Film evaporator

Introduction

The main advantages of film evaporators over batch-type evaporators are:

a) Short residence time (little fluid volume) in the apparatus
b) Intensive heat transfer due to the temperature profile and resultant concentration profile along the tube.

Therefore film evaporators are used in the treatment of heat sensitive materials, namely foods, bio-active agents. A vacuum is often used in order to lower the boiling temperature in the evaporation process.
There are several types of film evaporators:

a) long tube evaporators, in which the liquid film falls or climbs,
b) centrifugal evaporators, in which the film is formed by a rotating heated surface,
c) wiped film evaporators, consisting of a jacketed, straight, or tapered tube incorporating fixed or floated blades.

Evaporators having moving parts are fairly expensive, but the control of the film formation is exact, the intensity if heat transfer is higher. The wiped film evaporator widens the field of applications to include highly viscous fluids or even crystallization.

The aim of this exercise:

a) acquaintance with a pilot evaporator,
b) operation of the evaporator in steady state conditions,
c) estimation of capacity under given experimental conditions,
d) determination of the overall heat transfer coefficient,
e) calculation of the steam and solution side heat transfer coefficients, and their dependence on the temperature driving force.

Since only the solvent is evaporated in an evaporator then there is no need to use a real solution (sugar, salt). Feeding distilled water at the limiting capacity makes the coefficients measureable and the exercise easier.

Equipment

The evaporator is a wiped-type film evaporator with floating Teflon blades in a stainless steel tube (Fig. 1, 2). Four baffles are inserted and separate the steam condensate from the heating surface. Continuous removal of the steam condensate lowers the steam side resistance to heat transfer.

Two manometers are situated in the steam pipe enabling the measurement of the steam pressure P_G, and the determination of steam temperature (ϑ). The feed stream is regulated from a 200 litre tank, monitored by a rotameter, and preheated by a shell-and-tube type heat exchanger. It is important that the inlet temperature (t_0) is maintained as close to the boiling point as possible, thus providing the evaporator with a feed stream at its boiling point. The concentrate (thick liquor) flows to a receiver which is incorporated with a cooling coil. Vapour leaves the evaporator to a cross-flow condenser. One can measure the vapour rate by cubage since the tank content is indicated by an air level-meter.

Experimental measurements

The apparatus is complicated, and it is essential that the student takes some time to get acquainted with it. One has to look her/himself at all the devices, stream flow routes, and valve positions. Prior to the plant start up, it is essential that the valves of receivers are fully closed, and the tap under the glass tube for condensate measurement is fully opened. The liquid level in the tanks must be checked, and if it is necessary filled under vacuum with distilled water.
Open cooling water of the wiper bearing (upstairs) and of the condenser (downstairs). Start feeding, switch the apparatus on, start heating the evaporator, and finally start preheating.

Advisable experimental values for the inlet parameters:

a) feed rate: S_0 = 16-20 L/h
b) preheater steam pressure: 0.2 – 0.4 bar, in order to obtain a minimum inlet temperature (t_0) of 95 °C. (Boiling must not be allowed to occur, and this may be checked by visual inspection of the sight glass window.)
c) evaporator steam pressure: high setting: 0.8 – 1.0 bar
   low setting: 0.4 – 0.6 bar

Steady state conditions can only be obtained if all the inlet parameters are maintained at a constant value. After about half an hour the outlet parameters (temperatures, vapour rate) become constant. The vapour rate is measured when the temperature of cooling water effluent (t_h) is constant. If the deviations of parallel determinations are ~~not~~ more than 5%, change steam pressure and wait for the next steady state.

Record your experimental date in the following table.

Barometric pressure (p_b): mbar;
Steam pressure (P_G): bar gauge;
Feed rate: L/h; Scale of rotameter:

Time	Steam pressure, bar gauge		Temperature, °C					Distillate		
	P_G preheater	P_G	t_0 feed	t_1 conc.	$t_{h,in}$ vapor	$t_{h,out}$ cooler	ϑ_K condenser	quant. cm^3	time s	$\dot{V}$, cm^3/s

Mean:

Calculations

1) The performance of the evaporator is expressed in terms of the rate of heat transfer. The enthalpy balance for the system is given by:

$$G \cdot i_G + S_0 \cdot i_0 = G \cdot i_K + S_1 \cdot i_1 + V \cdot i_V + q_1$$

where

G	steam rate (kg/s)
S_0	solution feed rate (kg/s)
S_1	rate of concentrate (kg/s)
V	vapour rate (kg/s)
q_1	heat loss (kW)
i	enthalpy (kJ/kg) of the corresponding stream

Since $S_0 = S_1 + V$, then the heat balance is given by:

$$q_{total} = G \cdot r_G = S_0 (i_1 - i_0) + V \cdot r_V + q_1 = q_{trans} + q_1$$

where

$r_G = (i_G - i_K)$	heat of vaporisation of water at steam pressure measured accurately by a manometer
r_V	heat of vaporisation of water at operating temperature
$i_1 - i_0$	heat required to bring feed stream to the boiling point. Because of inaccuracy or bad installation it is not the same as indicated neither the concentrate (t_1) nor the vapour (t_p) temperature.

Since the feed temperature must be near to the boiling point, the performance of evaporator expressed as transferred heat rate is reduced to:

$$q_{trans} \cong V \cdot r_V$$

2) Overall heat transfer coefficient:

$$K = \frac{q_{trans}}{F(\vartheta - t)_{mean}} \qquad (\mathrm{W/m^2K})$$

where

F	heating surface: 0.15 m^2
$\vartheta - t$	driving force for heat transfer (temperature difference between the two phases). Generally it varies from point to point, so it must be averaged. Since we use distilled water feed near boiling, both the temperatures can be considered constant along the tube length.

3) Steam side heat transfer coefficient

$$\alpha_G = 1{,}88 \lambda \left(Re_L \frac{\eta^2}{\rho^2 g} \right)^{-1/3}$$

where

λ heat conductivity coefficient (W/mK)
η dynamic viscosity (kg/(ms))
ρ density (kg/m^3)
g acceleration du to gravity: 9.81 m/s^2

$$Re_\mathrm{L} = \frac{4\dot{Q}}{5 r_G \mathrm{D} \pi \eta} \qquad \text{Reynolds number}$$

D outer diameter of the heating surface: 0.09 m

All the physical parameters relate to the steam condensate film are taken as water at a temperature of condensation (ϑ_{P_G}).

4) Solution side heat transfer coefficient
Assuming the heating surface is a plane wall, then:

$$\alpha_S = \frac{1}{\dfrac{1}{K} - \left(\dfrac{1}{\alpha_G} + \dfrac{e}{\lambda_{steel}} \right)}$$

where

e thickness of the wall: $5 \cdot 10^{-3}$ m
λ_{steel} thermal conductivity of the wall: 14.5 W/mK

5) Finally summarize your results in the following table:

Steam	Capacity	Heat resistances of							
Pressure P_G	V	Overall, $1/K$		Steam, $1/\alpha_g$		Wall, e/λ		Solution, $1/\alpha_S$	
bar	kg/h	$\frac{\mathrm{m^2K}}{\mathrm{kW}}$	%	$\frac{\mathrm{m^2K}}{\mathrm{kW}}$	%	$\frac{\mathrm{m^2K}}{\mathrm{kW}}$	%	$\frac{\mathrm{m^2K}}{\mathrm{kW}}$	%
			100						
			100						

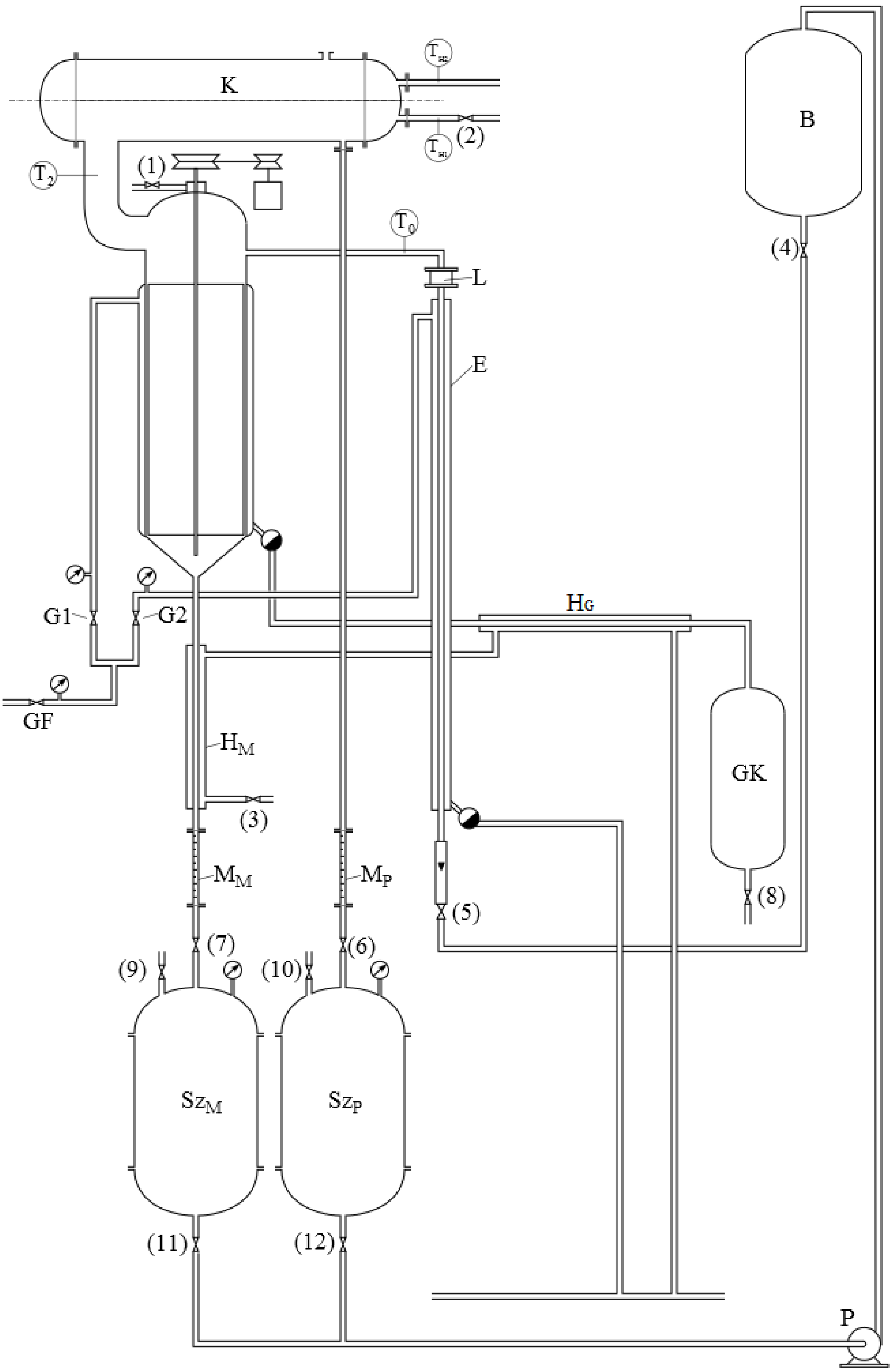

Fig. 1. Flow sheet of the film evaporator

Notations on Fig. 1.

(1)-(12) valves
GF main valve of steam

G1	steam heating of the evaporator
G2	steam heating of the preheater
B	storage tank of feed
E	preheater
L	observation pathway
H_M	cooler of residue
M_M	calibrated glass
H_G	cooler of steam condensate
GK	collection of steam condensate
K	condenser
M_P	calibrated glass
SZ_M	residue
SZ_P	condensed vapor
P	pump

T_0	temperature of feed
T_2	temperature of vapor
T_{H1}	temperature of cooling water inlet
T_{H2}	temperature of cooling water outlet