EVAPORATION

Frequently in the food industry a raw material or a potential foodstuff contains more water than is required in the final product. When the foodstuff is a liquid, the easiest method of removing the water, in general, is to apply heat to evaporate it. Evaporation is thus a process that is often used by the food technologist

The basic factors that affect the rate of evaporation are the:

- rate at which heat can be transferred to the liquid,
- quantity of heat required to evaporate each kg of water,
- maximum allowable temperature of the liquid,
- pressure at which the evaporation takes place,
- changes that may occur in the foodstuff during the course of the evaporation process

Considered as a piece of process plant, the evaporator has two principal functions, to exchange heat and to separate the vapour that is formed from the liquid

Important practical considerations in evaporators are the:

-maximum allowable temperature, which may be substantially below 100°C.

- promotion of circulation of the liquid across the heat transfer surfaces, to attain reasonably high heat transfer coefficients and to prevent any local overheating

- viscosity of the fluid which will often increase substantially as the concentration of the dissolved materials increases

- tendency to foam which makes separation of liquid and vapour difficult.

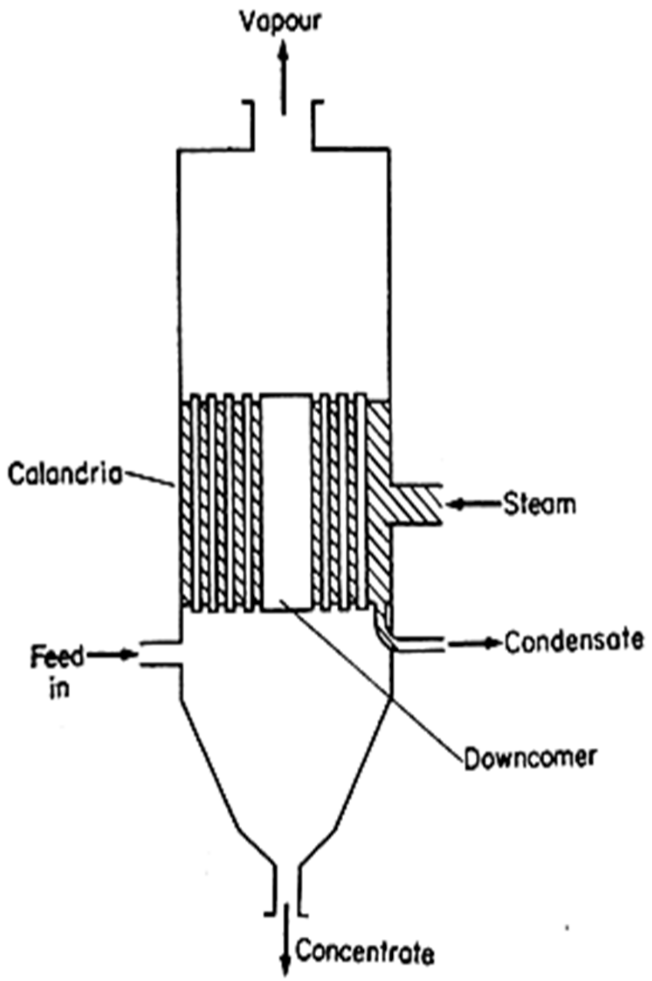
The typical evaporator is made up of three functional sections:

1 - the heat exchanger,
2 - the evaporating section, where the liquid boils and evaporates,
3 - the separator in which the vapour leaves the liquid and passes off to the condenser or to other equipment.

In many evaporators, all three sections are contained in a single vertical cylinder.

In the centre of the cylinder there is a steam heating section, with pipes passing through it in which the evaporating liquors rise.

At the top of the cylinder, there are baffles, which allow the vapors to escape but check liquid droplets that may accompany the vapors from the liquid surface.



In the heat exchanger section, called a calandria in this type of evaporator, steam condenses in the outer jacket and the liquid being evaporated boils on the inside of the tubes and in the space above the upper tube plate.

The resistance to heat flow is imposed by the steam and liquid film coefficients and by the material of the tube walls

Values of overall heat transfer coefficients that have been reported for evaporators are of the order of 1800-5000 $J\ m^{-2}\ s^{-1}\ °C^{-1}$ for the evaporation of distilled water in a vertical-tube evaporator with heat supplied by condensing steam.

However, with dissolved solids in increasing quantities as evaporation proceeds leading to increased viscosity and poorer circulation, heat transfer coefficients in practice may be much lower than this.

As evaporation proceeds, the remaining fluids become more concentrated and because of this the boiling temperatures rise.

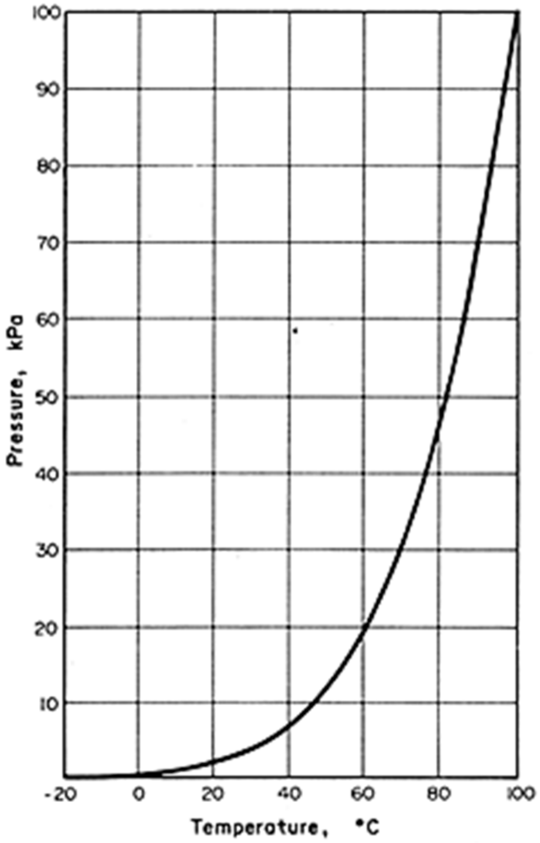
The rise in the temperature of boiling reduces the available temperature drop, assuming no change in the heat source and so the total rate of heat transfer will drop accordingly.

Also, with increasing solute concentration, the viscosity of the liquid will increase, often quite substantially, and this affects circulation and the heat transfer coefficients leading again to lower rates of boiling.

Yet another complication is that measured, overall heat transfer coefficients have been found to vary with the actual temperature drop, so that the design of an evaporator on theoretical grounds is inevitably subject to wide margins of uncertainty.

Vacuum Evaporation

For the evaporation of liquids that are adversely affected by high temperatures, it may be necessary to reduce the temperature of boiling by operating under reduced pressure. The relationship between vapor pressure and boiling temperature, for water, is shown in figure. When the vapor pressure of the liquid reaches the pressure of its surroundings, the liquid boils



When the vapor pressure of the liquid reaches the pressure of its surroundings, the liquid boils

Heat Transfer in Evaporators

Heat transfer in evaporators is governed by the equations for heat transfer to boiling liquids and by the convection and conduction equations. The heat must be provided from a source at a suitable temperature and this is condensing steam in most cases

The steam comes either directly from a boiler or from a previous stage of evaporation in another evaporator.

Major objections to other forms of heating, such as direct firing or electric resistance heaters, arise because of the need to avoid local high temperatures and because of the high costs in the case of electricity.

In some cases the temperatures of condensing steam may be too high for the product and hot water may be used. Low-pressure steam can also be used but the large volumes create design problems.

APPENDIX 8

STEAM TABLE - SATURATED STEAM

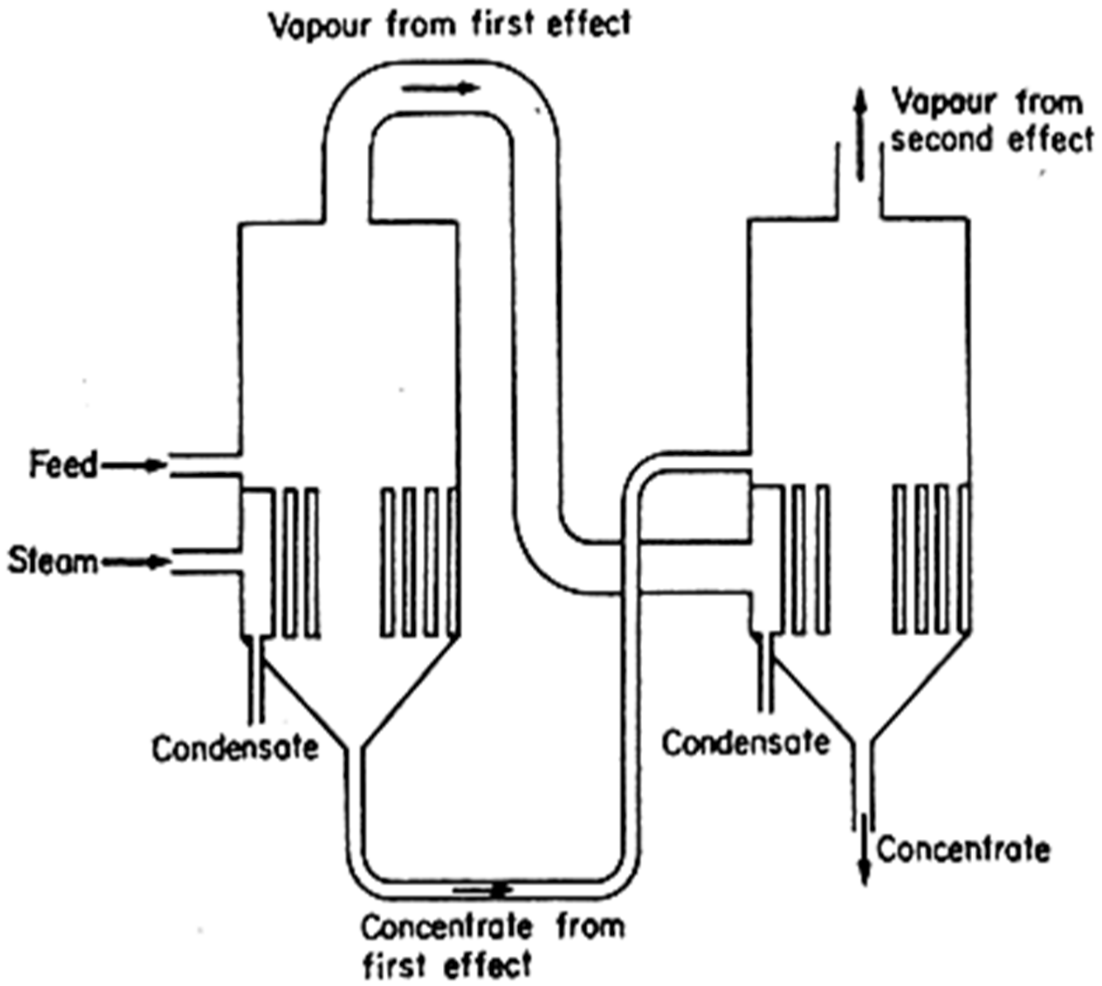
Temperature Table

Temperature (°C)	Pressure (kPa)	Enthalpy (sat. vap.) (kJ kg^{-1})	Latent heat (kJ kg^{-1})	Specific volume (m^3 kg^{-1})
0	0.611	2501	2501	206
1	0.66	2503	2499	193
2	0.71	2505	2497	180
4	0.81	2509	2492	157
6	0.93	2512	2487	138
8	1.07	2516	2483	121
10	1.23	2520	2478	106
12	1.40	2523	2473	93.8
14	1.60	2527	2468	82.8
16	1.82	2531	2464	73.3
18	2.06	2534	2459	65.0
20	2.34	2538	2454	57.8
22	2.65	2542	2449	51.4
24	2.99	2545	2445	45.9
26	3.36	2549	2440	40.0
28	3.78	2553	2435	36.6
30	4.25	2556	2431	32.9
40	7.38	2574	2407	19.5
50	12.3	2592	2383	12.0
60	19.9	2610	2359	7.67
70	31.2	2627	2334	5.04
80	47.4	2644	2309	3.41
90	70.1	2660	2283	2.36
100	101.35	2676	2257	1.673
105	120.8	2684	2244	1.42
110	143.3	2692	2230	1.21
115	169.1	2699	2217	1.04
120	198.5	2706	2203	0.892
125	232.1	2714	2189	0.771
130	270.1	2721	2174	0.669

Pressure Table

7.0	1.0	2514	2485	129
9.7	1.2	2519	2479	109
12.0	1.4	2523	2473	93.9
14.0	1.6	2527	2468	82.8
15.8	1.8	2531	2464	74.0
17.5	2.0	2534	2460	67.0
21.1	2.5	2540	2452	54.3
24.1	3.0	2546	2445	45.7
29.0	4.0	2554	2433	34.8
32.9	5.0	2562	2424	28.2
40.3	7.5	2575	2406	19.2
45.8	10.0	2585	2393	14.7
60.1	20.0	2610	2358	7.65
75.9	40.0	2637	2319	3.99
93.5	80.0	2666	2274	2.09
99.6	100	2676	2258	1.69
102.3	119	2680	2251	1.55
104.8	120	2684	2244	1.43
107.1	130	2687	2238	1.33
109.3	140	2690	2232	1.24
111.4	150	2694	2227	1.16
113.3	160	2696	2221	1.09
115.2	170	2699	2216	1.03
116.9	180	2702	2211	0.978
118.6	190	2704	2207	0.929
120.2	200	2707	2202	0.886
127.4	250	2717	2182	0.719
133.6	300	2725	2164	0.606
138.9	350	2732	2148	0.524
143.6	400	2739	2134	0.463
147.9	450	2744	2121	0.414
151.6	500	2749	2109	0.375
167.8	750	2766	2057	0.256
179.9	1000	2778	2015	0.194

MULTIPLE EFFECT EVAPORATION



An evaporator is essentially a heat exchanger in which a liquid is boiled to give a vapor, so that it is also, simultaneously, a low pressure steam generator.

It may be possible to make use of this, to treat an evaporator as a low pressure boiler, and to make use of the steam thus produced for further heating in another following evaporator called another effect

Figure Double effect evaporator – forward feed

Consider two evaporators connected so that the vapor line from one is connected to the steam chest of the other as shown in Figure, making up a two effect evaporator.

If liquid is to be evaporated in each effect, and if the boiling point of this liquid is unaffected by the solute concentration, then writing a heat balance for the first evaporator:

$$q_1 = U_1A_1(T_s - T_1) = U_1A_1\,\Delta T_1$$

where q_1 is the rate of heat transfer, U_1 is the overall heat transfer coefficient in evaporator 1, A_1 is the heat-transfer area in evaporator 1, T_s is the temperature of condensing steam from the boiler, T_1 is the boiling temperature of the liquid in evaporator 1 and ΔT_1 is the temperature difference in evaporator 1, = $(T_s - T_1)$.

Similarly, in the second evaporator, remembering that the "steam" in the second is the vapor from the first evaporator and that this will condense at approximately the same temperature as it boiled, since pressure changes are small,

$$q_2 = U_2A_2(T_1 - T_2) = U_2A_2\,\Delta T_2$$

in which the subscripts 2 indicate the conditions in the second evaporator.

If the evaporators are working in balance, then all of the vapors from the first effect are condensing and in their turn evaporating vapors in the second effect. Also assuming that heat losses can be neglected, there is no appreciable boiling-point elevation of the more concentrated solution, and the feed is supplied at its boiling point

$$q_1 = q_2$$

Further, if the evaporators are so constructed that $A_1 = A_2$, the foregoing equations can be combined.

$$U_2/U_1 = \Delta T_1/\Delta T_2.$$

Equation states that the temperature differences are inversely proportional to the overall heat transfer coefficients in the two effects. This analysis may be extended to any number of effects operated in series, in the same way.