GRADUAL ENLARGEMENT OF EVAPORATOR CAPACITY

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Abstract

A method for gradually increasing of evaporator capacity is discussed. More specifically, it is shown that the first increase by + 25% can be achieved conveniently by paralleling the last vessels and by the addition of one more vessel of a size indentical to the others.

General

Accurate evaporator calculations should be made by determining heat balances for each of the vessels of the set under consideration. Changes in the operating conditions of one vessel will always influence conditions in the other vessels. These calculations are shown in numerous handbooks, and it will achieve no purpose to repeat them here. Simplified calculations, based on the assumption that 1 kg of vapour will evaporate 1 kg of water in each of the effects, have been found satisfactory for practical purposes and this method is followed in this paper.

There may be confusion about the definition of the Heat Transfer Coefficient, as radiation losses, boiling point elevations, etc. must not be discounted in accurate calculations. For the purpose of this paper the Overall Heat Transfer Coefficient is taken as the apparent rate by which heat is transferred on the basis that 1 kg of vapour evaporates 1 kg of water.

It is further assumed, for the sake of simplicity, that all vapours have a latent heat of 2120 kJ kg^{-1}. This figure will actually vary between approximately 2 050 and 2 200 in evaporators operating under normal conditions.

Then : $$E = \frac{3600\ U\Delta_t}{2120}$$

$$= 1{,}7\ U\Delta_t \text{ in which :}$$

E = evaporation rate in kg m^{-2} h^{-1}
U = O.H.T.C. in kW m^{-2} $^0C^{-1}$
Δ = Temperature difference in ^0C

This simple formula will be used to explain a convenient way to increase evaporator capacity.

Basic limitations.

For a given state of cleanliness and mode of operation (withdrawal of condensate and incodensible gases, maintaining of optimum levels, etc.), the amount of evaporation is determined by:-

1. The heating surface available.
2. The steam pressure applied.
3. The vacuum in the last vessel.
4. The bleeding of vapour from any vessel.

The operator of the evaporator can do little to increase the capacity, save to increase the steam pressure, which is often limited by the practical backpressure allowable on prime movers.

In this paper, an occasion where the steam pressure cannot be increased and where evaporators are fully loaded will be discussed.

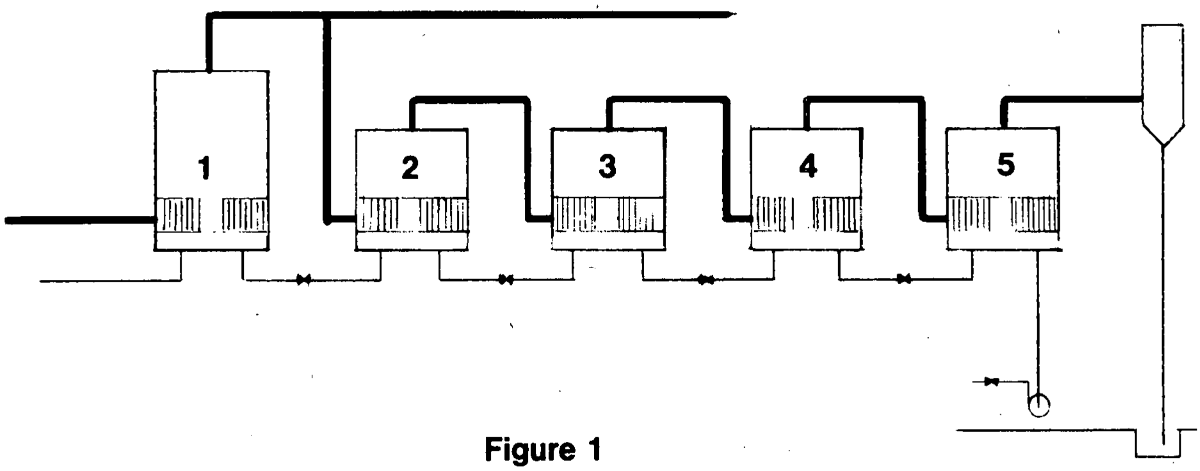

Figure 1

In figure 1 a simple evaporator set-up is shown. A larger pre-evaporator is followed by a quad of vessels of identical size from which no vapour is bled. The total evaporation by the quad is dependent on the Vapour I pressure, which in turn will influence the exhaust steam pressure.

Evaporator capacity is sometimes conveniently increased by increased vapour bleeding but invariably there will be a time when the 'tail end' has to be increased because there is no further use for bled vapours and the Vapour I pressure cannot be further increased.

It is the purpose of this paper to discuss a convenient way to obtain a considerable increase in capacity of the 'tail end' without adding to the heating surface of each vessel of the quad.

Consider the following case :-

Vessel No.	H.S. m^2	O.H.T.C. $kW\ m^{-2}\ ^{\circ}C^{-1}$
2	1 000	2,6
3	1 000	2,0
4	1 000	1,4
5	1 000	0,8

If, further, the (saturated) vapour I pressure is 1,4 bar absolute and the vacuum 0,2 bar absolute, then the total temperature drop available (Δ_t) will be :-

$$109 - 60 - 7 = 42^{\circ}C$$

($7^{\circ}C$ allowance is made for the sum of the Boiling Point Elevations in the vessels).

as : $\Delta_t = \Delta_{t_2} + \Delta_{t_3} + \Delta_{t_4} + \Delta_{t_5}$

and $E_2 = E_3 = E_4 = E_5$

it follows that :

$$42 = \frac{E^2}{1,7 \times 2,6} + \frac{E^3}{1,7 \times 2,0} + \frac{E^4}{1,7 \times 1,4} + \frac{E^5}{1,7 \times 0,8}$$

and thus $E_{2.....5} = 25,05\ kg\ m^{-2}\ h^{-1}$

This evaporation rate is identical to 5,1 lbs/sq.ft/h and this would be good quad by South African standards.

The various temperature drops over the vessels would be :-

$$\Delta_{t_1} = \frac{25,05}{1,7 \times 2,6} = 5,7\ ^{\circ}C$$

$$\Delta_{t_2} = \frac{25,05}{1,7 \times 2,0} = 7,4\ ^{\circ}C$$

$$\Delta_{t_3} = \frac{25,05}{1,7 \times 1,4} = 10,5\ ^{\circ}C$$

$$\Delta_{t_4} = \frac{25,05}{1,7 \times 0,8} = 18,4\ ^{\circ}C$$

$$\Delta_t = \quad = \mathbf{42,0\ ^{\circ}C}$$

Extension of Capacity:

It is self explanatory that the capacity of the quad under consideration car be extended by X% by simply adding X% H.S. to each of the vessels. This is a difficult and impractical exercise unless the capacity increase has to be very big, say 100%. In that case one simply builds another evaporator parallel to the old one. However, if an increase of only 15 or 25% is envisaged, and this is more often the case, there is a simple method to increase the capacity of the 'tail end' by the addition of one single vessel only.

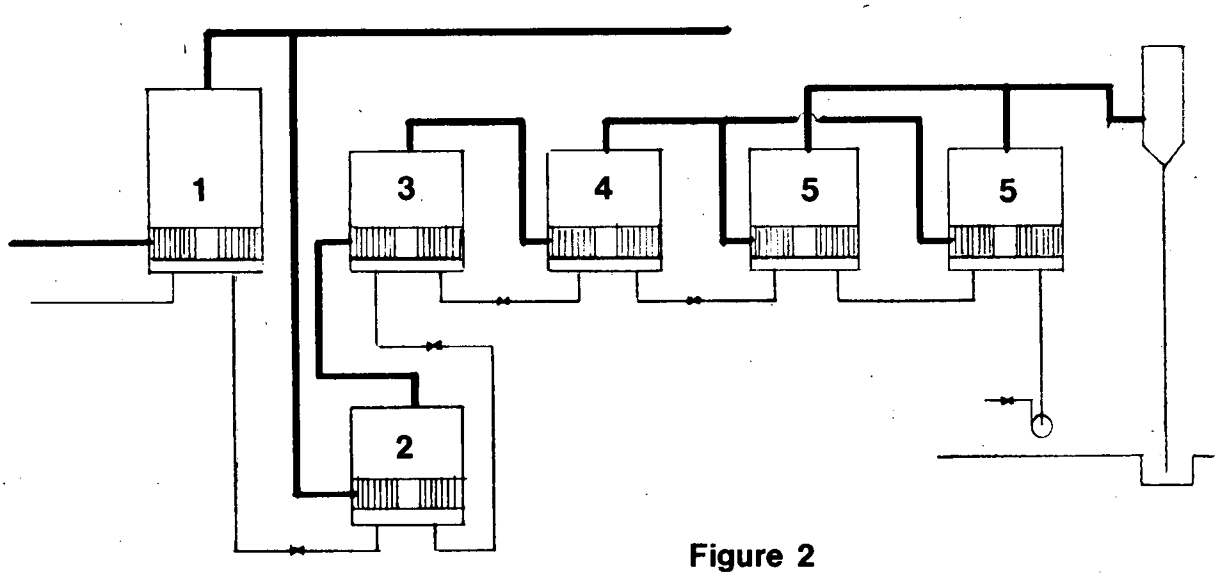

Figure 2

In figure 2, the same evaporator has been extended with a new second vessel of the same size. In addition the vessels 4 and 5 have been combined into a new, large, fifth effect. It will be noticed that the vapour is parallel but that the juice flow is in series. This is done to make use of the fact that the receiving vessel will work under lower brix conditions than the discharging vessel. As the receiving vessel will have an O.H.T.C. of in between 1,4 and 0,8 kW m^{-2} $^{0}C^{-1}$, a decidedly better O.H.T.C. for the combined last vessel should result. This can be estimated to be :

$$\frac{\frac{1,4 + 0,8}{2} + 0,8}{2} = 0,95 \text{ kW m}^{-2}\ {}^{0}\text{C}^{-1}$$

The set-up is now :

Vessel No.	H.S. m^2	O.H.T.C. kW m^{-2} °C^{-1}
2	1 000	2,5
3	1 000	1,9
4	1 000	1,2
5	2 000	0,95

The O.H.T.C. of the vessels 2, 3 and 4 have been slightly reduced, as these vessels will operate a bit colder and therefore under more unfavourable viscosity conditions. (Viscosity increases by approximately 2% per ^{0}C temperature decrease).

If the capacity of the evaporator tail is to be increased by X% then the evaporation rate of the last vessel will become :

$$\frac{100 + X}{100} \times \frac{E_5}{2} \text{ kg m}^{-2}\text{ h}^{-1}$$

and hence :

$$\frac{25,05\ (100 + X)}{200} = 1,7 \times 0,95 \times \Delta t_5'$$

$$\Delta t_5' = 7,76 + 0,0776\ X$$

This in turn will make available

$$42 - (7,76 + 0,0776\ X) = 34,24 - 0,0776\ X\ {}^{0}C$$

for the first 3 vessels.

Then, also :

$$34,24 - 0,0776\ X = \frac{(100 + X)}{(100)} \left\{ \frac{(E_2}{(1,7 \times 2,5} + \frac{E_3}{1,7 \times 1,9} + \frac{E_4)}{1,7 \times 1,2)} \right\}$$

from which follows that

$$X = 24,7\%$$

The evaporation rates and temperature drops for the respective vessels will then become :

Vessel No.	Evaporation Rate kg m^{-2} h^{-1}	Δt °C
2	1,247 x 25,05 =31,24	7,3
3	= 31,24	9,7
4	= 31,24	15,3
5	$\frac{1,247 \times 25,05}{2}$ = 15,62	9,7
	Total	42,0

It will be noted that the largest temperature drop is now no longer over the fifth but over the fourth vessel and it is obvious that the trick can be repeated, albeit not with the same large advantage, by a further addition of one more vessel as a new third effect. In this case the new, combined fourth effect would have 2 000 m^2 heating surface. The next step would then obviously be to install two more vessels to have a total of eight. This would in effect represent a 100% plus increase carried out in gradual stages. As each effect would consist of two vessels in series, the advantage in heat transfer will make the evaporation capacity relatively larger than the addition of the extra heating surface would suggest.