A NEW APPROACH TO EVAPORATION

By

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The ever growing need for the removal of water from solutions has brought forward the development of many new techniques. As the state-of-the-art has become more sophisticated, specialist designs have been evolved to cater for particular requirements.

Some of the design aims can be listed as:

A. Low initial capital cost
B. Low temperature and time multiple
C. Small space or headroom
D. Low operating cost
E. Resistance to fouling
F. Easy cleanability

There is general agreement that film evaporation offers the best approach to high heat transfer rates and therefore lower investment cost.

The APV/Rosenblad Evaporator offers a new approach to the geometry of film evaporation. The original design concept was to provide for high capacity and very high efficiency evaporation for the paper and pulp industry. Its success in that field has opened up the way to more general use in other areas, where its feasibility of design allows other of the design objectives previously listed to be incorporated.

The larger the evaporative load, the greater is the need for efficiency of operation. Whereas in the past a pound of steam

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for a pound of evaporation was common, as capacities have increased, so have the number of evaporator effects. For high evaporation loads, 50,000 lbs/hr or above, operating over 5,000 hrs/year, justification can usually be made for 5 effect evaporation, on the basis of evaluation of operational and capital cost.

With many products a limit must be placed on the highest temperature of evaporation. In the case of food and allied products containing protein or sugar a maximum first effect temperature would range from 155 - 200° F. At the other end of the evaporator, the temperature of the available cooling water and its cost of pumping economically the final effect temperature to 105° F or higher. The overall temperature difference is therefore restricted; this is further reduced by the inevitable pressure drop in each of the effect separators. A typical temperature distribution of a five effect evaporator is shown in Figure 1. It will be seen that the effective temperature difference per effect is only 16° F. A large amount of surface is therefore required; large capacity evaporators must therefore have good heat transfer coefficients and the cost per square foot must be kept to a minimum. Furthermore the evaporator must be capable of maintaining its performance without costly shut down time.

Figure 1.
Typical Operating Temp. for Five Effect Evaporator

Description of Falling Film Plate Element

The basic surface design of the APV/Rosenblad Evaporator has been arranged for falling film evaporation in order to achieve the highest possible heat transfer rate.

The evaporation surface comprises flat rectangular elements with a 3/4" inside steam condensing passage. The sheets from which the element is formed are suitably "quilted" and welded together for mechanical strength.
These elements are made in sizes ranging from 1' x 2' to 4' x 20'. They are vertically placed in a shell spaced about 1-1/2" apart and connected into the inlet stream header, and into the condensate and vent outlet.

The liquor being evaporated flows down the outside of the elements. Distribution of the feed to the plates is achieved by equal spraying over the top area of the element bank. The tops of the elements are equipped with distributor caps which ensure filming of the feed over the entire plate area. See Figures 2, 3, 4, and 5.

As the liquor flows down the plate, the vapor evaporated is free to disengage and flow horizontally towards vapor outlets on both sides of the element. This vapor path is so direct and free that very low velocities on the order of 5 fps are experienced. (Vapor flow is kept in a horizontal direction to a vapor plenum.) The normal pressure losses are avoided; vapor/liquid separation is automatically achieved without a separate separator vessel.

The geometry also allows the partitioning of the same evaporator body into sections. These can be used to carry out the evaporation in stages to maintain the highest possible overall heat transfer rate; they can also be used to provide "spare" sections which can be cleaned while the remainder of the unit stays on stream.

Evaporator modules can be constructed in either vertical or horizontal shells. Vertical modules house up to 11,500 square feet of surface whilst a horizontal module with 80,000 square feet has been installed.

**Evaporator Configuration**

The evaporator can be arranged as a simple or a multiple effect unit, each effect having a separate shell or module.

For high capacity evaporation, as we have seen, the multiple effect unit gives a low temperature difference per effect. A more efficient method of using a small temperature (or pressure) difference across an effect is by means of mechanical vapor recompression.

The heat required per effect of a five effect evaporator is approximately 200BTU/lb evaporation. An effect having an overall temperature difference of 15° F using mechanical vapor recompression will need approximately one ninth of that heat.

The use of Mechanical Vapor Recompression therefore gives a theoretical efficiency equivalent to over 40 effects. This theoretical
Figure 2. Diagrammatic Section of Module Indicating Basic Components

Figure 3. Diagrammatic View of Feed Distribution In APV/Rosenblad Evaporator

Figure 4. Falling Film Plate Evaporator

Figure 5. Total Energy & Enthalpy Values Mechanical Recompression
valve is however reduced by the inefficiency of the compressor (the efficiency of which can vary from 65 - 80% depending upon type and duty). Power to the recompressor can be supplied by electric motor, diesel or steam turbine, and the unit costs of power will vary accordingly.

Usually electric drive gives the net equivalent of 10 effects; a back pressure steam turbine drive will give about 30 effect efficiency. An approximate power requirement for electric drive is 10 KW for 1000 lbs/hr evaporation.

Mechanical Vapor Recompression can give other advantages. Multiple effect economy is achieved by operating through a range of temperatures - some of which must be elevated. With Mechanical Vapor Recompression any single optimum temperature of operation can be selected, and the high efficiencies obtained. This feature is very useful in the evaporation of food products, where the permissible operating temperature range is often too limited to permit an economic number of effects. For example an APV/Rosenblad was recently commissioned for blood evaporation where a temperature maximum of 110°F is experienced.

It must also be noted that as no live steam is used, no condenser cooling water is required. This not only saves the cost of pumping water but also the cost of its subsequent disposal.

In general the capital cost of a vapor recompressor is only slightly higher than the capital cost of a boiler and cooling tower that might otherwise be required.

Types of Recompressor

The types of compressor used with the evaporator are:

LOBE TYPE COMPRESSOR - This type of compressor has large revolving lobes; its application is for relatively low vapor volumes (up to 16,000 CFM). Compression ratio is no problem; the maximum pressure difference is usually 5 psig which is more than that normally required.

CENTRIFUGAL COMPRESSOR - This is an overgrown centrifugal pump which will handle water vapor compression up to a compression ratio of about 1-3. It is used for CFM's between 15,000 and 60,000.
FLEXIBLE BLADE COMPRESSOR - This compressor was specially designed for use on desalination plants where it works in conjunction with a freeze concentration process. The blades of the radial flow portion of the unit are of very slim metal - centrifugal force holding the blades straight during operation. It has the ability to handle up to 400,000 CFM water vapor with a maximum shaft horsepower of 1500. It is perfectly suited to vacuum vapor recompression below 200 m. m. Hg absolute and can operate with compression ratios as high as 2. This compressor can be integrally mounted on the APV/Rosenblad module, its mounting plate forming the top cover of the module. One such unit is in operation evaporating blood to over 50% solids at 100-105°F evaporation temperature.

Molasses Evaporation

A possible arrangement of this type of evaporator using Mechanical Vapor Recompression is shown in Figure 6.

This material is not particularly heat sensitive and at low concentrations evaporation at higher temperatures can be used. The later stages of evaporation are normally carried out in the region of 160°F as a compromise between viscosity and product temperature.

Feed material is preheated to 213°F in stages using condensate and vent gases from the evaporator. The condensate is rejected at 85°F. The evaporator rejected heat can heat the feed to about 210°F, and a final direct heating using steam is required to bring the feed to 213°F boiling temperature of the first stage of evaporation.

At a feed rate of 45,000 lbs/hr, the evaporation from 8% to 32% is 33,750 lbs/hr. Boiling at atmospheric pressure, the vapor generated is 14,000 CFM. This vapor is boosted to 5 psig which provides a 229°F condensing temperature. Allowing for a 5% bypass around the compressor to superheat the suction vapor, the consumed horsepower will be 440 HP. The vapor volume of 14,000 lbs/hr can be handled in a lobe type compressor. The energy put into the compression re-appears in two forms a) the heat necessary to raise the evaporated water from 213 to 229, and b) excess vent vapor.

Some of this vent vapor is used to preheat the feed by 10°F - the remainder is vented off to atmosphere by the pressure control system, which maintains the operating pressure level of the evaporator.

From this first stage of evaporation, the pre-concentrated liquid would be fed to a second stage operating at 150°F vapor with product temperatures from 151 to 160°F as BPE increases.
Figure 6.
Suggested Schematic of APV/Rosenblad Recompression Evaporator for Molasses

Figure 7.
Molasses Evaporator Operating Cost Comparison

Figure 8.
Orange Juice Evaporation Schematic
The operating temperature difference varies from $25^\circ F$ to $15^\circ F$ in order to accommodate the BPE. The efficiency of recompression is therefore about a half of that of the first stage and the power input will be about 165 HP.

Figure 7 gives a comparison between the operating costs of this system compared to a 4 effect evaporator. The valves for steam, water and power used are typical and may have to be varied for any particular plant.

As you can see, very substantial operating services costs savings are possible, even over a relatively efficient 4 effect evaporator.

Orange Juice Evaporation

The use of Mechanical Vapor Recompression makes it possible to use medium or low temperatures for orange juice concentration and at the same time far exceed presently accepted evaporator efficiency.

Figure 8 shows an outline scheme for preconcentrating juice two to one and following this evaporator with multiple effect units already installed. The juice could be stabilized at one half the normal single strength rate. Using a scheme such as this would give an overall plant capacity rise of perhaps 60 - 75% at a modest investment, with an overall increase in operating efficiency.

Many other schemes can be considered to suit any particular plant's requirements.

Conclusion

The geometry of the new design of plate surface falling film evaporator represents a new approach to the evaporation problem.

Its features can be summarized as follows:

1. High heat transfer from falling film evaporation
2. Low velocities and pressure drops on vapor side.
3. Very low entrainment losses.
4. Economic vapor recompression operation.
5. Compact outdoor self contained installation.
6. Use of condensate for preheating gives cool effluent discharge.
7. Use of evaporator sections can provide evaporator surface cleaning while full evaporation duty is maintained.
8. Capacities from 1,000 to 400,000 lbs/hr evaporation can be accommodated by simple scale up.