Energy Conservation Salt Evaporators

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ABSTRACT

Methods to conserve energy for salt evaporators are discussed. Utility requirements and utility costs for several, alternate evaporator designs are compared. Included are multiple-effect evaporators with and without turbine generator sets, multiple-effect evaporators with thermocompressors (thermal vapor recompression) and mechanical vapor recompression evaporators. For most designs, both purified (calcium and magnesium free) and impure brine feeds are analyzed; less energy is needed for purified brine because the evaporator can be supplied with more vapor and condensate-heated brine preheaters. The multiple-effect evaporators include quadruple, quintuple and sextuple effects. In addition, steam and electric power comparisons are made for two-stage steam ejectors, liquid ring vacuum pumps and combination units (first-stage steam ejectors and second-stage vacuum pumps).

INTRODUCTION

The purpose of this paper is to discuss methods to conserve energy for salt evaporators and compare the utility requirements and utility costs for alternate, energy-efficient designs.

There are many ways to reduce energy consumption for a salt evaporator. Some are relatively easy to implement and will provide excellent returns on nominal investments. Others require large capital expenditures. The equipment cost comparisons for alternate, energy-efficient designs are outside the scope of this paper. In fact, such comparisons are more applicable to new, "grass-roots" plants. More realistically, new equipment is used in conjunction with, and must complement, existing evaporators. The cost for a retrofit design is influenced by a number of variables, which include the sizes of existing equipment, boiler capacity, availability of cooling water, space limitations, etc. In other words, cost comparisons should be made for a specific plant.

All of the costs given in this paper are in United States currency. Tons stated are short tons.

Methods to conserve energy for salt evaporators are listed in Table 1.

TABLE 1

Methods to Conserve Energy Salt Evaporators

Reduce water additions to decrease evaporation
- Meter water streams
- Measure slurry flow rates to reduce line washing
- Use continuous brine flush for heavy slurry lines
- Redesign slurry lines that frequently plug
- Maintain pump packing
- Replace packed stuffing boxes with double mechanical seals

Utilize energy from evaporator condensate
- Use condensate-heated brine preheaters
- Use condensate flash systems where preheaters are impractical due to scale

Use vapor-heated brine preheaters

Miscellaneous
- Use high efficiency electric motors
- Use two smaller pumps in parallel in place of one large pump
- Reduce radiation losses.

Vacuum equipment
- Replace steam ejector with combination first-stage steam ejector and second-stage vacuum pump
- Replace steam ejector with liquid ring vacuum pump
- Use two smaller vacuum systems in place of one large unit

Multiple-effect evaporators
- Increase number of effects
- Use a turbine generator set
- Add a thermocompressor

Use mechanical vapor recompression

WATER ADDITIONS

Unnecessary water additions increase steam cost and reduce evaporator capacity. Some operators wash lines and equipment too often. Water additions should be metered so that the quantity of water added per shift can be logged. This will motivate operators and supervisors to be "water conscious."

It is useful to measure heavy slurry flow rates; this can be done economically, without obstruction to flow, with an ultrasonic flow meter. Flow rates should be indicated both locally and in the control room. For caustic soda evaporators, which also crystallize sodium chloride, ultrasonic flow meters have dramatically reduced the frequency and duration of line washing. Unnecessary, precautionary washes were eliminated because an operator knows, by a decrease in flow rate, exactly when to wash a line. In addition, guided by the local flow indicator, the operator can add minimal water to the line to re-establish full flow.

If a line plugs frequently, it may be necessary to do one, or several, of the following to reduce water washing:

1. Add brine continuously to a pipe to reduce slurry density and increase slurry velocity
2. Reduce pipe size to increase slurry velocity
3. Add a recirculation line so that the slurry flow is not periodically inhibited or stopped
4. Reroute pipe to reduce the number of elbows and other restrictive fittings.

To prevent excessive seal water leakage through the packing into the process, packed stuffing boxes for circulating and transfer pumps should be adequately maintained; the seal water pressure inside the lantern ring should not be more than 5 to 10 psi above the internal pump pressure; and a rotameter should be used to monitor the seal water flow rate.

To essentially eliminate seal water additions, packing can be replaced with double mechanical seals.

EVAPORATOR CONDENSATE

Unless there is another worthwhile use for hot, contaminated evaporator condensate (such as boiler makeup), the condensate should be cooled in preheaters or alternately by flash evaporation when brine preheating is impractical because of rapid scaling.

Condensate-heated brine preheaters can usually be justified based upon a short pay-back period in steam savings. Impure brine feed can be preheated to at least 130°F with condensate or vapor, preferably at a maximum inlet temperature of 140°F to minimize gypsum scale. Higher temperatures for impure brine preheat are possible; however, it may be necessary to have spare heat exchangers so that one unit can be in operation while the spare is being cleaned. For a purified brine feed (calcium and magnesium free), there are no temperature limitations for brine preheat; however, periodic acid washing of the high temperature preheaters may be necessary to remove calcium carbonate scale.

Condensate cooled in a preheater saves more energy than condensate flashed. To illustrate this, two different flowsheets will be described. Figure 1 shows a triple-effect, parallel-feed evaporator with a condensate flash tank vented to the vapor inlet of the third-effect heat exchanger. Condensate from the second-effect heat exchanger is flash cooled in this tank, and the vapor generated is condensed in the third-effect heat exchanger. This extra energy transferred into the brine increases evaporation in the third-effect body. Because this supplemental energy is used exclusively in the third effect, the net result is single-effect steam economy.

The same evaporator with a feed preheater is shown in Figure 2. Second-effect heat exchanger condensate is cooled in the preheater to heat the feed to the first and second effects. This reduces the sensible heat requirements for the first and second-effect heat exchangers. Heat added to the second-effect feed causes additional evaporation to occur in the second-effect body. The extra vapor is condensed in the third-effect heat exchanger to generate more vapor in the third-effect body. More succinctly, heat added to the second-effect feed produces double-effect steam economy. With similar logic, heat added to the first-effect feed provides triple-effect steam economy.

When the total evaporation rate is kept constant, less steam is required to the evaporator with a preheater than that required to the evaporator with the condensate flash system.

VAPOR-HEATED PREHEATERS

Vapor-heated brine preheaters can be used in conjunction with condensate-heated brine preheaters to provide additional steam savings. This is true if the vapor from an evaporator effect is used to heat feed to the same effect or to preceding effects. Probably the best application for this preheater is to condense vapor from the last effect to heat fresh brine. For example, 10.6% of the fourth-effect vapor from an impure brine-fed, quadruple-effect evaporator will be condensed to heat fresh brine from 70 to 95°F. Obviously, the condenser water rate will be reduced by the same 10.6% for an additional benefit.

MISCELLANEOUS ENERGY SAVINGS

For each new or replacement application, energy-efficient electric motors should be evaluated. The power savings for these motors versus standard designs could be as high as 10% for small motors or as low as 2% to 3% for large motors. For evaluation, two 100 hp motors will be compared, one 95% efficient and the other 91.6% efficient. The difference in power cost per 8,000-hr year at 5 cents per kwhr is $1,165. The small saving per motor adds up to a more significant amount when all of the motors in a plant are included.

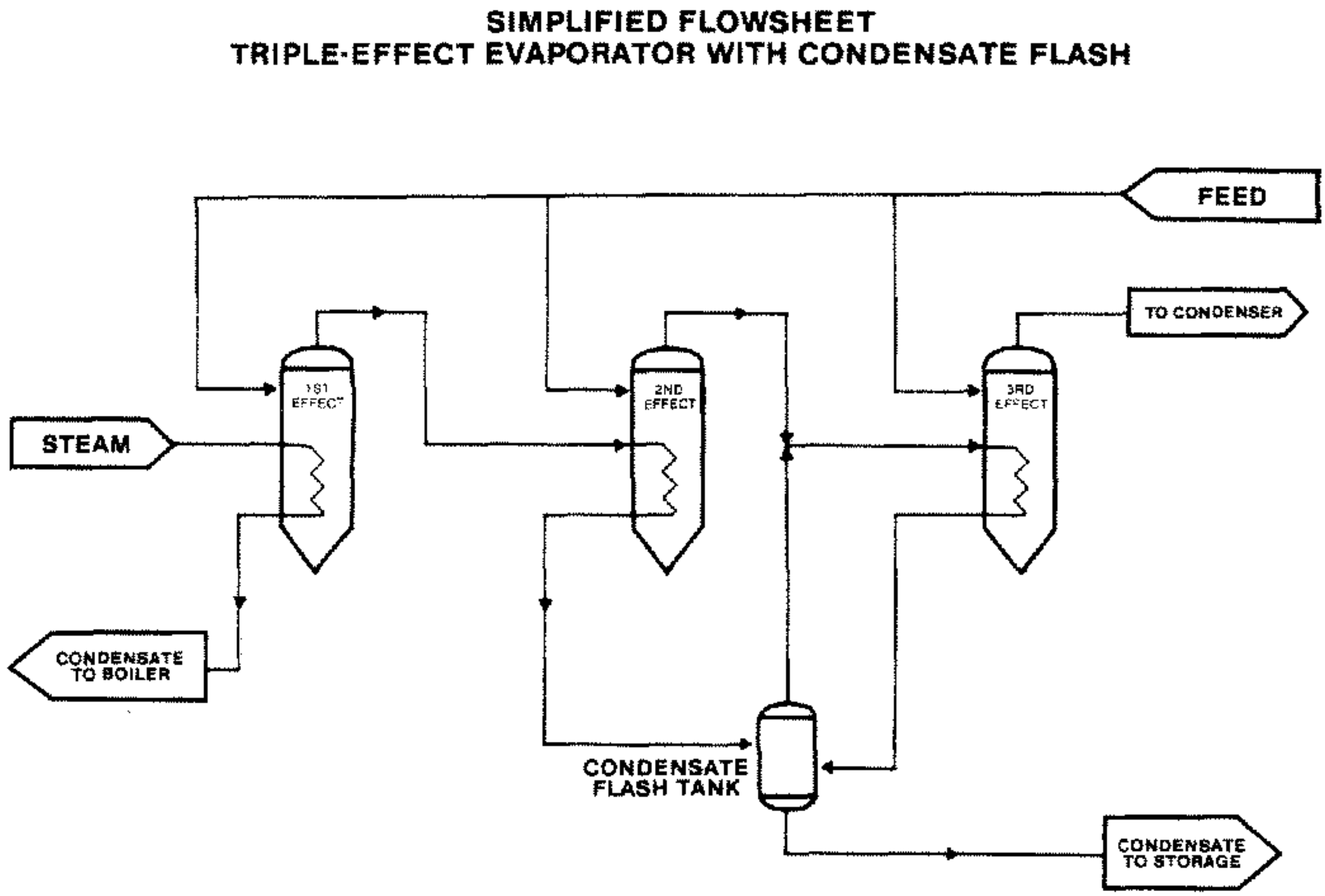

Figure 1.

More substantial power saving can be realized when it is possible to remove a pump from service. A water supply pump for a barometric condenser will be evaluated for this simplified example. In the summer, 8,000 gpm at 60-ft TDH is required; when the water is colder, 4,000 gpm will suffice. If two 4,000 gpm pumps are installed, only one pump will be operated during winter months or when the evaporator is operated at reduced capacities. If this period is 3,000 hours per year and the power cost is 5 cents per kwhr, the annual saving will be approximately $9,500.

If an evaporator is poorly insulated, the radiation losses could be significant, especially for an outdoor installation. The pay-out period in steam saving for additional insulation should be computed.

VACUUM EQUIPMENT

Until recently, most evaporators in the United States were equipped with two-stage, steam-jet air ejectors. It was difficult to justify other alternates when the cost of steam was only 50 cents to one dollar per 1,000 pounds. Today, other choices are more desirable.

A two-stage steam ejector can be replaced with a liquid ring vacuum pump or a combination unit which includes a first-stage steam ejector with a second-stage vacuum pump. Other selections are possible but will not be covered in this paper.

Steam and electric power comparisons for two-stage steam ejectors, liquid ring vacuum pumps and combination units are given in Table 2 for air handling capacities of 100, 150 and 200 lb/hr and cooling water temperatures of 65°, 75° and 85°F.

An annual (8,000 hours) utility cost comparison for the three different vacuum systems ejecting 150 lb/hr air plus moisture of saturation is given in Figure 3. The steam and power costs are based upon $5 per 1,000 lb and 5 cents per kwhr, respectively. The utility costs *do not* include an allowance for cooling water.

For the steam and power costs selected, the best choice is the combination steam ejector and vacuum pump. Compared to the two-stage steam ejector, the annual utility saving for the combination unit is $14,840 and for the vacuum pump is $8,560; the basis is 85°F cooling water.

Colder water reduces energy consumption for vacuum systems dramatically as shown in Figure 3. For the com-

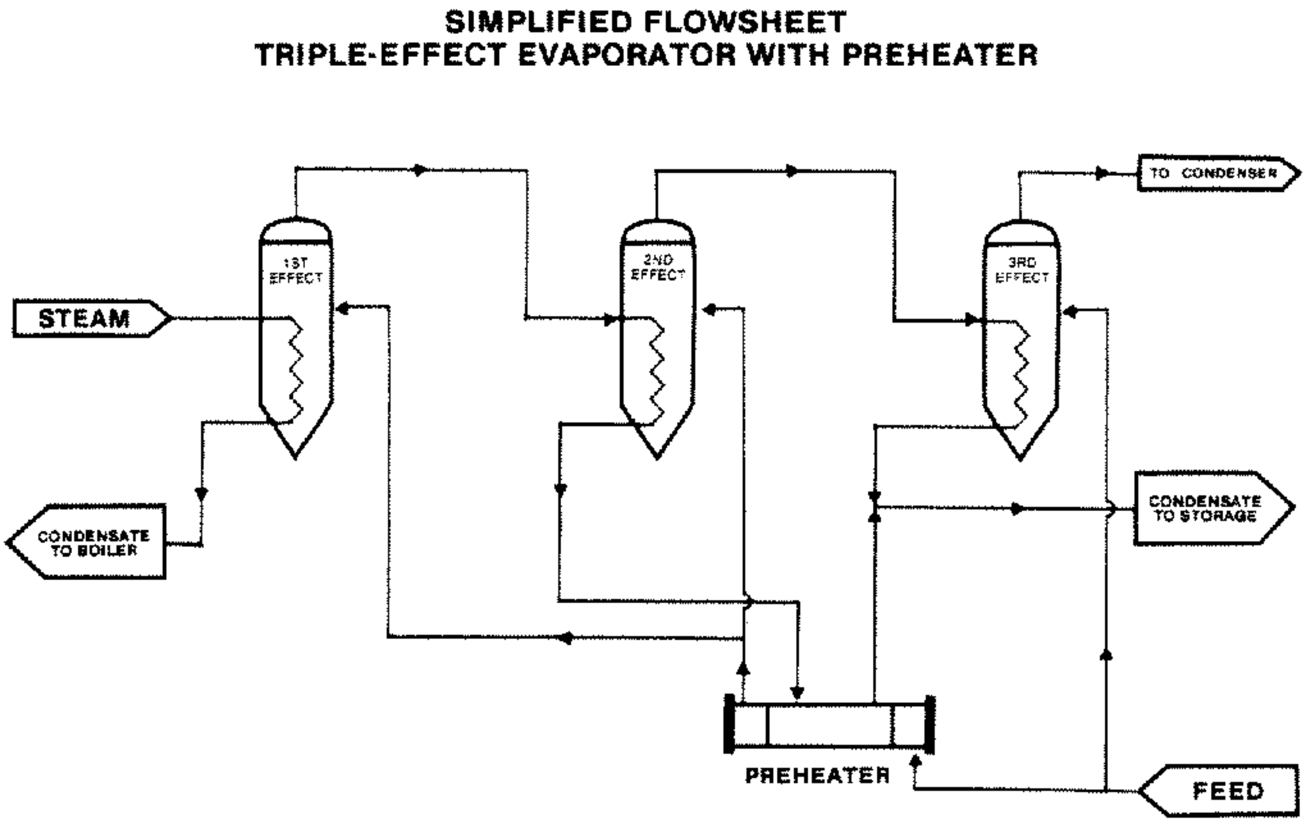

Figure 2.

bination unit the annual cost of utilities with 85°F water is $25,200 and with 65°F water is $13,960. This is an important point that should not be ignored in design. In particular, two smaller vacuum systems should be considered in place of one large unit to take advantage of colder, winter water.

On a recent caustic soda evaporator installation, the two-stage steam ejector was supplied with two first stages, two second stages and a common intercondenser. When the cooling water temperature is 70°F or less, only one first and one second-stage ejector is used and the steam required is 890 lb/hr. With all ejectors in service, the steam rate is 1,670 lb/hr. Based upon the reduced steam rate for 3,000 hours per year and steam valued at $5 per 1,000 lb, the annual steam saving for this selection versus one larger, two-stage steam ejector is $11,700.

One final point—if a limited source of inexpensive, colder water is available, it may be economical to add a small barometric condenser to cool the air in order to reduce the quantity of water vapor that is sent to the vacuum equipment. The colder water would be used only in this precooler and in the intercondenser and/or vacuum pump to save energy.

MULTIPLE-EFFECT EVAPORATORS

Most salt evaporators are of the multiple-effect design. As discussed previously, the energy required for an existing evaporator can be reduced with less water additions, with condensate and vapor-heated brine preheaters, with high efficiency electric motors and with a more prudent selection of vacuum equipment. Energy for an existing evaporator can also be conserved with additional evaporator effects, with a thermocompressor, with a turbine generator set and by conversion to mechanical vapor recompression; in order to compare these alternates, calculations were made on the same bases for quadruple, quintuple and sextuple-effect evaporators and for mechanical vapor recompression evaporators. Both purified (calcium and magnesium free) and impure brine feeds were analyzed because of the difference in energy recovery from brine preheat. A turbine generator set was then added to each multiple-effect evaporator and a thermocompressor was added to each impure brine-fed, multiple-effect evaporator. All of these will be compared.

First, the discussion will be about multiple-effect evaporators. Three alternate designs are shown in Figure 4.

TABLE 2

Steam and Electric Power Comparisons for Two-Stage Steam Ejector, Combination First-Stage Steam Ejector with Second-Stage Vacuum Pump, and a Liquid Ring Vacuum Pump

Absolute pressure: 1.99 in. Hg
Steam : 140 psig, 362°F
Cooling water : 65°, 75° and 85°F
Air : 100, 150 and 200 lb/hr

Cooling water temp. →	65°F		75°F		85°F	
Saturated air temp. →	70°F		80°F		90°F	
	Steam lb/hr	Power kwhr	Steam lb/hr	Power kwhr	Steam lb/hr	Power kwhr
100 lb/hr Air + Water Vapor						
Two-Stage Ejector	446	—	527	—	667	—
Combination Unit	161	5.3	206	5.3	346	7.1
Vacuum Pump	—	24.9	—	37.3	—	58.0
150 lb/hr Air + Water Vapor						
Two-Stage Ejector	669	—	791	—	1001	—
Combination Unit	241	10.8	312	10.8	522	10.8
Vacuum Pump	—	49.7	—	62.1	—	78.7
200 lb/hr Air + Water Vapor						
Two-Stage Ejector	892	—	1054	—	1334	—
Combination Unit	326	13.3	337	13.3	617	15.7
Vacuum Pump	—	62.1	—	66.3	—	116

Utility requirements courtesy of Graham Manufacturing Co., Inc.

All of the steam rates that will be given are for 150 psig, dry and saturated steam, with condensate returned to the boiler at 210°F. In essence, the condensate was cooled by flash or in a brine preheater so that the condensate would not evaporate to the atmosphere in a storage tank; however, *there is absolutely no value* in cooling this condensate if a pressurized, boiler feed water system is available.

The pressure inside the first-effect heat exchanger will be less than 37 psig; therefore, the 150 psig steam supply pressure must be reduced. This can be done with a pressure regulating valve followed by a steam flow control valve. Since this is an adiabatic expansion, the enthalpy of the low pressure steam will be exactly the same as that of the 150 psig steam.

As an alternate to this, the steam pressure can be reduced through a steam flow control valve to 145 psig and then through a thermocompressor, which is similar to a steam-jet air ejector used to maintain vacuum in an evaporator. Water vapor from the first-effect body is entrained and compressed with the high pressure steam so that the mixture discharged from the thermocompressor is at sufficient pressure to condense inside the first-effect heat exchanger. This is called thermal vapor recompression. Only a portion of the vapor generated in the first effect can be compressed in the thermocompressor; the remainder is condensed in the second-effect heat exchanger. The purpose of thermal vapor recompression is to reduce the motive steam required through the use of supplemental energy from evaporator vapor.

The third choice is to reduce the 150 psig steam pressure through a steam flow control valve to 145 psig and then through a turbine connected to a generator to produce electric power. Wet steam will be discharged from the turbine. More steam is needed for this system than is required for the other options, to replenish the energy transmitted to the generator.

In place of a generator, the turbine could be coupled to a centrifugal compressor for a mechanical vapor recompression evaporator; this worthwhile alternate will not be evaluated in this paper.

Some salt companies use turbines to drive evaporator circulating pumps, other large pumps and the exhauster for a top feed filter. This reduces flexibility because no steam is available to operate these turbines when the evaporator is shut down, or insufficient steam is available to operate all of the turbines when the evaporator is operated at reduced capacities. Furthermore, a single large turbine operated at 3,600 rpm to drive a generator is measurably more efficient than multiple, smaller turbines, especially if the smaller turbines are operated at 1,750 rpm or less.

MECHANICAL VAPOR RECOMPRESSION

Each mechanical vapor recompression evaporator (purified and impure brine feeds) was designed to use a single-stage centrifugal compressor driven by an electric motor. Vapor from the evaporator body was compressed

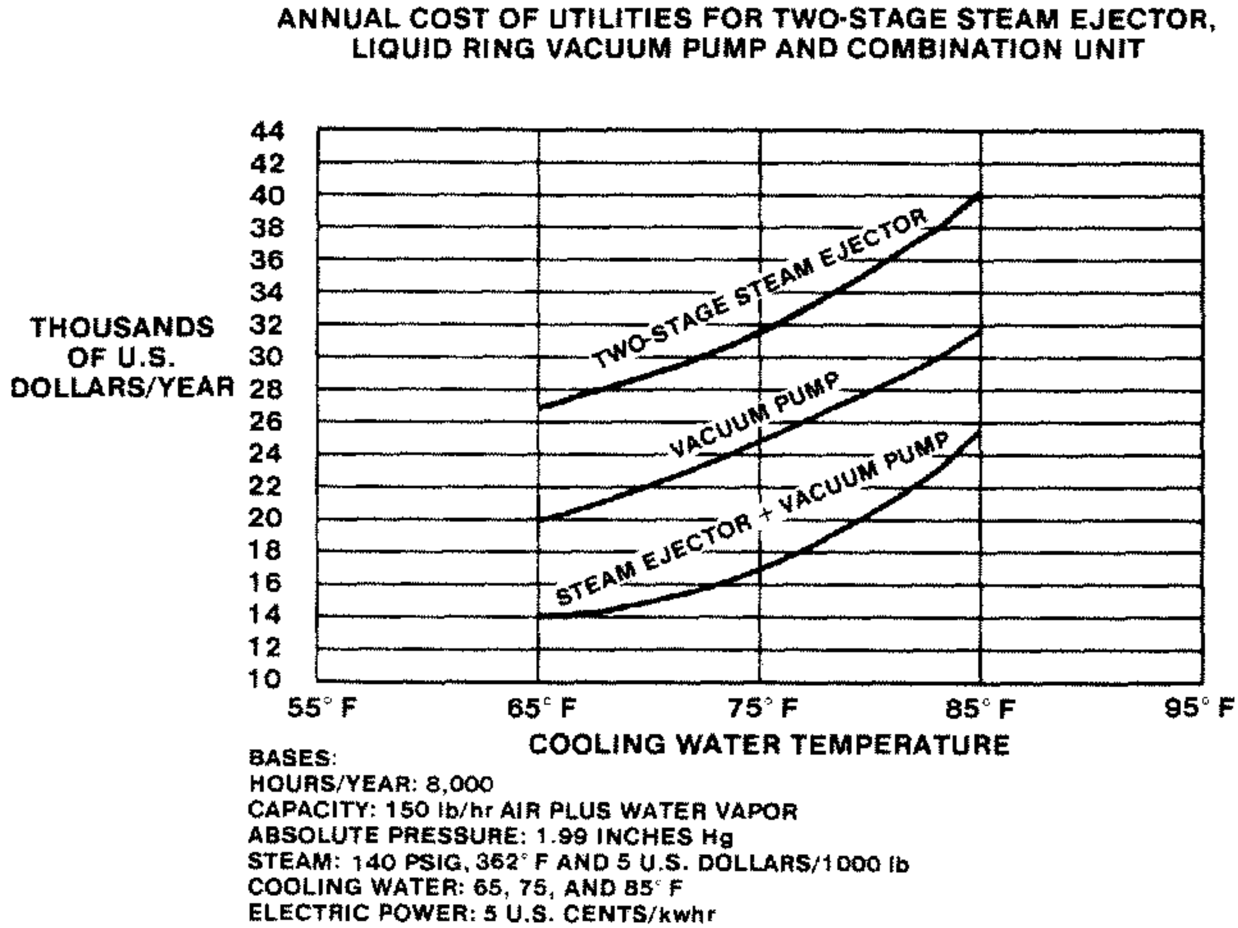

Figure 3.

to a sufficient pressure so that it could be condensed in the evaporator heat exchanger. Ample allowances were included for pressure drops in the piping to and from the compressor. For purified brine feed, it was possible to supply sufficient feed preheat to preclude the need for make-up steam; only steam for startup will be required. For impure brine, the feed was preheated to 130°F. The merits of vapor recompression will become evident in the comparison that will be made.

DESIGN BASES

The design bases for the calculations, which include multiple effect and mechanical vapor recompression, are given in Table 3. For purified brine-fed evaporators, none of the evaporator condensate was flash cooled; all of the condensate streams were cooled in brine preheaters. The contrary is true for impure brine-fed, multiple-effect evaporators; all of the evaporator condensate was flash cooled. Preheating of impure brine was restricted to 130°F maximum and was done in three preheaters for the multiple-effect evaporators; two preheaters condensed vapors from the last and penultimate effects and the third preheater cooled the total, contaminated evaporator condensate to 105°F. The same three preheaters and additional condensate-heated and vapor-heated preheaters were used for purified brine-fed, multiple-effect evaporators. Parallel feed was used for all multiple-effect evaporators.

For all cases, which include mechanical vapor recompression, a deaerator was included in the calculations to flash cool the total feed (fresh brine and filtrate or centrate) to remove air. This increased the energy requirement by a nominal amount. The advantage of feed deaeration is reduced evaporator corrosion.

The evaporation rates for purified and impure brine-fed evaporators are slightly different because more impurities are present in the impure brine and the purge compositions are not alike.

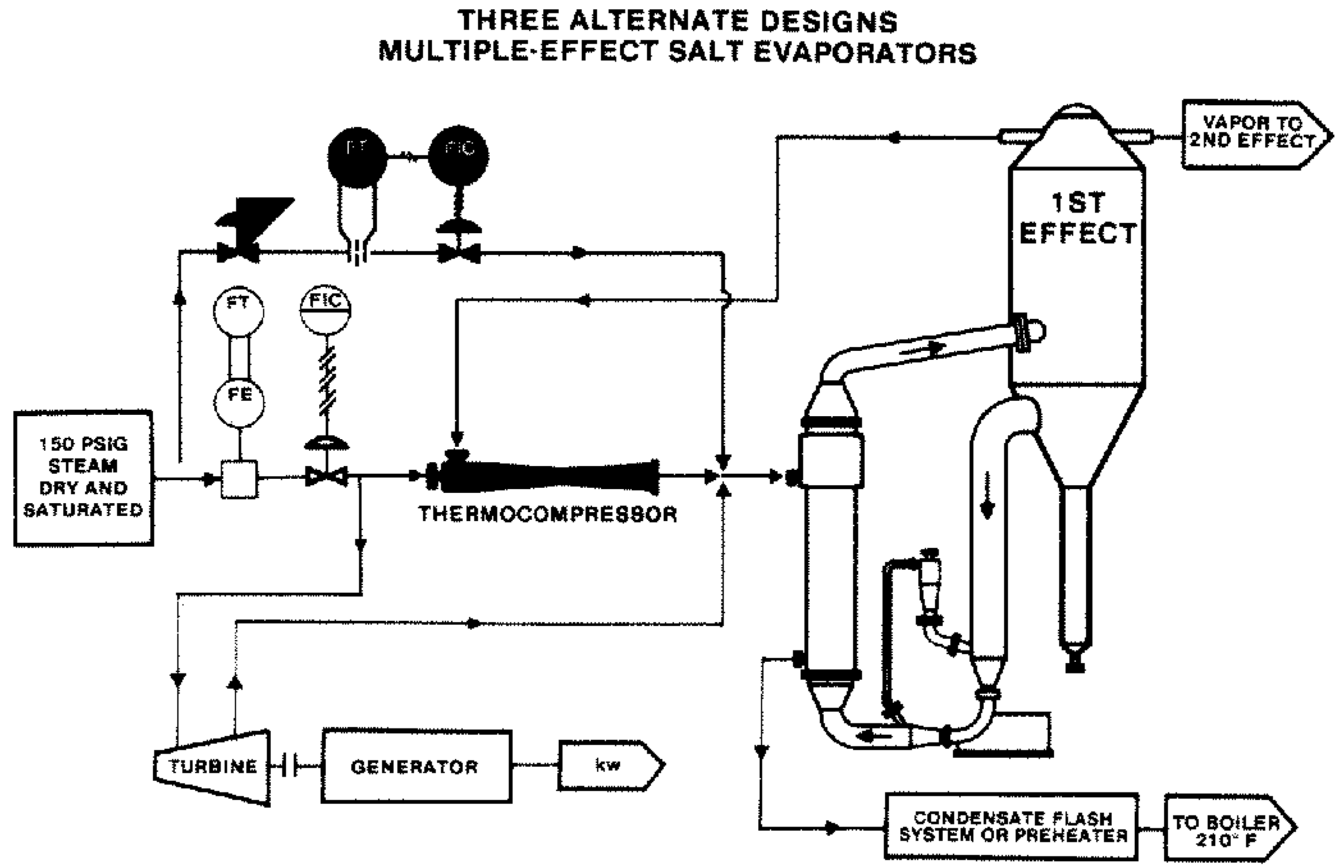

Figure 4.

COMPARISONS FOR ALTERNATE SALT EVAPORATOR CONFIGURATIONS

The steam and electric power comparisons for multiple-effect and mechanical vapor recompression salt evaporators are given in Table 4. Included are the steam and electric power requirements to produce the evaporation rates given in Table 3 and the electric power provided by the turbine-driven generators. *Not included* are steam and electric power for vacuum equipment and electric power to drive evaporator circulating pumps, agitators and centrifugal pumps. Table 4 summarizes the results of the calculations for all of the evaporator models analyzed for this paper, and it is the basis for Figures 5 through 10.

Barometric condenser water rates for all of the evaporators are given in Table 5 for both 15° and 20°F temperature rises. Not included in this table is water needed for vacuum equipment. The cooling water required decreases as the number of effects increase, because less evaporation occurs in each body. For a multiple-effect evaporator, the evaporation rate increases in the front end and decreases in the back end with the addition of preheaters (purified brine feed) or a thermocompressor; therefore, less condenser water is required for purified brine-fed and thermal vapor recompression evaporators. Only nominal water is needed for a mechanical vapor recompression evaporator.

The steam costs for multiple-effect evaporators are shown in Figure 5. For each case, 150 psig steam was expanded through a pressure control valve. As discussed previously, and emphasized in this figure, less steam is needed when the brine is treated; however, if the only criteria to treat brine were to conserve steam, then brine treatment *could not* be justified. If the steam cost were as high as $8 per 1,000 lb, the steam saving associated with more brine preheat, for both quintuple- and sextuple-effect evaporators, would be only $1.04 per ton of salt—not enough to pay for brine treatment.

Additional effects save steam, as dramatically illustrated in Figure 5, 16.2% less steam for quintuple in place of quadruple and 13.3% less steam for sextuple in place of quintuple. This is based upon impure brine feed; the percentages are higher for purified brine. Stated differently, for steam valued at $5 per 1,000 lb, the steam

TABLE 3

Design Bases for Calculations

Steam rates
150 psig, dry and saturated steam
Steam condensate returned to boiler at 210°F
Include ample allowance for radiation losses
Do not include steam for vacuum equipment

Evaporation rates
Include condensate for screen or cake wash
Include miscellaneous water additions
lb evaporation/short ton of salt
5974 for impure brine
6112 for purified brine mechanical recompression
6062 for purified brine (rest of alternates)

Feed
Temperature 70°F
Purified brine: 25.6% NaCl; 0.333% Na_2SO_4
Impure brine : 25.6% NaCl; 0.38% ($CaCl_2+MgCl_2$); 0.36% $CaSO_4$

Purge
7% of brine feed rate

Contaminated condensate
Cooled in preheaters or by flash to lower pressure
Combined condensate exit temperature 105°F (except 97°F for purified brine-fed, mechanical vapor recompression evaporator)

Preheating of impure brine
Limited to 130°F maximum

Vapor pressure
1.10 psia last effect of multiple-effect evaporators

Deaerator
Deaeration (by flash evaporation) of feed brine and filtrate (or centrate) is included for each alternate

Efficiencies
95 % for generator
95 % for compressor drive motor
95 % for compressor gear reducer
83.8% isentropic for compressor (impure brine)
84 % isentropic for compressor (purified brine)
90 % for liquid ring vacuum pump drive motor

Electric power requirements
Do not include kwhr for drive motors for agitators and for circulating, transfer and vacuum pumps

costs per ton of salt for impure brine-fed quadruple, quintuple and sextuple-effect evaporators are $8.95, $7.50 and $6.50, respectively.

Steam costs for multiple-effect evaporators with turbine generator sets are compared in Figure 6. All of the steam costs are higher than those given in Figure 5 because the steam was expanded through a turbine to provide useful work in the form of electric power. It is, therefore, necessary to deduct the value of the power generated (given in Figure 7) from the steam cost (given in Figure 6) to obtain the net cost per ton of salt. To illustrate this, an example will be given for quadruple-effect evaporators fed impure brine. If the price of steam were $5 per 1,000 lb and the value of electricity generated were 4 cents per kwhr, the net cost per ton of salt would be $9.55 for steam less $1.27 credit for power or $8.28, which is 67 cents less than the steam cost of $8.95 per ton of salt given in Figure 5.

The costs for make-up steam for a mechanical vapor recompression evaporator and steam for multiple-effect evaporators with thermocompressors are given in Figure 8 for impure brine feed. As expected, less steam is required for a multiple-effect evaporator with a thermocompressor than for either a plain evaporator (Figure 5) or an evaporator provided with a turbine generator set (Figure 6). This could be an important advantage for thermal vapor recompression in plants with limited boiler capacity. The three alternate designs shown in Figure 4 are compared in Table 6 for various steam costs and values for power generated.

The word "plain" designates that the steam to the evaporator is expanded through a pressure control valve. This alternate is not energy efficient; it results in a loss of available energy to do useful work. As the comparisons illustrate, it is more beneficial to expand steam through a turbine or through a thermocompressor.

The costs of electricity to operate the compressor drive motors for recompression evaporators are presented in Figure 9 for both purified and impure brine feeds. Make-up steam is required for the impure brine-fed evaporator; the costs for which are given in Figure 8.

The annual costs of utilities for multiple-effect evaporators and mechanical vapor recompression evaporators for a yearly salt production of 200,000 tons are shown in Figure 10.

For purified brine, the annual utility cost for each of the following multiple-effect evaporators is compared with that for a mechanical vapor recompression evaporator:

$52,000 less for sextuple effect with turbine generator

$20,000 more for plain sextuple effect

$134,000 more for quintuple effect with turbine generator

The same comparison of annual utility costs is now made for the following impure brine fed, multiple-effect evaporators versus a mechanical vapor recompression evaporator:

$164,000 less for sextuple effect with turbine generator

$147,000 less for sextuple effect with thermocompressor

$77,000 less for plain sextuple effect

$3,000 more for quintuple effect with thermocompressor

TABLE 4

Steam and Electric Power Comparisons for Several Different Salt Evaporator Configurations and for Purified and Impure Brine Feeds

	Steam lb/short ton salt		Electric power kwhr/short ton salt	
Feed brine →	**Impure**	**Purified**	**Impure**	**Purified**
Multiple effect				
Quadruple	1790	1680	—	—
Quintuple	1500	1370	—	—
Sextuple	1300	1170	—	—
Multiple effect with turbine generator				
Quadruple	1910	1780	+31.7	+29.0
Quintuple	1580	1440	+21.1	+19.5
Sextuple	1360	1230	+18.4	+16.5
Multiple effect with Thermal recompression				
Quadruple	1570	—	—	—
Quintuple	1380	—	—	—
Sextuple	1230	—	—	—
Mechanical recompression	367	0	−101	−115

Note: + = power generated
− = power input required

MULTIPLE-EFFECT EVAPORATORS
COMPARISONS OF STEAM COSTS FOR IMPURE AND PURIFIED BRINE FEEDS

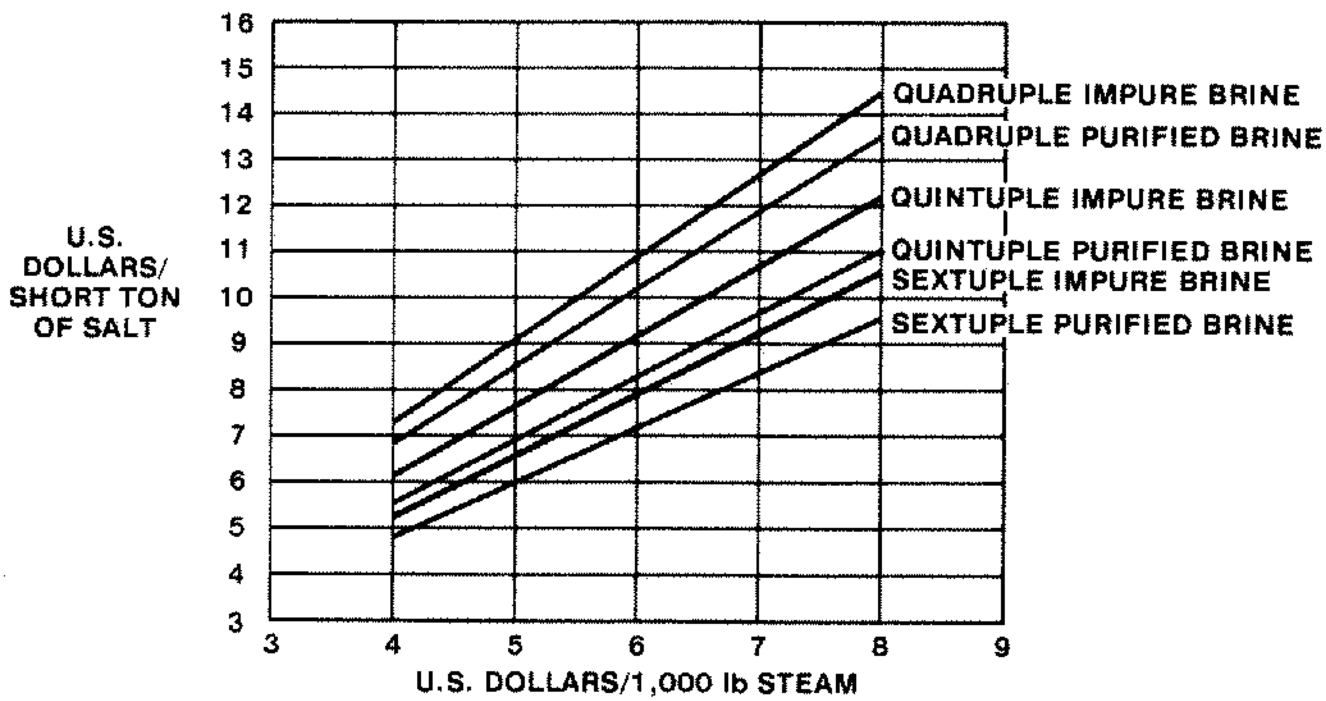

Figure 5.

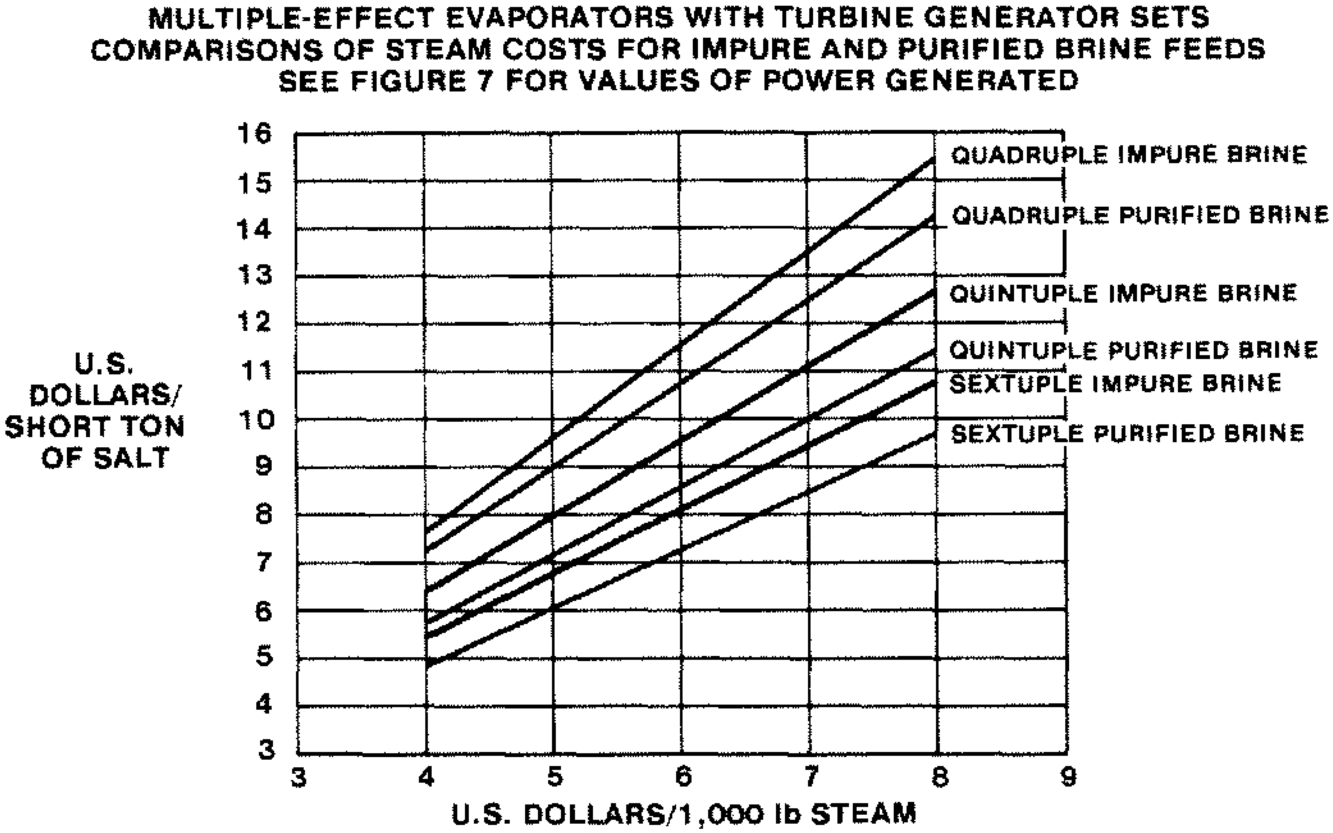

Figure 6.

$34,000 more for quintuple effect with turbine generator

$123,000 more for plain quintuple effect

The utility values given in Figure 10 do not include the cost of condenser water; this is emphasized because minimal water is needed for mechanical vapor recompression evaporators.

The comparisons could, of course, be significantly altered for utility costs that are different from those selected for Figure 10. It is obvious that the comparisons will be more favorable for multiple-effect evaporators when the steam costs are lower and the power costs are higher than those used in Figure 10; conversely, the comparisons will be more favorable for a mechanical vapor recompression evaporator when the steam costs are higher and the power costs are lower than those used in this figure.

DISCUSSION

For an existing evaporator that condenses steam at a low pressure, it is easy to add a new, first effect (topping pan) to supply vapor to the older evaporator; however, higher pressure steam must be available to operate the new first effect. It is more difficult to add two new effects because heat-transfer surface must be added to the existing evaporator to compensate for lower delta T's.

For a vapor recompression evaporator, thermal or mechanical, the heat exchanger should be designed for a small delta T to minimize the compression range. If the temperature difference is large, more power will be required to drive the compressor, or more steam will be needed to the thermocompressor, and vapor recompression becomes a less attractive alternate. In other words, it may not be practical to simply add a compressor, or thermocompressor, and vapor pipe to convert an existing evaporator to vapor recompression; additional heat-transfer surface may be needed.

Entrainment from a vapor recompression evaporator must be minimized to reduce contamination of the steam condensate because the steam and compressed vapors from the evaporator are intermixed. In addition, entrained brine can cause accelerated corrosion of the thermocompressor or the mechanical compressor. As a minimum, a mesh-type entrainment separator should be installed in the evaporator.

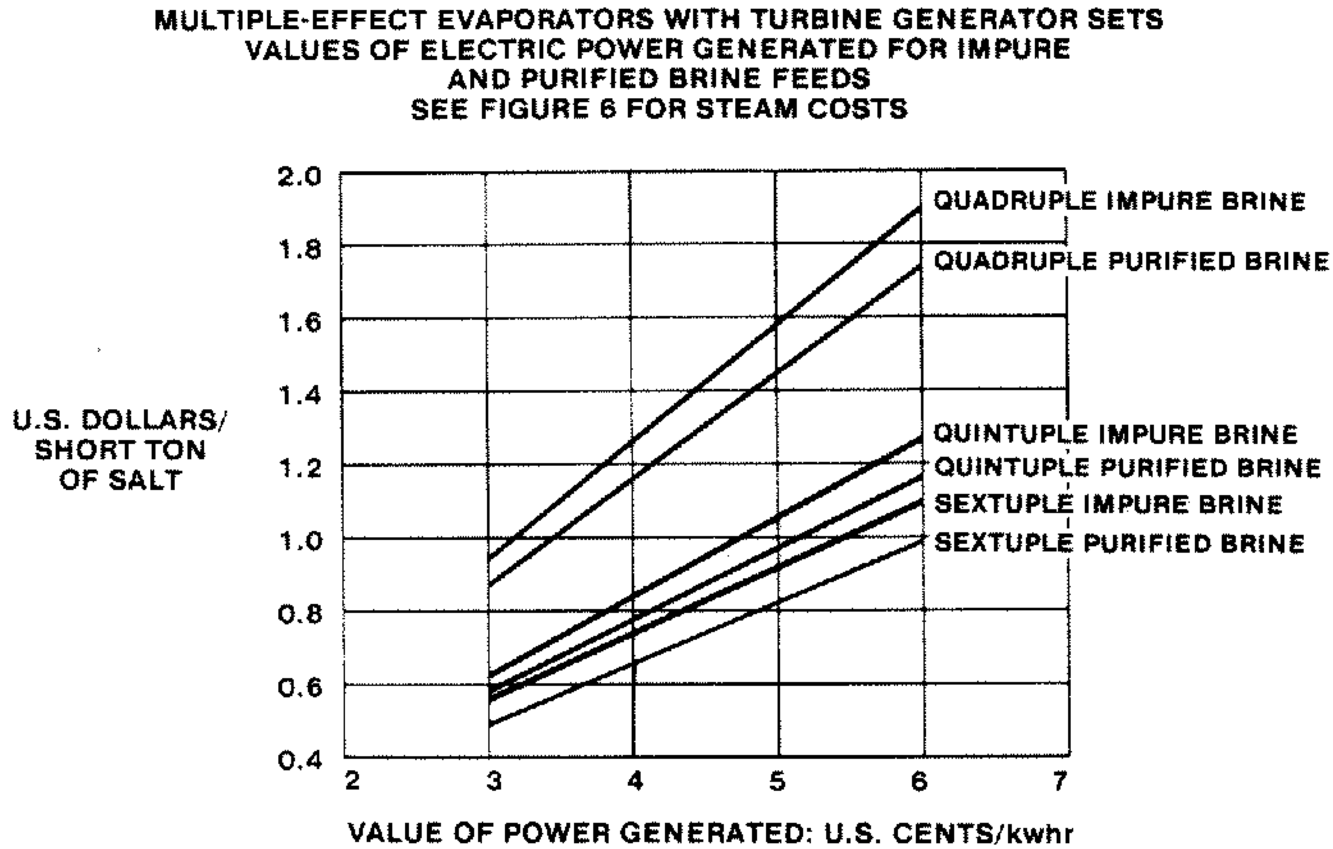

Figure 7.

TABLE 5

Barometric Condenser Water Rates for Several Different Salt Evaporator Configurations and for Purified and Impure Brine Feeds

	85°F water 15°F temperature rise gpm/short ton salt		80°F water 20°F temperature rise gpm/short ton salt	
Feed brine →	**Impure**	**Purified**	**Impure**	**Purified**
Multiple effect with and without turbine generator				
Quadruple	202	185	151	139
Quintuple	164	145	123	109
Sextuple	138	120	103	90.0
Multiple effect with Thermal recompression				
Quadruple	171	—	128	—
Quintuple	147	—	110	—
Sextuple	127	—	95.2	—
Mechanical recompression	48.5	7.30	36.4	5.48

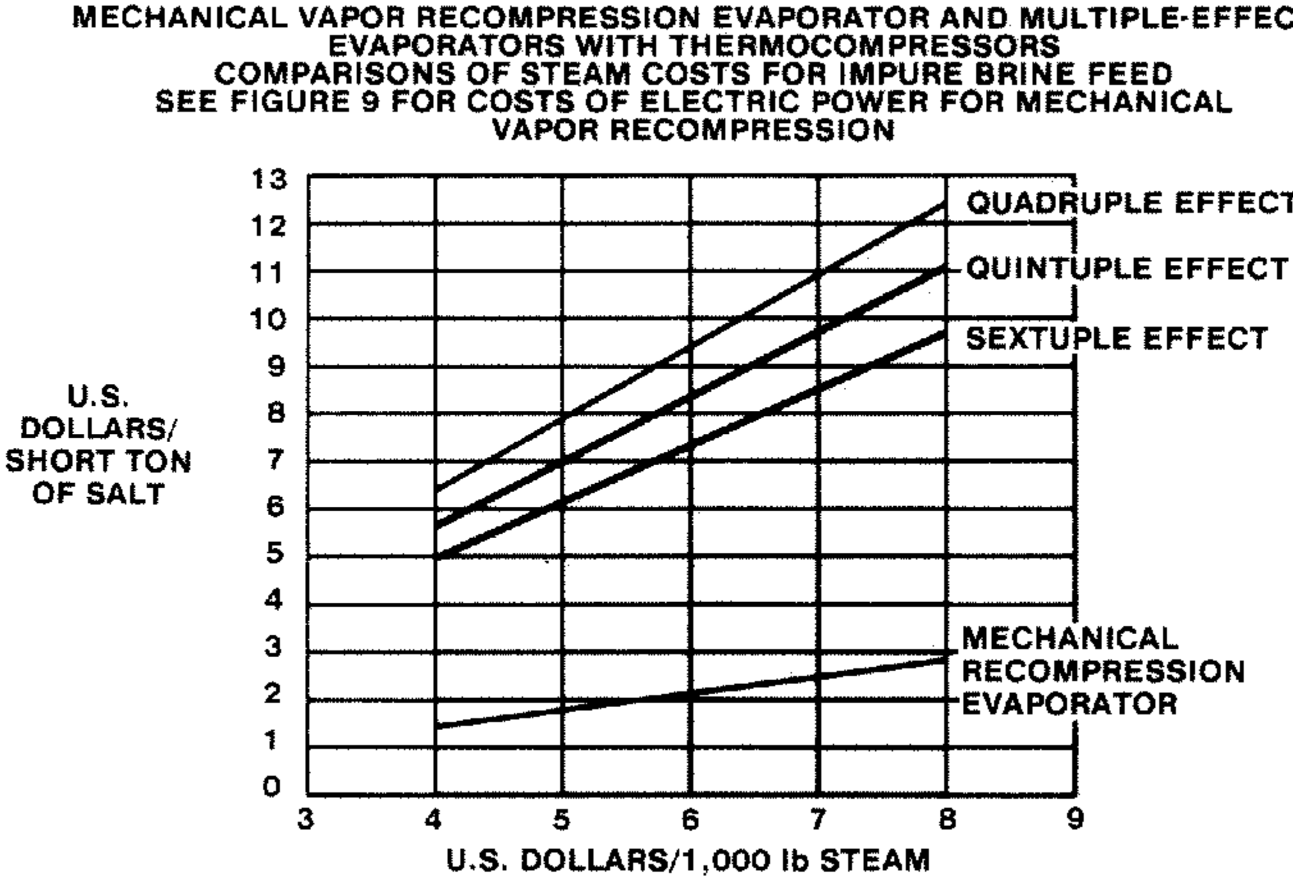

Figure 8.

The evaporation rate in the first effect of a thermal recompression evaporator will be greater than that in the first effect of a conventional evaporator. For the three multiple-effect evaporators that were analyzed, the evaporation rate in the first effect is approximately 50% higher. Stated differently, the first-effect body diameter would need to be 22% larger for thermal vapor recompression.

Modification of an existing evaporator will not be necessary if a turbine generator set is added.

The last point to be discussed is evaporator "turn down." A conventional, multiple-effect evaporator can be operated efficiently over a wide range of capacities. The steam flow control valve is simply throttled to reduce the steam and production rates. This is not an efficient way to lower the capacity of an evaporator provided with a thermocompressor or turbine generator set, because each unit is designed to operate at a specified steam inlet pressure; therefore, it is not desirable to lower the inlet pressure with a large pressure drop across the steam control valve.

A thermocompressor has an optimum efficiency for a given pressure profile and steam rate. To improve the efficiency of a thermal vapor recompression evaporator at lower capacities, it is necessary to use multiple thermocompressors, each designed for a specific rate. For example, three units could be supplied sized for production rates of 50%, 75% and 100% of design. Only one ther-

TABLE 6

Comparisons of Costs for Three Alternate Designs
Impure Brine Feed

	U.S. Dollars/Short Ton of Salt		
Steam Cost $/1,000 lb →	**4**	**5**	**6**
Quadruple Effect			
Plain	7.16	8.95	10.74
Thermocompressor	6.28	7.85	9.42
Turbine Generator			
3¢/kwhr	6.69	8.60	10.51
4¢/kwhr	6.37	8.28	10.19
5¢/kwhr	6.05	7.96	9.87

MECHANICAL VAPOR RECOMPRESSION EVAPORATORS
COMPARISONS OF ELECTRIC POWER COSTS FOR IMPURE AND PURIFIED BRINE FEEDS
SEE FIGURE 8 FOR COSTS OF MAKE-UP STEAM REQUIRED FOR IMPURE BRINE FED EVAPORATOR
NO MAKE-UP STEAM REQUIRED FOR PURIFIED BRINE FED EVAPORATOR

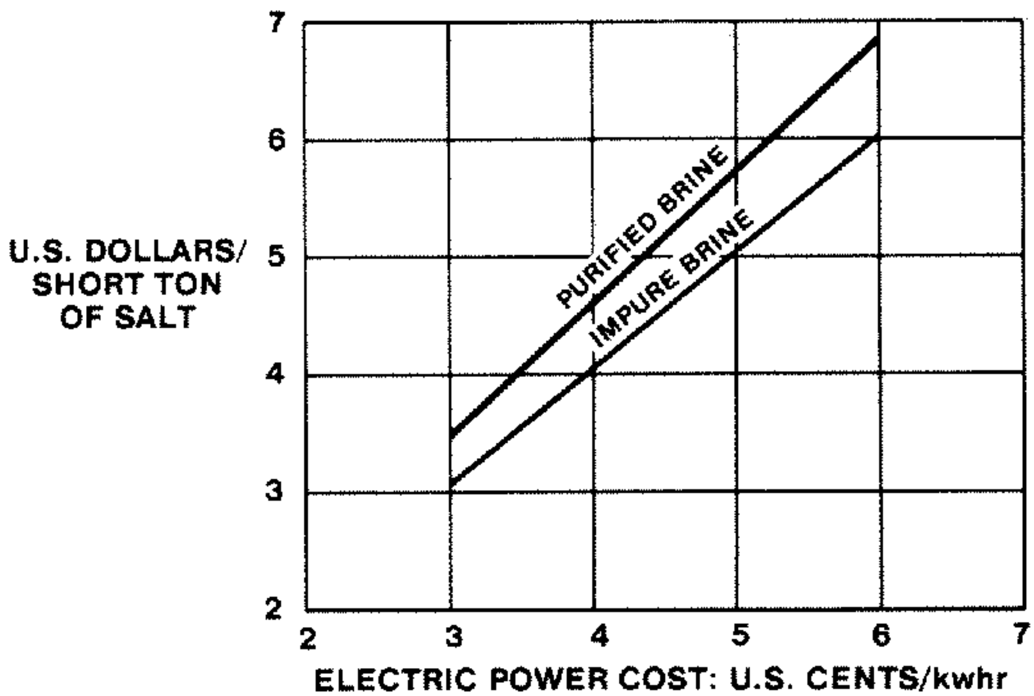

Figure 9.

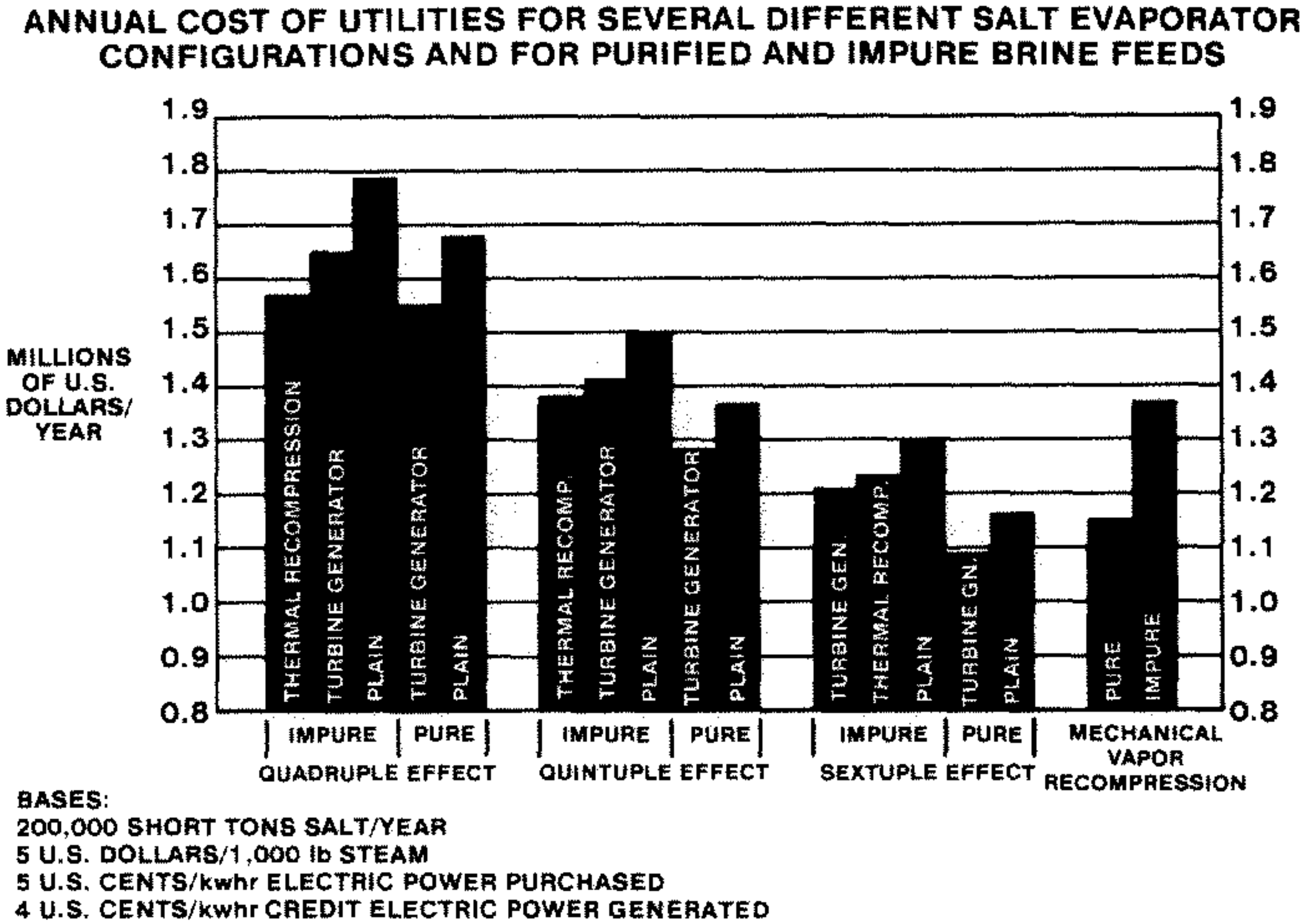

Figure 10.

mocompressor at a time would be in operation. A less efficient alternate is a single thermocompressor equipped with an adjustable spindle to change the orifice size of the steam nozzle.

To operate a turbine generator set efficiently at lower rates, it is necessary to reduce the number of nozzles that direct steam to the blades of the turbine wheel. This lowers the steam rate without reducing the steam pressure. Turbines are provided with hand valves; each valve will shut off steam to a group of nozzles.

The capacity of a motor-driven centrifugal compressor for a recompression evaporator can be decreased by throttling a control valve in the inlet vapor pipe; however, it is more efficient to use adjustable inlet guide vanes. If the compressor is turbine driven, the speed of the turbine can be varied to efficiently change capacity.

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