LARGE FALLING FILM EVAPORATORS AND VAPOUR COMPRESSION

By W. ADDISON
c/o A.P.V. Kestner (S.A.) (Pty.) Limited

Abstract

The application of large falling film evaporators to the evaporation of dilute cane sugar solutions is discussed and operating problems are defined. An unusual evaporator configuration is described. The application of mechanical vapour compression to this type of evaporator is described and its possible application to the overall energy balance in a sugar mill is discussed.

Section 1 — Large Falling Film Evaporators

The concept of film evaporation was first practically applied in rising film evaporation which was pioneered by Paul Kestner in the early 1900's. The rising film concept overcame the problem of liquor distribution among tubes by careful design of the bottom of the tube and an appropriate pre heating of the liquor.

However the rising film is only established by heating the incoming liquid to above the equivalent boiling temperature of the liquid at the top of the tube, this superheating being imposed by hydrostatic and velocity pressures present during the passage of the liquid up the tube. This reduces the effective temperature difference and in multiple effect evaporation limits the number of effects which can be operated in series.

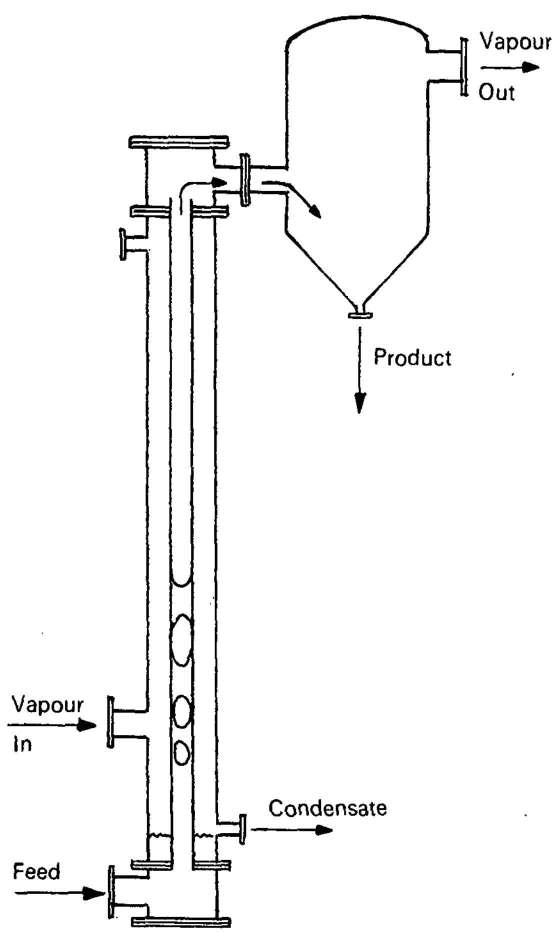

FIGURE 1 Rising Film Evaporator.

The mechanism of the rising film is dependent solely on the vapour ascending the tube, thus imposing a limit on the minimum percentage evaporation per pass and making the mechanism less effective the higher the operating pressure due to reduction in vapour volume and hence, velocity.

It was a logical development to arrange long vertical tubes in falling film mode where the liquid is introduced at the top of the calandria and the liquid descends the tubes thus overcoming the hydrostatic head problem even though velocity pressure problems are still present to some extent.

In practice liquor distribution problems, especially in large calandrias with many tubes, are considerable. To attempt to overcome these problems by merely increasing the amount of liquor descending each tube (by recirculation) is limited by the ability of a tube to handle comparatively large volumes of vapour and liquid at the same time.

An examination of the literature will indicate that development work on liquor distribution devices is receiving much

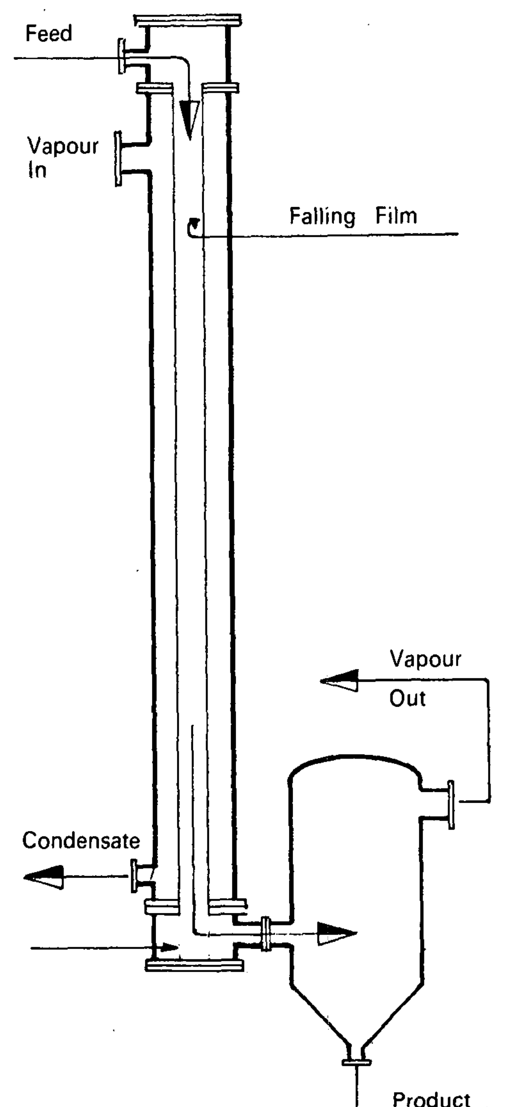

FIGURE 2 Falling Film Evaporator.

attention, but this is probably mostly confined to the food industry where short residence time, which is a feature of falling film evaporation, is of paramount importance and recirculation is to be avoided. Thus the liquor distribution devices attempt to ensure that minimal, equally distributed amounts of liquid are introduced at the top of each tube. This imposes in most cases either small orifices or other devices with small clearances which in many applications produce severe problems of their own.

In many large scale applications of evaporation, recirculation is permissible, especially where comparatively small percentage evaporation on rather thin liquors are required. A good example of this would be a pre-evaporator in a sugar mill before a conventional evaporator train. Here the percentage evaporation can be kept low, and recirculation minimised.

In order to capitalise on the advantages of the falling film evaporator and to minimise some of the disadvantages mentioned above the Rosenblad Corporation of Princeton, New Jersey, has developed a unique falling film evaporator which is briefly described as follows.

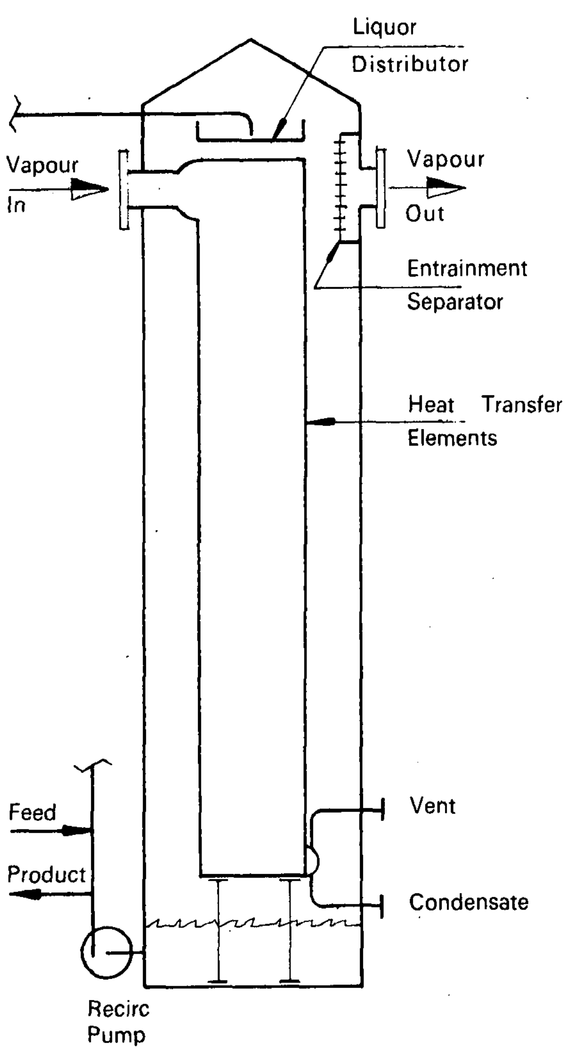

FIGURE 3 Rosco "Freeflo" Evaporator Module.

To overcome the disadvantage of handling large liquid flows through tubes and to produce a compact cheap heat transfer surface, a flat vertical plate type heat transfer element has been developed. Each element is made from two plates of stainless steel which are edge welded together and additionally spot welded together over the surface after which the composite plate is inflated by hydraulic pressure to form a hollow plate some 1,2 m wide by 7,3 m long which is flat, rigid, and capable of withstanding considerable internal pressure.

Banks of these elements are fabricated together with fairly large gaps between adjacent plates so that a manifold is formed at one corner of the bank through which heated vapour is introduced into the inside of bank. A smaller manifold is usually arranged at the opposite corner, from which non condensible gases can be vented. Vapour condensing on the inside of the elements flows down the element vapour and is removed from the bottom manifold.

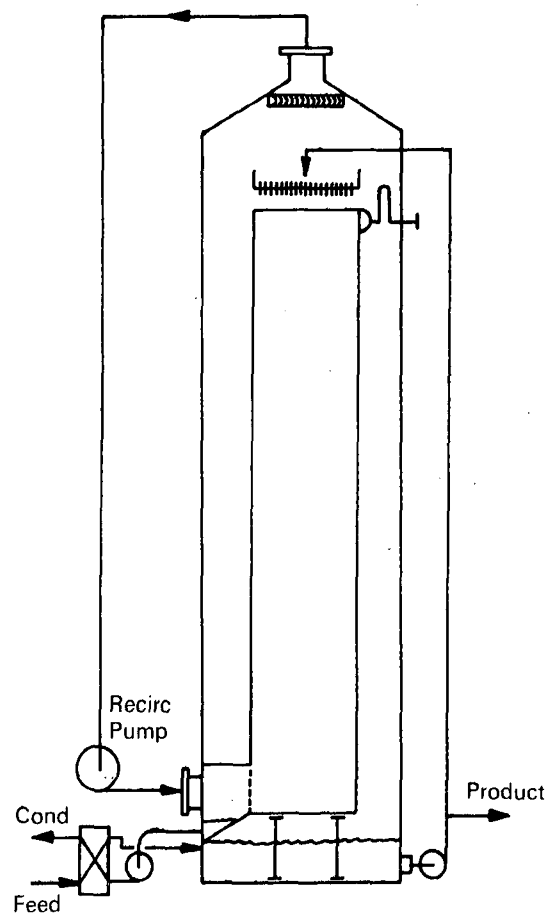

FIGURE 4 "Freeflo" V.C.E. Module.

In operation, liquid to be evaporated is introduced at the top of the vertical elements through a perforated liquid distributor using large openings (in the order of 12 mm) to introduce liquid onto the top edges. Liquid flowing down the elements is heated and evaporation takes place, vapour being released sideways at low velocity from between the elements. Sufficient recycle is used on the liquid to ensure that a substantial and easily maintained falling film is present on the plates at all times.

As vapour is evolved at low velocity, mist type entrainment is usually absent and separating efficiencies are extremely high even using simple de-entrainment equipment. Typically, evolved vapour is removed from the top of the cylindrical body and is available for heating the next effect in a multiple effect configuration or for compression for vapour compression applications which are described later.

Although developed principally for the paper industry where over 100 applications are in successful operation this type of evaporator has been applied to many liquors including highly scaling duties, where the incoming feed is saturated with calcium sulphate, for instance in organic applications in the fermentation industry where scaling, both organic and inorganic, is considerable. The elements are typically cleaned by in-place methods, i.e. washing, but mechanical descaling using high pressure jets has been applied on a routine basis in several installations.

The advantage of this type of evaporator is that all the benefits of the falling film configuration are retained while comparatively heavy recirculation rate can be easily accommodated and the liquor distributor with its large flow passages is not prone to blocking. In addition the unit can be so arranged that the heat transfer surface is divided into sections which can be successfully isolated from the evaporation circuit and cleaned on the run so that the whole evaporator need never be taken out of service for cleaning.

Section 2 — Vapour Compression Applications

The unit described above with its inherent advantages of falling film evaporation which allows very close vapour to liquid temperature differences to be utilised, its inherent low velocity on the vapour side which minimises pressure losses, and its general physical confirmation, makes it ideally suited for the use of mechanical vapour compression and many installations of this type are successfully running.

The use of mechanical vapour compression is gaining rapid acceptance due mainly to the high energy efficiency of this system and a glance at a Mollier diagram will indicate the reasons (Figure 5). From this it will be seen that at round about atmospheric pressure it only requires approximately 47 kJ in an ideal system to increase the enthalpy of a kilogram of saturated steam from a temperature of 100°C

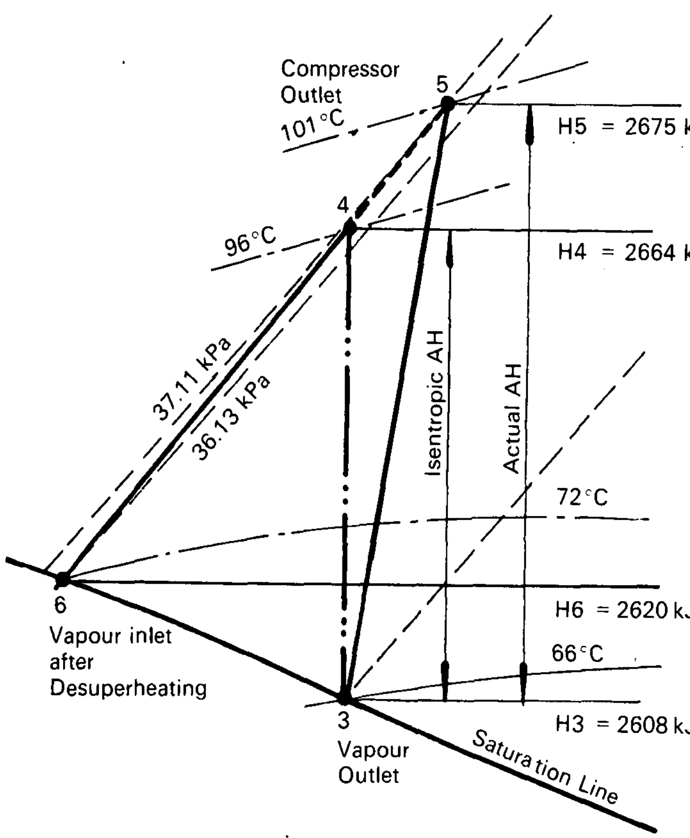

FIGURE 5 Mollier Diagram.

to say 109°C. If this is done by using a centrifugal compressor and when the efficiency of the compressor and drives are taken into account, this figure becomes approximately 70 kJ/kg of water vapour compressd. If this is applied to an evaporation process it can be seen that this is equivalent to an evaporator of conventional type of between 30 and 35 effects. From Figure 6 it can be seen that the power required

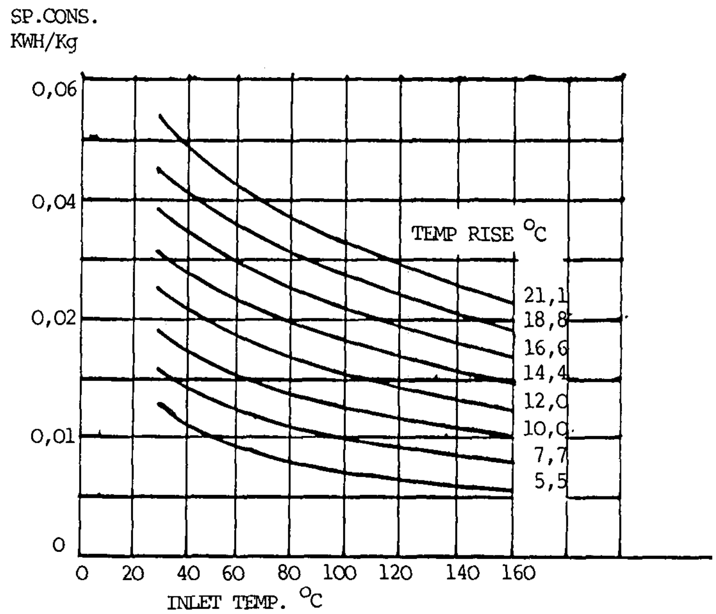

FIGURE 6 Specific power consumption against inlet temperature and temperature rise.

to compress a kilogram of vapour increases as the pressure ratio increases. It is for this reason that many vapour compression cycles operate over comparatively narrow temperature ranges, 7 - 9°C being typical. This obviously dictates large heat transfer surfaces. Here again a cheap easily manufactured transfer surface is an economic advantage.

Simple, reliable, robust single wheel turbines are in every day use and they operate over the pressure ratio mentioned, efficiencies of 80 percent or above are achievable and they can be driven by any prime mover. This allows great freedom of the overall design of the energy balance in industrial processes. For instance, a back pressure turbine could be used as a prime mover, exhaust from the turbine being used elsewhere in the factory. Alternatively high pressure steam can be generated which is let down through a back pressure turbine driving a generator and the vapour compression evaporator could be driven by an electric motor, or power could be bought from the grid to operate the electric motor, or a completely separate power source, e.g. a diesel engine, could be used.

In practice single body designs with evaporation rates of up to 180 000 kg/h are available, and operating installations in the 70 000 to 80 000 kg/h hour range are quite usual.

In summary it is felt that large falling film evaporators have a place in the sugar industry especially if advantage of new technology as far as heat transfer surface and liquor distribution is taken into account and further that in special applications the proven vapour compression evaporator could be usefully applied.