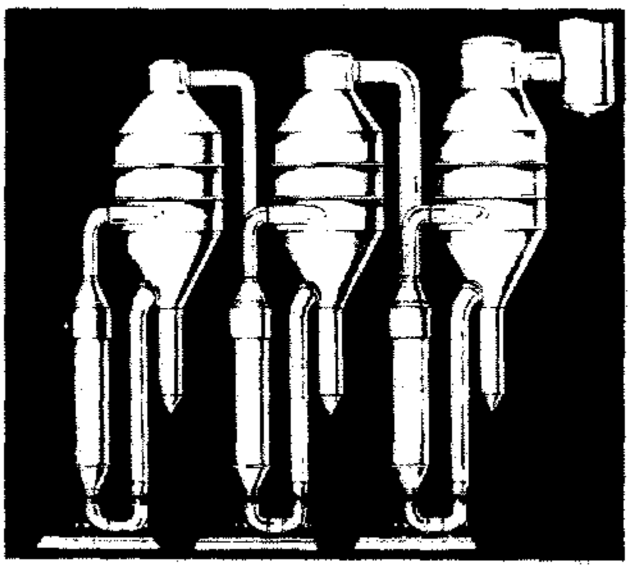


Figure 5. Forced circulation evaporator.

For purposes of comparison, Figure 6 shows a 22′ diameter calandria evaporator and a 50′ diameter multiple heater forced circulation evaporator. The bar charts in the upper right of the figure indicate the relative capacities.

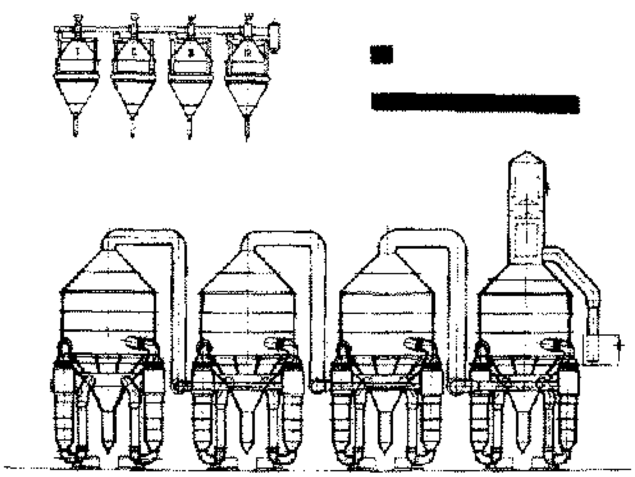


Figure 6. Size comparison.

The purpose of this paper is to discuss the continuing development of large single train evaporators. The principal elements in the design of a forced circulation evaporator consist of the following:

1. Vapor Heads
2. Heating Elements
3. Circulating Piping
4. Circulating Pumps
5. Vapor Piping
6. Condenser
7. Instrumentation
8. Supporting Steelwork
9. Building

The design of each of these elements for a large evaporator has requirements which differ from those for a smaller one. The main considerations are outlined below:

Vapor Heads.

The earlier vapor head or body designs were generally cast iron, but in recent years the tendency has been to use Monel or other Alloy construction for several reasons. In the first place, cast iron has risen in cost more rapidly than the welded Alloys, and in the second place, elimination of iron specks in the product salt is important. In addition there is the generally lower corrosion rate of Alloy construction, together with the reduced tendency for salt to build up on the walls and the elimination of air leaks.

Generally speaking, the earlier and smaller Alloy bodies were of one single thickness throughout. With the trend toward larger and larger bodies, it has become important to vary the thickness throughout the vessel as required for strength. Figure 7 shows some details of a typical body and illustrates this thickness variation. Generally the designer has a choice between a thicker wall with fewer reinforcing bars, or a thinner wall with more bars. This choice may be affected by the location of large openings which limit minimum bar spacing. In actual practice, it has proven desirable to use a computer program to optimize the design with relation to body thickness versus number and size of reinforcing bars.

One important consideration in the design of very large vessels is the pressure which may exist at the bottom when the vessel is filled to the top, even at atmospheric pressure. With an overall height of say 80 ft. this pressure would be over 41 psi when filled with brine at a specific gravity of 1.2.

Heating Elements.

With respect to heater design, the tendency has been towards single pass vertical heaters because of the following factors:

1. Less tendency for the tubes to plug.

2. Lower power requirement than multiple pass horizontal heaters because of fewer losses.

3. Lower cost than multiple pass heaters because of smaller diameter Alloy tubesheets and liquor

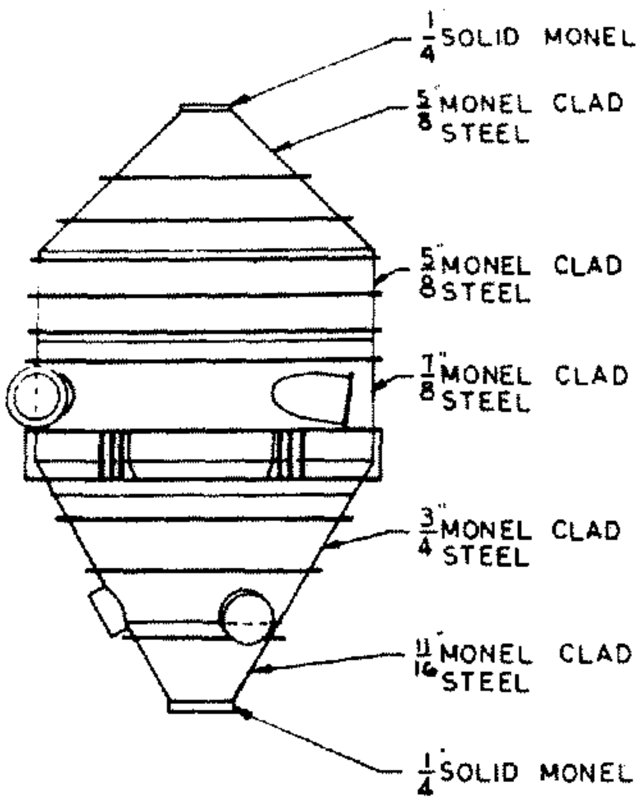


Figure 7. Vapor head–thickness variation.

chambers, fewer holes to drill and fewer tubes to roll in.

In the design of these single pass vertical heaters, the general tendency has been towards longer tubes as the size of the evaporator increases as illustrated graphically by Figure 8. These longer tubes can be larger in diameter while still retaining the same ratio of heating surface to cross-sectional area, which is desirable because of the reduced tendency for larger tubes to plug with salt and because of the lower cost involved with fewer and longer tubes.

The maximum size single heating element which can be fabricated and installed is limited because of weights involved, particularly if the heating elements are to be installed with the tubes already rolled in. By installing the tubes after the heating element is erected, the limiting size becomes much larger. Because of these size and weight limitations, the use of multiple heater and circulating pump circuits per body has worked out advantageously. The use of multiple heaters also provides flexibility since the initial installation need not be for full capacity, the final heater-pump circuits being added as more capacity is needed.

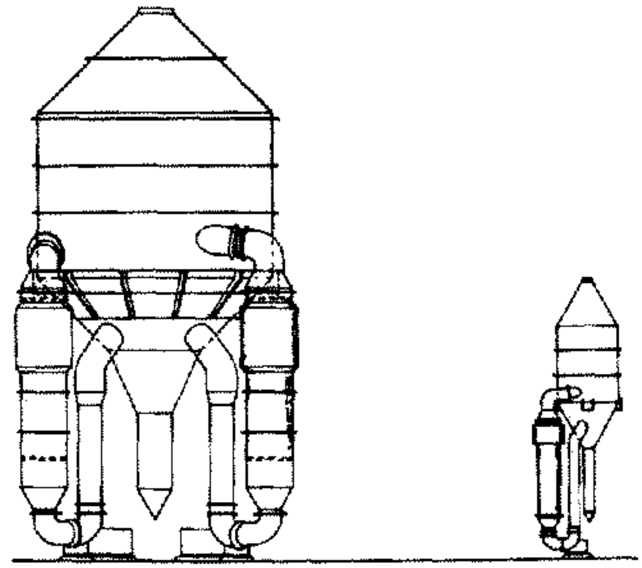


Figure 8. Tube length variation.

Circulating Piping.

As in the case of vapor heads, circulating piping reaches diameters where the questions of thickness versus the use of spacing of reinforcing bars should be considered carefully.

Circulating Pumps.

As of ten years ago, the capacity of individual circulating pumps of the heavy duty chemical type was limited and in order to obtain the total circulation required, this limitation dictated the number of heater and pump circulating loops necessary per pan. In the last few years, however, the pump sizes available in cast construction have increased in capacity appreciably, and by employing fabricated construction there is almost no limitation in the practical sense.

Vapor Piping.

With vapor piping of very large sizes (over 7' in diameter) it becomes particularly important to analyze for stresses due to thermal expansion and contraction. Computer programs are available to make this analysis more exact and easier to accomplish.

A further problem in connection with large vapor piping is the necessity to plan for supporting it under test conditions when the entire equipment may be filled to the top with water. Under these conditions, the weight of water in the vapor piping can become very appreciable.

Condenser.

The condenser serving a large salt evaporator may be designed for water flows of from 20,000 to 40,000 GPM and it will be apparent that this is a large piece of equipment with diameters of the order of 14 to 20 ft. or larger. Where possible, it is desirable to mount the condenser directly on top of the last effect body, as illustrated in Figure 9, thus eliminating a support problem as well as the mechanical difficulties and temperature drop loss involved in large vapor piping. With a top mounted condenser, the vapor passes directly from the last effect body into the condenser which may well save 3° or more of available temperature drop.

Instrumentation.

With increasing evaporator size complete instrumentation becomes a necessity, both for good control and because it is not physically practical for an operator to manually supervise the equipment. Minimum instrumentation would consist of:

- Steam flow control (or measurement)
- Level control and high and low alarms
- Pressure and vacuum indication
- Magma density indication—or sample lines brought to a central location
- Control of slurry removal rate

Desirable additional instrumentation would include:

- Multipoint temperature recorder to detect changes in operation
- Ammeters on circulating pumps
- Feed flow recorder

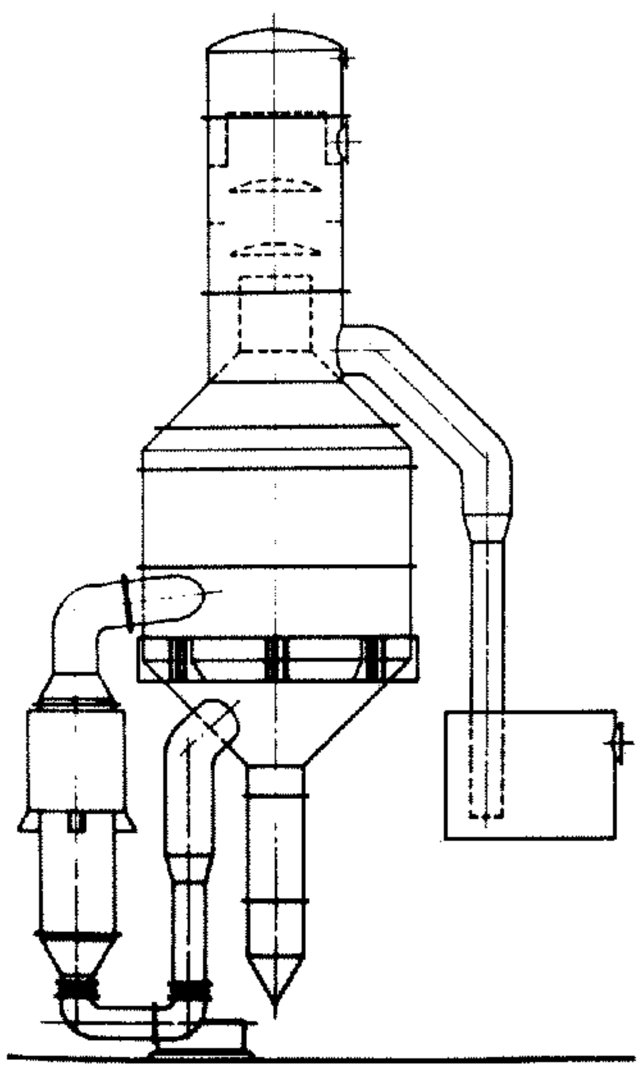


Figure 9. Top mounted condenser.

Supporting Steel Work:

Design of the supporting steel work becomes increasingly important as evaporator size and specific loading increases. In any evaporator in which boiling begins below the liquid surface there can be powerful horizontal reactions from the turbulence created by boiling. It is important to have knowledge of the magnitude of these reactions in order to design the steel work for tolerable deflections. As a matter of interest, careful measurements were made of the deflection in operation of the steel work supporting a very large salting evaporator. This steel work had been designed for a horizontal deflection of 1/16″ under operating load and measurements with dial indicators showed actual deflections of 0.05″ to 0.065″ at somewhat beyond the design rate.

In general, evaporator supporting steelwork can consist of either a boxlike structure common to all vessels, or separate rings of columns supporting the bodies individually. This latter method is generally used for large evaporators. It is less desirable for smaller units because the space under the evaporator becomes more crowded.

Building.

With increasing evaporator size the design of the building to house the installation becomes an important consideration costwise. Except in extremely cold climates, complete or partial outdoor installation is indicated.

Minimum building requirements would be to house the control room only. The next degree of housing for progressively colder climates would include bringing the pumps and small piping under cover to make maintenance more convenient. Generally the salt separation and drying equipment would also be sheltered in this case. Finally in very cold locations it would become desirable to house the entire installation. Figure 10 illustrates these various degrees of housing.

Since the capacity in a single train can be increased almost without limit by increasing the number of heater and pump circulating loops, it will be apparent that the maximum body size becomes the overall limiting factor. At the present writing, it appears that the maximum body size is of the order of 50 ft. in diameter taking into consideration the capacity of readily available metal forming equipment.

To illustrate the capacity available from an evaporator having the maximum size body–50 ft. in diameter–let us consider what the capacity, appearance, and general characteristics of such an evaporator might be. Figure 11 illustrates a quadruple effect having four heater and circulating pump loops per body and with the heaters limited to 28,000 square feet each to keep them in the size range not too difficult to transport and erect.

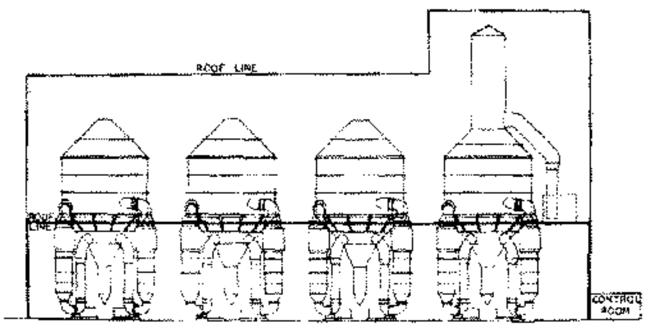


Figure 10. Enclosure variations.

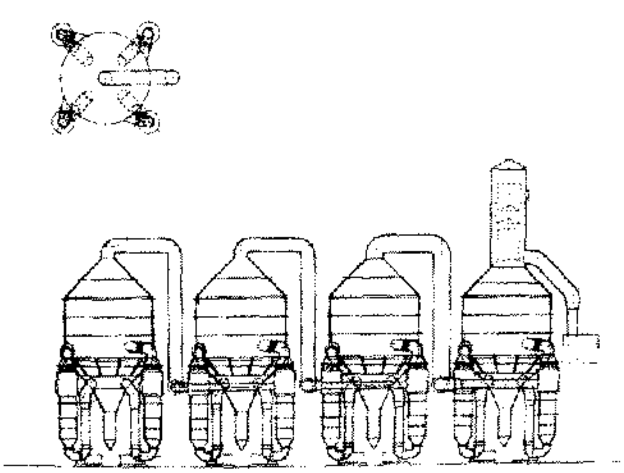


Figure 11. Evaporator with maximum size bodies.

When supplied with steam at 10 pounds gauge and cooling water at 75°F, this evaporator would have a potential capacity of approximately 2,200,000 PPH evaporation corresponding to approximately 9,000 tons of salt per day from saturated brine. By using entrainment separators and increasing the heating surface, this evaporator could be pushed to even higher capacity.

With the same size limitations, a quintuple effect evaporator operating on 35 pound steam would have a capacity of over 2,900,000 PPH evaporation corresponding to 12,000 tons per day of granulated salt.

Up to this point, our discussion has been concerned with straight multiple effect evaporators, operating on low pressure or exhaust steam at 10 to 35 pounds gauge pressure. In the United States where fuel costs are relatively low, this has been accepted as the most economical arrangement.

However, where fuel costs are high, as in Europe, it becomes desirable to consider other possible arrangements. Figure 12 is a flow diagram of an evaporator system combining mechanical recompression with multiple effect. In this arrangement 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 a single effect evaporator so that it can be re-used in the heating elements of the single effect.

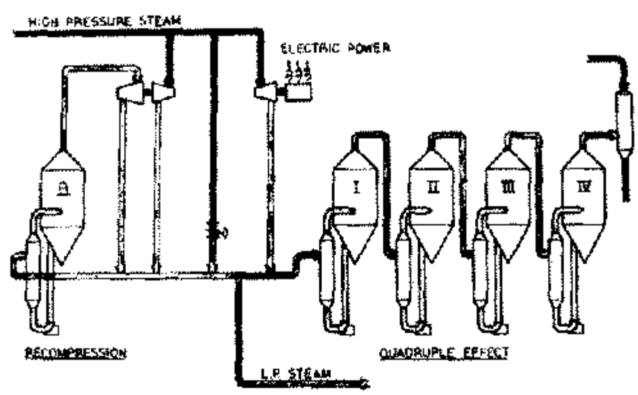


Figure 12. Combined recompression and multiple effect evaporator.

The exhaust steam from both turbines is used to drive a multiple effect evaporator. Upon studying this arrangement, it will be clear that the balance of evaporation between the recompression and multiple effect portions of the evaporator system depends upon a number of factors, the principle of these being as follows:

1. Initial steam pressure
2. Turbine efficiency
3. Generator efficiency
4. Compressor efficiency
5. Heating surface in the recompression heaters
6. Whether or not steam is withdrawn for other heating purposes
7. Amount of power to be generated
8. Turbine exhaust pressure selected

With such a complex relationship, it has proven highly advantageous to have a computer problem to determine the equilibrium operating conditions.

As a matter of interest, in one of the cases which has been worked out, with an initial steam pressure of approximately 880 psi and with no steam withdrawn for heating purposes, the balance worked out to be approximately 38% of the total evaporation done in the recompression evaporator and 62% in the multiple effect evaporator.

In this particular case, the steam economy of evaporator system worked out as 4.54 pounds evaporation per pound of steam, or 1,325 per ton of salt. To get a true comparison between this arrangement and a quadruple effect evaporator however, it is necessary to consider in each case the pounds of steam as generated and the heat in the to consider in each case the pounds of steam generated and the difference between the total heat content of the steam as generated and the heat in the condensate as returned to the boiler. The product of these numbers is the heat which has to be added in the boiler installation and is a measure of the economy of the system.

On this basis the comparison is as follows:

1. Recompression plus quadruple effect arrangement
   — 1,626,000 BTU/ton of salt
2. Straight quadruple effect evaporator
   — 2,230,000 BTU/ton of salt.

It should be mentioned that these heat requirements applied to an evaporator operating on purified brine and therefore, equipped with preheaters for increased economy.