Thermal Analysis on Triple Effect Falling Film Evaporator

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Abstract— Evaporation is an operation used to remove a liquid from a solution, suspension, or emulsion by boiling off some of the liquid. It is thus a thermal separation, or thermal concentration process. When a single effect evaporator is used to produce a concentrated liquid or crystal the vapour generated is a by-product with a latent heat content that goes to waste. Multiple effect arrangements are designed to utilize this waste heat and reduce steam consumption and heating power. This is done by using the vapour generated in the first stage as the heat source in the second stage and heat source in third stage. In this paper varying the input pressures at inlet from 24 bar to 16 bar mass flow rate of distilled water at three different stages are estimated using mass balance and energy balance equations. Steam generation rates of triple effect forward feed evaporator at different stages are compared with single effect evaporator. Graphs are drawn to predict the variation of enthalpies, heat for evaporation mass flow rate of distilled water for a triple effect forward feed evaporator.

Key words: Pressure, Rate of Evaporation, Mass Flow Rate, Dryness Fraction, Steam Generation Ratio

I. INTRODUCTION

Evaporation is the removal of solvent as vapour from a solution, slurry or suspension of solid in a liquid. The most common solvent in most of the evaporation systems is water. Multiple effect evaporator are designed to utilize this waste heat and reduce steam consumption and heating power. This is done by using the vapour generated in the first stage as the heat source in the second stage and so on. Each successive stage has to operate at a lower pressure than the preceding one in order to achieve the required vapour flow.

A. *Selection of the Type of Evaporator:*

In selecting the type of evaporator for a particular application, the designer will be influenced by the properties of the product required, the source of heat and the space available. Applications fall under the four headings listed below

- Vapor generation from a pure liquid e.g.. the vaporization of liquefied gas
- Vapor generation from an impure liquid e.g.. desalination
- Evaporation as a means of concentrating a solution
- Evaporation as a means of crystallizing a solution

B. *Types of Evaporator:*

1) Falling film evaporator
2) Rising film evaporator
3) Forced circulation evaporator
4) Plate evaporator.

1) Falling film evaporator:

In this paper falling film evaporator is taken and it consists of head, calandria, calandria lower part and separator as shown in the fig.1. The essential feature of the falling film evaporator is calandria which comprises a bundle of tubes. The tubes in these type of evaporators are 20 about 25 to 80 mm in diameter. The liquid enter from the head to the heating tubes where it is distributed in a way as to flow down the inside of the tube walls as a thin film. The heating steam is used a source to heat the feed liquid entered from the top of the evaporator to tubes. In the heating chamber where heat distribution takes between the heating steam and feed liquid where vaporization takes place due to external heating of the tubes. The evaporated vapour flows downwards parallel to liquid flow. In falling film evaporators due to gravity the liquid forms a continuous liquid film. The condensed water is taken out from the out let where as in separating chamber the liquid product is separated and remaining steam can be used a secondary heating source for another evaporator.

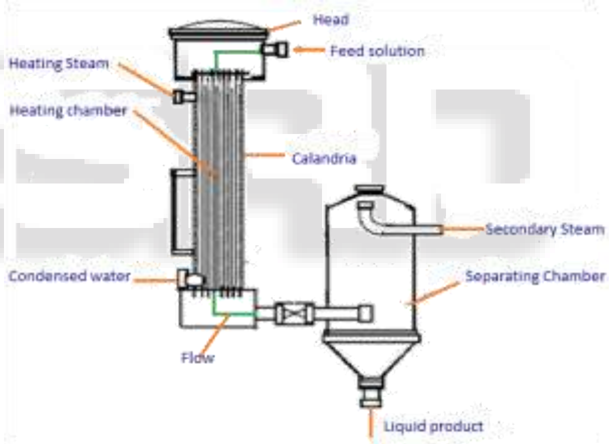

Fig. 1: Falling Film Evaporator

II. LITERATURE REVIEW

With the ever increasing demand for fresh water in many industries, multi effect evaporation processes is most widely used and are considered as reliable sources for the production of fresh water from the feed water. The development of multiple effect evaporator started by Izumi [1] for making fresh water from sea water, comprising a multistage flash evaporator serving the purpose of sea water preheating, in which multistage flash evaporator is combined with a multistage fresh water flash evaporator so that pure water can also be made, and the evaporation, condensation area is distributed according to the amount of vapour generated at each evaporation stage to enhance the thermal efficiency and further, the evaporator effects and multistage flash evaporator are arranged in a single casing to eliminate a certain piping and thereby to simplify the construction of the evaporator. Nishitani and Kunugita [2] studied a TEE (Triple effect evaporator) system, with forward, backward and mixed sequences for concentrating milk.

Darwish and Dessousky [3] studied technical factors affecting the choice of distillation system for desalting water. In particular, the thermal vapour-compression process is compared with the predominant multi-stage flash (MSF) desalting system. Nafey et al. [4] made comparisons for Multi Effect Evaporation (MEE) as well as hybrid Multi Effect Evaporation and Multi Stage Flash (MEE-MSF) systems have been performed using the exergy and thermo economics analysis. This is performed based on the same platform and working under the same operating conditions. Thermo economics analysis is applied to account for both energy and cost simultaneously. Karimi and Jahanmiri [5] in paper proposed a nonlinear modeling and cascade control design for multi effect falling film evaporators. They designed a cascade algorithm to control the product concentration in a milk powder in the three effect falling film evaporator. Chandak et al. [6] designed and experimented with multistage evaporation system for production of distilled water. Two Scheffler concentrators of 16 Sq m each were used for generating steam in the first stage at 8 bar pressure and the pressure is gradually brought down to 1 bar, in four stage distillation unit. Total yield obtained in the project was 2.3 times that of single stage distillation. Khanam and Mohanty [7] proposed linear model for septuplet effect evaporator system based on principles of process integration. They incorporated many complexities of MEE system such as different feed flow sequences, steam splitting, feed, product and condensate flashing, vapour bleeding, etc. Shah and Bhagchandani [8] describes a steady state model of multiple effect evaporators for simulation purpose. The model includes overall as well as component mass balance equations, energy balance equations and heat transfer rate equations for area calculation for all the effects. Sen et al. [9] developed small scaled multi effect distillation units for application in rural areas. They described a micro scale MED specifically for a low heat source where amount of steam generated is low as with small solar energy collectors.

The present work is related to the development of model for the performance of Triple effect falling film evaporator system requiring comparison of its results with single effect evaporator which is using flashing technique

III. DESCRIPTION OF TRIPLE EFFECT FALLING FILM EVAPORATOR

Multi-effect evaporation uses the steam produced from evaporation in one effect to provide the heat to evaporate product in a second effect which is maintained at a lower pressure. Multiple effect evaporator having a multistage flash evaporator and adapted for making fresh water from feed water, and more particularly to a single casing multiple effect evaporator. Multiple effect evaporators generally have several evaporator effects which are arranged serially according to the operating temperature. e.g, feed water, passing in the evaporator effects is heated by heating means. The feed water is passed from a first evaporator effect heated at a high temperature sequentially to the successive evaporator effects maintained at progressively lowered temperatures and the vapour generated at a preceding higher temperature evaporator effect is used as a heating source for the following evaporator effect and cooled per sec. The multiple effect evaporators usually have vertical tube type heat exchanging means, and the feed water flows down in the tubes in the form of a film and is heated during the flow-down by the heated vapour exterior of the tube. The feed water is partially evaporated in this case and led into a vapour-liquid separating chamber together with the vapour thus generated. The hot vapour is condensed and collected as fresh water.

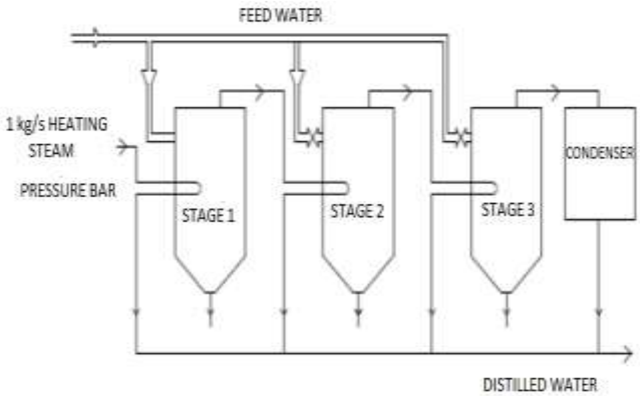

Fig. 2 Triple Effect Evaporator

IV. ANALYSIS

Triple effect forward feed evaporator considered which is used for production of distilled water. The feed flow sequence is parallel, that is the liquid feed and product removal are arranged in parallel as shown in figure Fig.2. Alternatively each effect may have its own separate feed and concentrate removal line. The operating pressures for the three stages are later to give approximately equal values of the temperature difference between the condensing steam and the evaporating water.

The following equations are taken for a triple feed evaporator

A. Stage 1:

1) The rate of heat for evaporation:

$Q_1 = m \times H_{LG}$ ...(1)

where,

Q = heat for evaporation J/s.

m = mass flow rate of steam kg/s.

H_{LG} = latent heat of steam J/kg.

2) Heat balance equation:

$Q_1 + M_{F1}H_{L1} = 0.9\ M_{F1}\ H_{G1} + 0.9\ M_{F1}\ H_{L1}$ ... (2)

where,

M_{F1} = Mass flow rate of steam kg/s.

H_{G1} = Enthalpy of steam J/kg

H_{L1} = Enthalpy of water J/kg.

B. Stage 2:

1) The rate of heat for evaporation:

$Q_2 = m \times H_{L1G1}$ ...(3)

where,

Q_2 = heat for evaporation J/s.

m = mass flow rate of steam kg/s.

$H_{L1G\ 1}$ = latent heat of steam J/kg.

2) Heat balance equation:

$Q_2 + M_{F2}H_{L1} = 0.9\ M_{F2}\ H_{G2} + 0.9\ M_{F2}\ H_{L2}$ ... (4)

where,

M_{F2} = Mass flow rate of steam kg/s.

H_{G2}= Enthalpy of steam J/kg
H_{L2}= Enthalpy of water J/kg.

C. Stage 3:

1) The rate of heat for evaporation:

$Q_3 = m \times H_{L2G2}$ ...(5)

where,
Q_3 = heat for evaporation J/s.
m = mass flow rate of steam kg/s.
H_{L2G2}= latent heat of steam J/kg.

2) Heat balance equation:

$Q_3 + M_{F3}H_{L1} = 0.9\ M_{F3}\ H_{G3} + 0.1\ M_{F3}\ H_{L3}$ ...(6)

where,
M_{F3} = Mass flow rate of steam kg/s.
H_{G3}= Enthalpy of steam J/kg
H_{L3}= Enthalpy of water J/kg.

The total amount of distilled water produced is sum of stage1 +stage2 +stage3+ Condenser.

The following equations are taken for single effect evaporator.

3) Dryness fraction:

$X = (H_{L1} - H_{L3})/H_{LG3}$.

Where,
H_{L1} = Enthalpy of liquid kg/s.
H_{L3} = Enthalpy of water J/kg.
H_{LG3} = Latent heat of steam J/kg.

4) Steam generation ratio:

It is the ratio of total amount of distilled water produced with the sum of heating steam flow rate and potential rate of steam generation by feed flashing.

V. RESULTS AND DISCUSSIONS

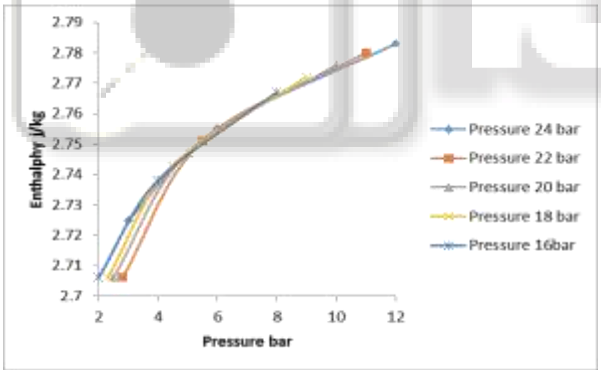

Fig. 5.1 Variation of Enthalpy for Different Input Pressures

The graph fig. 5.1 drawn between enthalpy vs. pressure shows an increase in enthalpy with increase in pressure. It was found that the enthalpy remains almost equal at higher pressures that is at stage 1and stage 2 but it has a small effect at lower pressures corresponding to stage 3.

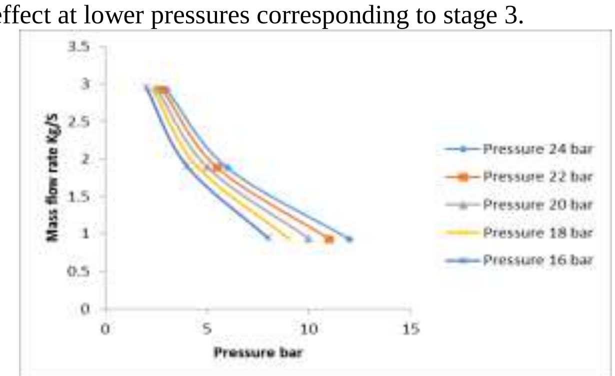

Fig.5.2 Effect of Mass Flow Rate on Inlet Pressure

The graph presented above fig.5.2 shows the variation of mass flow rate in a triple effect evaporator, As the pressure decreases to 16 bar at stage 1 the mass flow rate of distilled water gets increased. It was also observed that as the pressure decreases there is a steep increase in mass flow rate of distilled water.

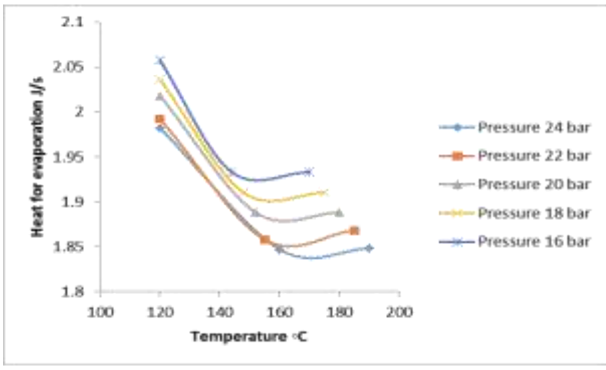

Fig.5.3 Variation of Heat for Evaporation at Different Temperatures.

The graph presented above fig 5.3 shows the rate of evaporation increases at lower temperature corresponding to the input pressure. It was seen from the above graph that at different saturation temperature at different stages the latent heat of vaporization that is heat for evaporation is decreasing at higher temperatures. However, at different saturation temperature the heat for evaporation curves follow the same trend decreasing with increasing in saturation temperature.

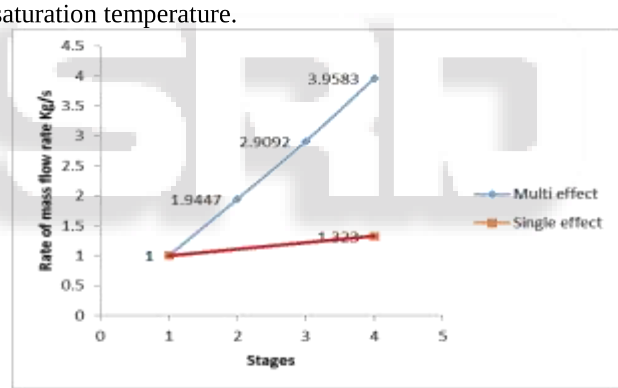

Fig.5.4 Comparison of Mass flow rates for Triple Effect Evaporator with Single Effect Evaporator for an Input Pressure of 20 bar.

The above graph fig 5.4 presented for mass flow rate at different stages of multi effect evaporator and single stage evaporator. It is we observed from the graph that higher mass flow rate is obtained for multi effect evaporator when compared to single stage evaporator.

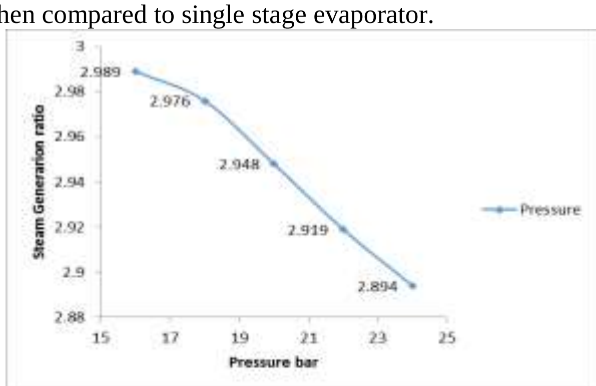

Fig: 5.5 Steam Generation rate for Different Input Pressures in Multi Effect Evaporator

As per the fig.5.5 the graph is plotted between steam generation rate and pressure. It is observed that as the inlet pressure decreases steam generation rate increases. Hence multi effect evaporator are more suitable at low input inlet pressures corresponding to equal values of the temperature difference between condensing steam and the evaporating water.

VI. CONCLUSION AND FUTURE SCOPE OF WORK

In the present study, the triple effect evaporator with parallel feed is evaluated at different input pressures. This is solved by mass balance and energy balance equations.
The following conclusions are arrived.

- As the pressure in the triple feed evaporator decreases to around 2 bar. At different input pressures 24, 22, 20, 18 and 16 bar enthalpy almost remains same and decreases by 2.08%, 2.09%, 2.12%, 2.13% and 2.20%.
- The inlet pressure taken in a triple feed evaporator decreasing from 24 bar to 16 bar, mass flow rate increases by 11.90%, 11.88%, 11.73%, 11.26% and 11.12%
- The rate of evaporation increases at lower temperatures corresponding to the different input pressures. The rate of evaporation increases by 7.25%, 6.95%, 6.67%, 6.59%, and 6.41%
- Comparing the multi effect evaporator with single effect evaporator the percentage increase in mass flow rate is 199.19%.

Based on the conclusions drawn from the above graphs, the following works related to the triple effect evaporator can be taken up in future

- In the present work of a triple effect evaporator the pressure corresponding to the stages is limited to 2 bar. For safe conditions however decreasing the pressures to a lower value greater than atmospheric pressure can increases the mass of distilled water.
- Triple feed evaporator used here for production of distilled water. However these evaporator can be used for other purpose like food industry, paper industry, and sugar industry e.t.c.

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