RISING FILM EVAPORATOR

Introduction

In rising film evaporators the product is introduced into the evaporator from the bottom. As the product enters the bottom of the heating tubes, it begins to boil, creating vapor. The pressure of the vapor causes the product to start rising as a thin film, pressing it against the heating tubes. As the product rises at boiling point, more evaporation takes place. The product may be recycled in order to achieve the desired concentration.

The highly turbulent flow of the rising product is beneficial in the evaporation of highly viscous products or products that have a fouling tendency.

In order for the vapor flow to have enough energy to start rising the product, the temperature difference between the heating side and the boiling needs to be high. Otherwise the rising film is not created.

The Rising Film Evaporator in our laboratory is a floor standing unit of hygienic design suitable for practical training in the operation of large modern evaporator equipment in industry. It is also ideal for project work, particularly the study of evaporation performance under differing operating conditions and also to provide concentrated product for down-stream drying processes.

PROCESS CAPABILITIES

The equipment is designed to allow studies of:

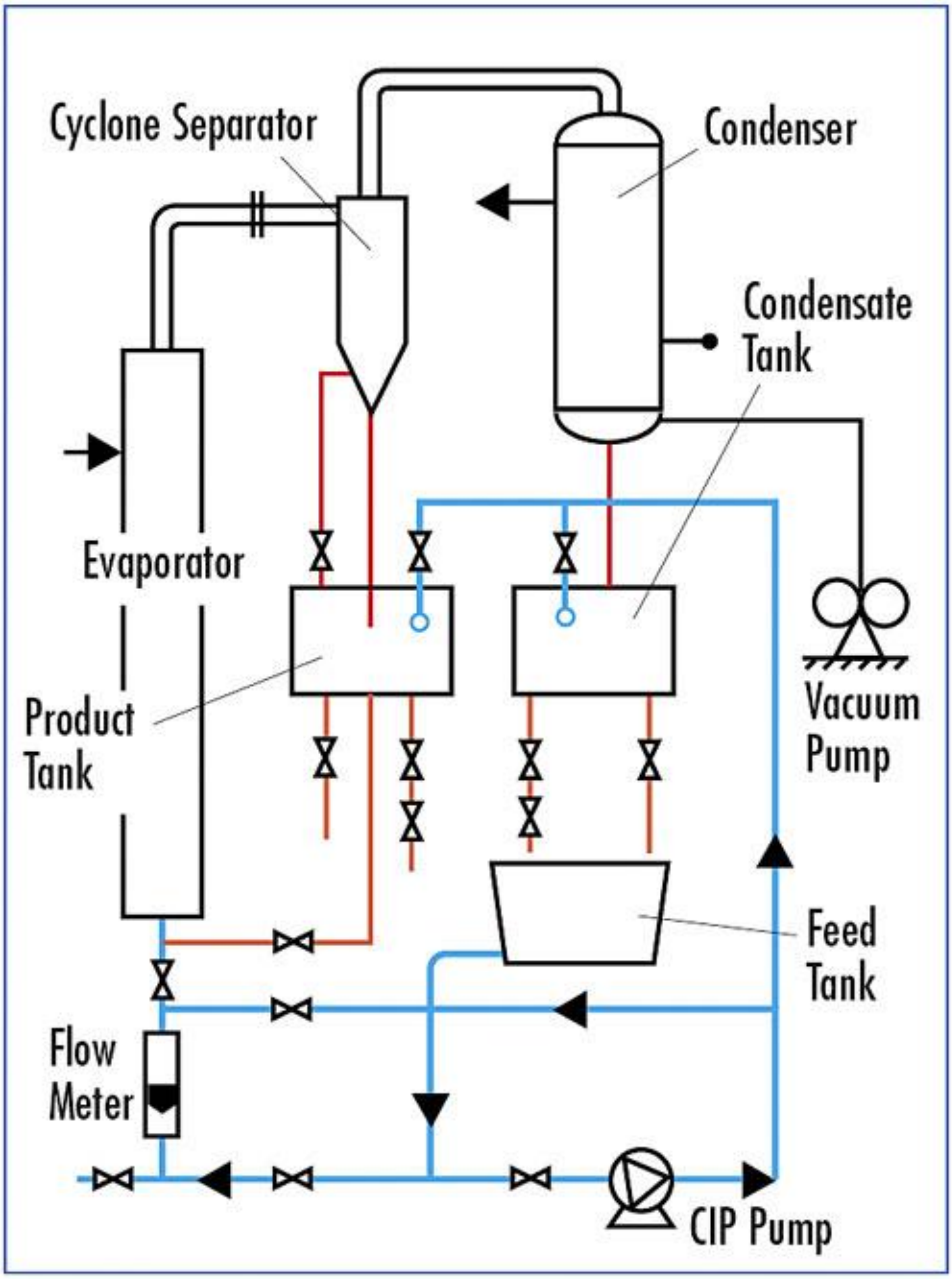
➢ Operation of a continuous rising film evaporation plant using a variety of liquid foods

➢ Investigation of effect of varying process parameters such as: vacuum, flow rate, temperature, recycle rate

➢ Production of concentrated liquid food products

➢ Heat transfer measurements and calculations

➢ Importance of ‘clean-in-place’ procedures



Schematic diagram of the FT22

Fig. 1 Schematic diagram of the rising-film evaporator
(Further detailed explanation related with the evaporator unit is given on pages 11-12)

DESCRIPTION

The evaporator is essentially a vertical single tube in shell arrangement in which the product to be evaporated is on the tube side and the heating medium, steam, on the shell side.
The process liquid feed is by gravity from a stainless steel feed tank through a flow meter and manually operated control valve. Vapor, produced by boiling in the tube, rises and carries a `film´ of more concentrated liquid up the tube and into a cyclone separator where the vapor and liquid are separated.
The vapor enters a water-cooled condenser where it condenses and flows out into a condensate collecting tank. The liquid concentrate can be recycled back through the evaporator tube or collected as product in the product collecting tank.
The evaporator ducting, cyclone and condenser, are all constructed from stainless steel, and a glass 'elbow' at the top of the evaporator allows the vapor/liquid film mechanism to be seen before entering the cyclone.
Both concentrate and condensate collecting tanks are borosilicate glass to allow the condition and quantity of products to be observed.
A clean-in-place pump is included which allows efficient cleaning by re-circulation of the system and also utilizes the industrial spray nozzle technique to clean the glass collecting tanks.
Vacuum can be applied to the system by a diaphragm type vacuum pump, giving suitable reduced boiling temperatures for the evaporation of milk and other heat sensitive food products.
All important temperatures in the system are detected by sensors which are connected to a digital read-out display with selector switch. The temperatures can also be monitored on any appropriate instrumentation such as a chart recorder or computer data logger, using analogue output ports on the control panel. These give a voltage output of 0-1V dc.

EXPERIMENTAL

A. VARIATION OF EVAPORATION RATE WITH STEAM PRESSURE AT CONSTANT VACUUM

Object of experiment: to investigate the variation of the rate of evaporation with steam pressure and calculate the overall heat transfer coefficient U as a function of temperature difference ΔT.

Procedure:
Fill the feed vessel with the solution to be concentrated, and follow the preliminary and start up procedure with a feed rate of 10 L/h. 0.2L/min. Then carry out a series of experiments at different steam pressures holding the system (vacuum) pressure constant.

Summary of theory:

The rate of evaporation of water, m, from the solution is given by:

$$m = \frac{Q}{h_{fg}} \qquad (1)$$

Where, m = rate of evaporation (=rate of condensation) in kg/h

Q = rate of heat transfer in kj/h

h_{fg} = latent heat of evaporation of water at system(vacuum) pressure in kj/kg

The rate of heat transfer Q is given by:

$$Q = UA\Delta T \qquad (2)$$

Where, U= overall heat transfer coefficient between boiling solution under vacuum and the heat-supplying steam in the jacket, in kj/m^2.h.^{o}C

A= the surface area for heat transfer, m^2

$\Delta T=(T_S-T_V)$=the temperature difference between the heat-supplying steam in the jacket and the temperature of boiling solution under vacuum, in ^{o}C

Substituting (2) in to (1) we have:

$$m = \frac{UA\Delta T}{h_{fg}} \qquad (3)$$

Since in this experiment A, and h_{fg} are constant, (3) can be written as:

$$m = \beta U \Delta T \text{ where } \beta = A/h_{fg} \qquad (4)$$

On the other hand the overall heat transfer coefficient U is not constant, and is found to vary with temperature as follows:

$$U = \alpha(\Delta T)^n \qquad (5)$$

Where α and n are constants. The purpose of the calculation is to determine the constants $\boldsymbol{\alpha}$ and $\boldsymbol{n}$ Substituting (5) into (4) we finally find the required expression:

$$m = \beta\alpha(\Delta T)^n \Delta T = \gamma(\Delta T)^{n+1} \qquad (6)$$

Where

$$\gamma = \beta\alpha = \alpha A/h_{fg} \qquad (7)$$

From (Eq.6), *since* $m = \gamma(\Delta T)^{n+1}$ the rate of evaporation m, can be increased by increasing the temp. diff. $\Delta T=(T_S-T_V)$ by increasing T_S and holding T_V constant. In this experiment this is done by increasing the steam pressure P_S and hence the steam temperature T_S

Readings to be taken

Allow the evaporator to reach steady-state operation, and read the feed flow rate F_1, the boiling point $T_6=T_V$, the steam pressure P_S, and the condensate tank level for each steam pressure reading P_S, together with other temperatures (T_1 *through* T_7) and fill in the data sheet supplied by the instructor. The total mass (M_F) and °Brix (C_F) of the feed and those of the product (M_P) and °Brix (C_P) will also be recorded at the beginning and at the end of experiment.

Results and calculations

For each experiment:

1. Find the steam temp. T_S corresponding to the steam pressure P_S from the steam tables.
2. Calculate the average boiling point T_V. This can be done as follows:
   a) Read the gauge pressure in the vacuum gauge
   b) Obtain the barometric (atmospheric) pressure in Gaziantep.
   c) Find the absolute pressure for the boiling liquid in the evaporator: $P_{abs}=P_{atm}-P_{gauge}$
   d) Find the average boiling point, T_V, corresponding to P_{abs} from the steam tables
3. Calculate the temp diff. $\Delta T=T_S-T_V$
4. Assuming that 1 mm reading on the condensate tank corresponds to 18 mL volume of water and reading the density of water at that temperature (T_V) calculate the mass of collected condensate.
5. Divide the mass of condensate by the time of collection to find the rate of condensation *m*.

Take the logarithm of (6):

$$\log(m)=\log\gamma+(n+1)\log(\Delta T) \qquad (8)$$

6. Plot log(m) against log(ΔT). This plot should have two different slopes $m_1=(n_1+1)$ at **low values** of ΔT and $m_2=(n_2+1)$ at **high values** of ΔT. The intercept will be equal to logγ, from which γ can be calculated.

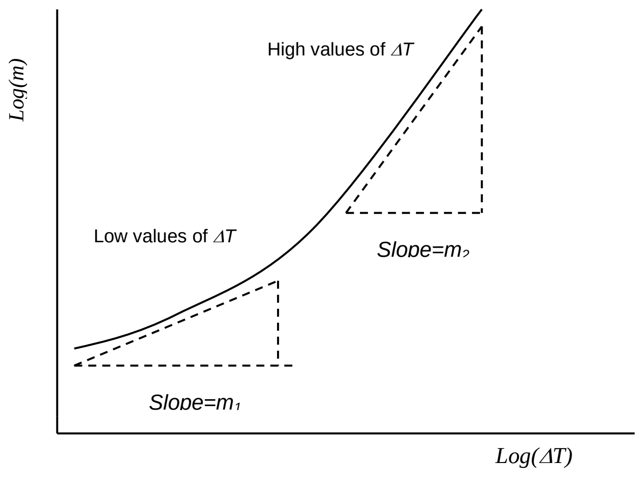


Fig. 2 *log(m) vs. log((ΔT)* for determination of dependence of *U* on *ΔT*

7. You will determine two sets of α and *n* for the first and second slopes and two *U's;* that is $U_1 = \alpha_1(\Delta T)^{n1}$ and $U_2 = \alpha_2(\Delta T)^{n2}$

8. Finally you will determine the percent loss of fruit juice, based on the total soluble solids (TSS) from the mass and concentration (brix) data.

B. VARIATION OF EVAPORATION RATE WITH SYSTEM(VACUUM) PRESSURE

The procedure to be followed is exactly the same as in the first part(experiment A) except that, in this case the steam pressure P_S and hence T_S will be maintained constant while varying the system(vacuum) pressure P_V and hence the system temp. T_V will be varied.

TECHNICAL DETAILS

Evaporator tube length: 1.36 m
Heat transfer area: 0.064 m^2
Max. evaporation rate: 10 L/hr
Max. steam consumption: 15 kg/hr
Max. steam pressure(working): 1.7 bar (gauge)
Condenser area: 0.17 m^2
Feed tank capacity: 30 liters
Concentrate collecting tank capacity: 5 liters
Condensate collecting tank capacity: 5 liters
CIP Pump (flexible impeller): 8 L/min @ 20ft H_2O
Max. Vacuum: 200mm Hg abs
(or less if pump heads connected in series)
Cyclone separator-Evaporator-Condenser-Vacuum pump-Condensate tank-Product tank- Feed tank-Flow meter-CIP pump
Flow diagram - Rising Film Evaporator

SPECIFICATIONS

● A floor standing, rising film evaporator of hygienic construction using stainless steel and borosilicate glass.

● Product throughput is approximately 10L/hr using a single evaporator tube, 1.36m long giving a total heat transfer area of 0.08m2.

● Heating is provided by steam to the jacket of the evaporator tube at pressures up to 1.7bar.

● The liquid-vapor mixture exits the top of the evaporator tube through a glass elbow before passing to the 85mm diameter cyclone where separation of the two phases occurs.

● Vapors enter a vertical shell and tube condenser and condensate collects in a 5-liter glass collecting vessel. The liquid phase is collected in a separate 5-liter glass vessel.

● The process may be run at pressures down to 200mm Hg and below using a diaphragm-type vacuum pump (supplied).

● Clean-in-place is facilitated by a hygienic centrifugal pump, the collection vessels being cleaned by multi-directional spray nozzles.

● The evaporator is gravity fed from a 30-liter stainless steel feed vessel via a variable area flow meter.

● Temperature sensors allow digital display of six relevant temperatures which can also be monitored on any appropriate instrumentation such as a chart recorder or computer data logger using analogue output ports on the control panel (Voltage range 0-1V d.c.).

● User instruction manual provides installation, commissioning and maintenance details together with suggested project exercises

● Exercises include:

➢ Investigation of the rate of evaporation with steam pressure.

➢ Investigation of the rate of evaporation with system pressure.

SERVICES REQUIRED

Electrical supply:

FT22-A: 220-240V/1ph/50Hz

FT22-B: 120V/1ph/60Hz

Water supply: Cooling water at up to

10 litres/min from a mains cold water supply

Steam supply: 25kg/hr at 2 bar

OVERALL DIMENSIONS

Height: 2.6m

Width: 0.78m

Depth: 0.65m