Economics of Recompression Salt Evaporation

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ABSTRACT

The intent of this paper is to examine the economics of mechanical evaporators as compared to the conventional multi-effect evaporators generally used in the salt industry. The advantages, disadvantages, and limitations of mechanical evaporators are discussed. Heat and material balance figures are considered to illustrate comparative energy economics of a mechanical recompression evaporator, and a conventional quadruple effect salt evaporator.

The types and limitations of mechanical compressors are discussed, and situations favoring recompression evaporators are listed.

INTRODUCTION

Numerous articles pertaining to this country's impending energy crisis have appeared. To many readers, this energy crisis is constantly brought to your attention in the form of higher fuel and steam costs. The evaporator is the major user of the energy required in the production of salt from saturated brine and it is therefore of paramount importance that the most economical evaporator scheme is employed to reduce total energy requirements per ton of salt produced.

Salt evaporator practice in the United States, as well as almost all other evaporator applications in this country, has traditionally been multiple effect. The only economic evaluation normally made was to decide how many effects should be utilized. This was readily determined by a comparison of utility costs versus capital expenditure, and then matching these figures against a reasonable economic pay-out of the equipment.

The choice of multiple effect evaporators was further justified because of their simplicity, mechanical reliability, and above all, because of the relative low cost of fuel in this country. In other countries where low cost fuel is not available, or where the available energy is principally in the form of electricity, mechanical recompression evaporators are used more extensively.

In the light of current (1973) predictions of an energy crisis and rapidly rising fuel costs, the traditional choice of a multiple effect evaporator may in certain instances be challenged. It may be interesting to compare recompression with multi-effect in the light of relative cost and availability of steam and electric power at the location being considered.

Mechanical recompression

A brief review of the principle of mechanical recompression to see where it might be of advantage will clarify pros and cons for its use.

Figure 1 shows a typical mechanical recompression evaporator configuration. The illustration is of a forced circulation design but the same configuration would apply to a Calandria unit, or any other evaporator design.

The basic evaporator components are the same for recompression as for a conventional evaporator, consisting of a vapor head, heating element, vapor piping, circulating piping and a circulating pump. The only difference is that in a mechanical recompression evaporator the vapor boiled off is compressed, raising its saturated temperature sufficiently to allow it to be reused as steam in the heating element, instead of being condensed in a condenser or the subsequent heating element. A mechanical recompression evaporator as shown in Figure 1, is generally a single effect. All of the evaporated vapor is compressed and reused in the heating element, eliminating the condenser water requirement normally associated with conventional evaporators.

Theoretical examples

Figure 2 is a schematic diagram illustrating a theoretical case of evaporating one pound of water at 212°F and

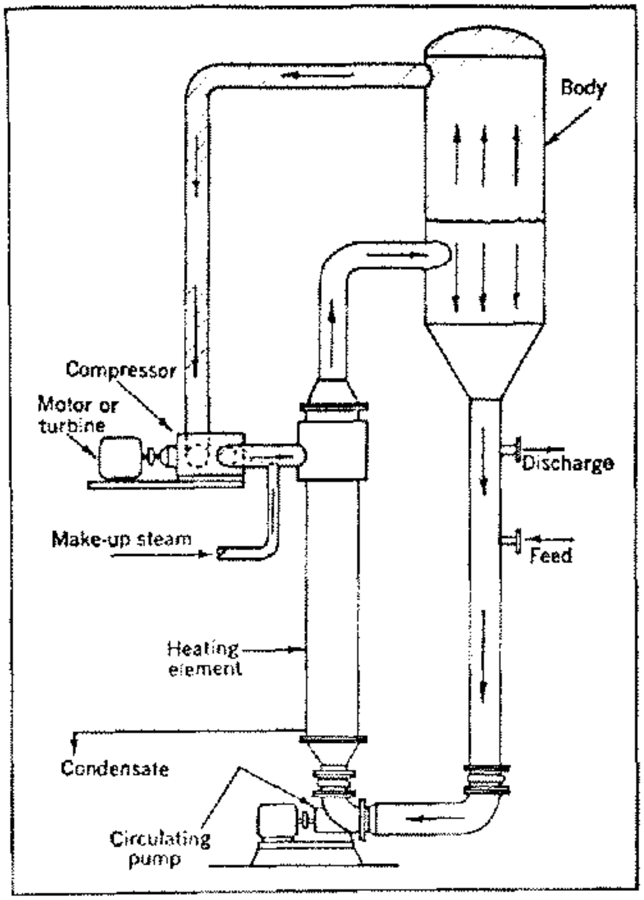

Figure 1. A mechanical recompression evaporator.

atmospheric pressure of 14.7 pounds per square inch absolute, then compressing the resultant one pound of water vapor to an absolute pressure of 20.78 pounds per square inch absolute. Under these conditions, the resultant saturated vapor temperature is 230°F giving us a total Delta T for the heating element of 18°F. Under these conditions, if we assume isentropic compression of the vapor the total theoretical energy addition to the evaporated vapor at atmospheric pressure is only 25.6 BTU's. If we assume that the compressor is 75% efficient, the total energy addition is increased to 34 BTU's. When you consider that a boiler would have to supply 959 BTU's for this same duty, the 34 BTU energy requirement of compressing the evaporated vapors, roughly 3.5% of the heat that would have to be supplied by a boiler, sounds on the surface like the answer to our energy crisis. A heat balance around the system illustrated in Figure 2 will show that the recompressed vapor will supply all heat needed if the feed is at a temperature of 196°F. For these conditions the compressor chosen must be capable of operating at a compression ratio of approximately 1.4:1.

Figure 3 shows a similar set of conditions but in this case the evaporated vapor at a saturated temperature of 212°F and atmospheric pressure is compressed to an absolute pressure of 29.8 pounds per square inch equivalent to a saturated compressed vapor temperature of 250°F. These conditions are equivalent to a compression ratio of 2:1 and require only 75 BTU's of outside energy of the total heat input of 946 BTU's required to evaporate one pound of water i.e., roughly 8%. The total Delta T avail-

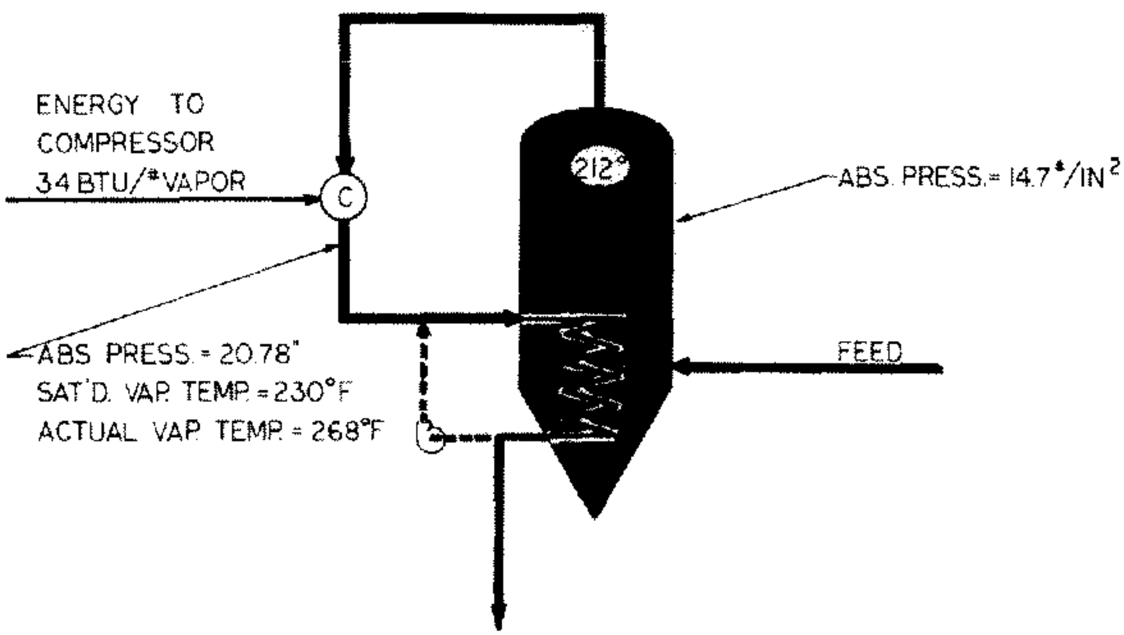

Figure 2. Theoretical case of evaporating one pound of water at 212°F and pressure of 14.7 pounds per square inch then compressing the resultant one pound of water vapor to an absolute pressure of 20.78 pounds per square inch.

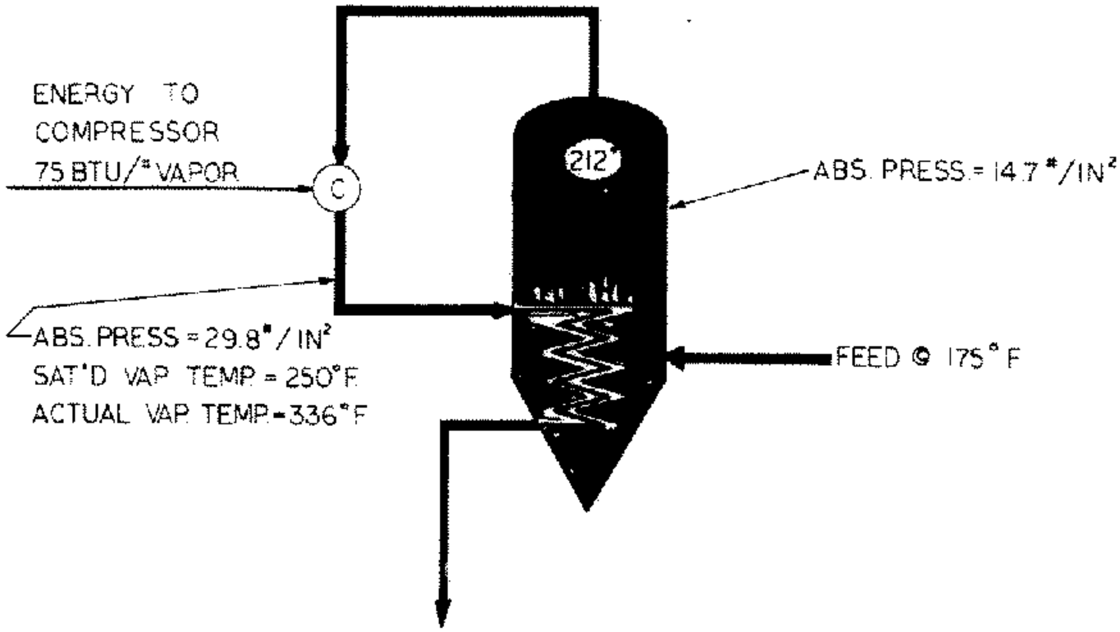

Figure 3. Theoretcial case similar to Figure 1, except that evaporated vapors is at a saturated temperature of 212°F and the atmospheric pressure is compressed to an absolute pressure of 29.8 pounds per square inch.

able for the heating element at this compression ratio is 38°F. A heat balance around this system will show that the recompressed vapor will supply all the needed heat for evaporation if the feed water temperature is 175°F.

The most interesting point about mechanical recompression is depicted in Figures 2 and 3 and that is the extremely small amount of energy required to compress the evaporated vapor to a useful pressure so that it can be re-used as steam in the heating element.

Figure 4 shows the same system as Figure 3 except that the feed is hotter than 175°F. Under these conditions, the total BTU's per pound supply from the compressor represents more heat than would be required to evaporate one pound of water and some type of vapor bleed would have to be supplied to control the vapor head pressure and keep the system in equilibrium.

Figure 5 is again an identical set of conditions except the feed is cooler than 175°F and in this case make-up steam is required since the total BTU's per pound supply from the compressor is insufficient heat to evaporate one pound of water from feed water at less than 175°F.

Figure 6 shows an alternate method of bringing such a system into balance by preheating feed colder than 175°F up to the equilibrium temperature of 175°F by using the condensate from the heating element in a heat exchanger. If, for example, the raw feed water is at 70°F, the necessary heat to reach the equilibrium feed temperature of 175°F could be obtained by cooling the condensate from 250°F to 145°F.

A combination of the methods illustrated in Figures 5 and 6 could be used, that is, preheating the feed to some intermediate temperature below 175°F and using make-up steam as a means of controlling vapor head pressure. It is essential to maintain a constant suction pressure to the compressor in order to prevent it from surging and causing the evaporator to cycle. This can be done by operating the system so that some make-up steam is required. This make-up steam can be controlled through an automatic valve by the compressor suction pressure. Additional make-up steam will cause additional evaporation and tend to increase vapor head compressor suction pressure whereas less make-up steam will decrease evaporation and tend to decrease the vapor head pressure.

Effect of boiling point rise on Delta T

All the cases shown in Figures 2 through 6 assumed the evaporation of water from pure water with zero boiling point rise. In Figure 2 the total Delta T was 18° achievable by the addition of 34 BTU's per pound of vapor evaporated and raising the saturated vapor temperature from 212°F to 230°F. In a mechanical recompression evaporator the vapor temperature increase necessary is the sum of the boiling point elevation (BPR) of the liquid plus the Delta T required for heat transfer. If the pound of water is evaporated from a saturated brine solution and 16°F BPR was deducted from the total 18°F saturated vapor temperature, only 2°F would be available for heat transfer. Assuming the same heat transfer coefficient, the heating surface required in an evaporator is directly proportional to the Delta T or drive force available, and in

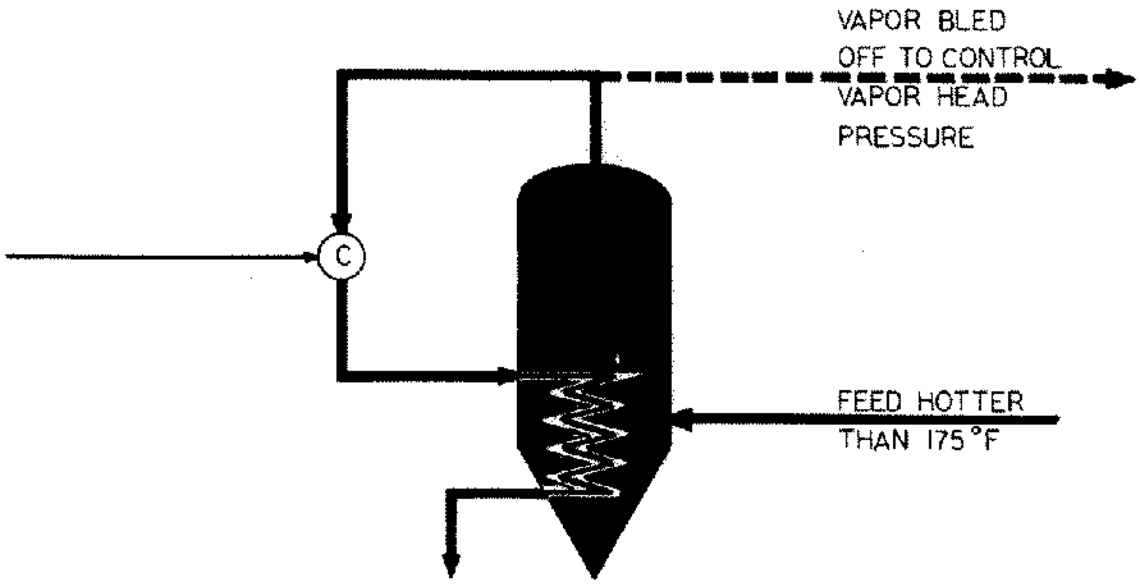

Figure 4. System is same as shown in Figure 3, except that the feed is hotter than 175°F.

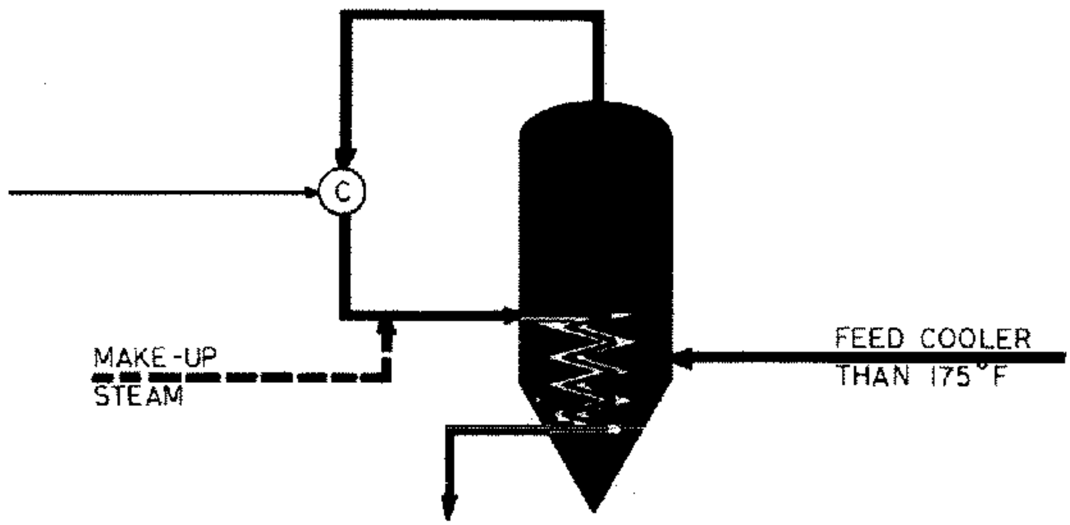

Figure 5. System is same as shown in Figure 4, except that the feed is cooler than 175°F.

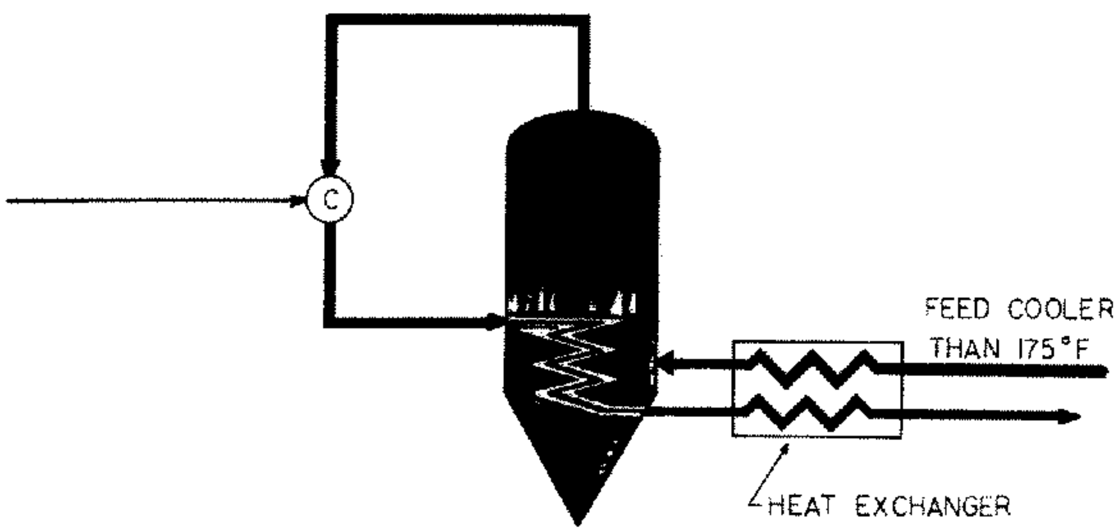

Figure 6. System shows an alternate method by preheating feed colder than 175°F to equilibrium temperature of 175°F by using condensate from heat exchanger.

this case the 2°F Delta T which would be available for heat transfer would result in an uneconomical evaporator. As a matter of fact, if some of the other losses such as short circuiting, pressure drop, and friction losses are considered, the net result could be 0°F available for heat transfer. The obvious conclusion to be reached from the above is that a mechanical recompression evaporator evaporating water from a saturated brine solution has to be designed for a higher compression ratio. Figures 3 through 6 show conditions whereby using a compression ratio of 2:1 a total Delta T of 22°F is available for heat transfer which is roughly equivalent to the average Delta T available per effect in the case of a quadruple effect conventional evaporator operating at 35 PSIA steam in the first effect heating element and 25-1/2" vacuum in the fourth effect vapor head. This set of conditions is an excellent design and economic compromise, considering the availability of standard compressor designs to meet these conditions.

Compressor designs

Figure 7 is a table listing the types of compressors available, approximate efficiency of each type, number of stages required to achieve a compression ratio of 2:1 and maximum vapor handling capacity conveniently converted to read in terms of "Tons of salt production per day." From this table you can see that the only type of compressor that can achieve the 2:1 compression ratio required in a single stage is a positive displacement unit. Unfortunately, this type of compressor design is limited as to vapor handling capacity. The maximum vapor handling capacity of one unit would be equivalent to approximately 100 tons salt production per day. An evaporator design using two or three such units operating in parallel resulting in a total maximum evaporator capacity of 300 tons per day salt production is feasible. These compressors are not available in a wide range of materials of construction. Cast iron construction is the only material readily available in a price range resulting in an economical evaporator. Above approximately 300 tons per day production it appears that a couple of centrifugal compressors operating in series are less costly, and represent less maintenance than multiple positive displacement units. The salt industry has considerable experience with centrifugal compressors operating as exhaust blowers on salt Top Feed Filters and is familiar with the maintenance associated with this type of equipment. Series operation of this type of compressor is mandatory to achieve the minimum compression ratio of approximately 2:1 required for a salt evaporator. This arrangement with two single stage units in series has vapor handling capacities equivalent to a production in excess of 1,000 tons per day. Multi-stage centrifugal machines and axial flow compressors are extremely expensive and a limited investigation indicates consideration for capacities under 2,000 tons per day be-

COMPRESSOR APPLICATIONS

	POSITIVE DISPLACEMENT	CENTRIFUGAL	AXIAL
COMPRESSION RATIO REQ'D.	2:1	2:1	2:1
NO. OF STAGES	1	2-SINGLE STAGE IN SERIES - OR 1-MULTI-STAGE	MULTI-STAGE
APPROX. EFFICIENCY	60%	75%	85%
APPROX. MAXIMUM CAPACITY TONS PER DAY SALT	100 (1 UNIT) 200 (2 UNITS)	>1000	> 2000

Figure 7. Available compressors and their efficiency.

ing much costlier than two single stage centrifugal machines in series.

Costs

In comparing equipment costs of a quadruple multiple effect evaporator having a capacity of 1,000 tons per day salt production, and a recompression unit of equivalent capacity, it is important to spell out what is included in the comparison. The multiple effect cost would have to include not only the evaporator with all of the associated piping, condenser, pumps, and vacuum equipment, but also such necessary items as the boiler, building, and in these days of the Environmental Protection Agency, the condenser water cooling tower. The recompression evaporator would require a somewhat smaller building, a very small package boiler for start-up and no cooling tower. The basic recompression evaporator would cost slightly less, as would the building to house it, however, even with the elimination of 90% of the cost of a boiler, and complete elimination of the cost of a water cooling tower, the compressor cost makes the two systems almost a stand-off in final cost.

Figure 8 shows the evaporative energy cost of a recompression evaporator requiring 75 BTU's of outside energy per pound of evaporation and a conventional quadruple effect evaporator requiring 2,100 pounds of steam per ton of salt. At 1-1/4 cents per KWH, the evaporative energy cost of a recompression unit is $2.16 per ton of salt. At a steam cost of $1.50 per 1,000 pounds and electrical cost of 1-1/4 cents per KWH, the evaporative energy cost per ton of salt favors recompression by approximately $1.00 per ton. A salt plant producing 1,000 tons per day under such conditions, could make a significant saving in evaporative energy cost in the range of several hundred thousand dollars annually. A 500 ton per day salt plant under these conditions could save in excess of $100,000 annually. An energy cost difference of this magnitude may be unrealistic, however, even a comparison of a 1-1/4 cent KWH to a steam cost of $1.25 per 1,000 pounds indicates substantial savings in evaporative energy costs. These ap-

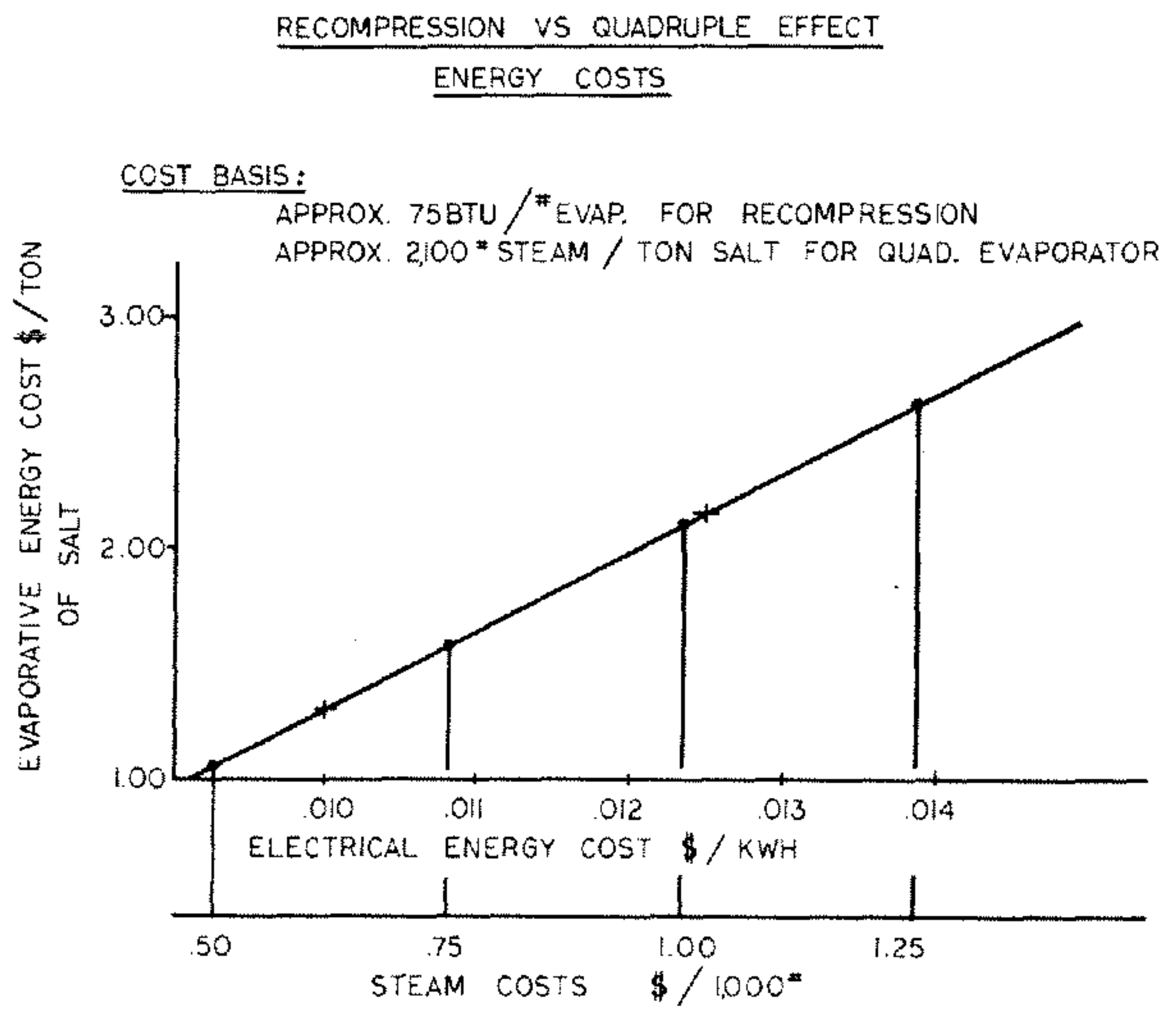

Figure 8. Evaporative Energy Costs.

parent savings must be tempered by other considerations such as maintenance, reliability, initial capital expenditure and labor costs. It is not the intent of this paper to delve very deeply or extensively into these complete capital and operating costs since each case must be considered separately and on its own merit. Generally speaking, maintenance and reliability would favor a multiple effect. Capital expenditures are probably equal. Operating labor might favor the recompression unit slightly.

Conclusions

From the foregoing, it is evident that the energy requirement for mechanical recompression is very low. In the illustrated case, with 75% compressor efficiency and a 2:1 compression ratio only about 75 BTU's per pound of evaporation are required *vs* in excess of 300 BTU's per pound for a quadruple effect.

With this inherent energy advantage, where might recompression be truly advantageous? These might be listed as follows:

1. In any situation where low cost electrical energy is available.
2. For small to medium-sized plants where a boiler and cooling tower installation cannot be justified.
3. For plants now reducing appreciable quantities of high pressure steam to low pressure by reducing valves. (Use high pressure steam to drive the compressor turbine.)
4. For large new plants where combined generating/recompression/multi-effect cycle might be employed.
5. Where sufficient fuel such as natural gas, oil or coal is simply not available in the quantity required to run an economical-sized plant.

In the final analysis, if you are contemplating a plant or expansion exceeding 500 tons per day, an economic and cost comparison between recompression and multi-effect should be made.