COMPUTER AIDEDS DESIGN AND SIMULATION OF DOUBLE EFFECT EVAPORATOR FOR CONCERTRATION OF SUCROSE SOLUTION.

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A RESEARCH PROJECT SUBMITTED TO
THE DEPARTMENT OF CHEMICAL ENGINEERING,
SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY,
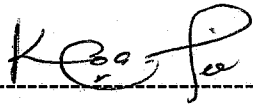FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA,
NIGER STATE

DECLARATION

I, Agbadaola Adekunle Gabriel with matriculation number 03/14933EH

declare that this research project report is my original work and has not been

presented elsewhere to the best of my knowledge.
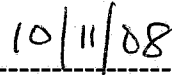

AGADAOLA ADEKUNLE G.   **DATE**

CERTIFICATION

This resarch project by Agbadaola Adekunle Gabriel has been examined and certified under the supervision of Prof.K.R onifade to be adequate in scope and quality for the partial fulfillment of the requirement for the Award of Bachelor of Engineering in chemical Engineering.

_____   __10|11|08__

(PROF. K .R ONIFADE)   DATE

PROJECT SUPERVISOR

_____   _____

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DR. M.O EDOGA   DATE

   (HOD)

_____   _____

EXTERNAL SUPERVISOR   DATE

iv

DEDICATION

To the glory of God and to my late Father Surveyor Ayodele Agbadaola of blessed memories.

ACKNOWLEDGEMENT

I want to use this medium to thank my mother Mrs. Margaret Agbadaola.

Whose contributions to my educational pursuit cannot be quantified?

I will like to acknowledge the support of my supervisor, professor K.O onifade

My good friends Richard Oyatekwa, Ellis Oshokha Alegieuno, Malcolm Esekhile, Nsikan Uboho lekan joks, raph banji, femi ,bada bola and my younger brothers Alabi Olubumni, Oshadola Opeyemi.

I seize this opportunity to show my appreciation to the entire family member of Mr. and Mrs. Ayodele Lawrence the family of dare clement and the family of Engineer TEE. for their unquantifiable contribution and assistance to the successful completion of my program.

Above all I wish to express my gratitude especially to the following people My big brother Mr. omoregie and my dearly friend ogundipe olalekan bright i will not forget my sweet younger sister Tolu Agbadaola. And my sweat lovely angel kemi omoniyi.

Finally, I give thanks to God for granting me all it takes for the successful completion of my program.

ABSTRACT

This research work is concerned with the computer aided design of a double effect evaporator for the concentration f sucrose solution using HYSYS process simulator. The purpose of this work is to get sucrose solution concentration. It was found the feed enter the pump at a temperature of 25°C and the pressure of 120kPa and the feed in pumped to the first effect evaporator and heat is applied giving a top product a the top of the evaporator with temperature 110.0°C and pressure of 130.0 kpa, and the bottom product from the evaporator having a temperature of 110.0°C and pressure of 130.0 kpa.

The remaining sucrose from the first evaporator enters the second effect evaporator the vapour (top product) from the evaporator comes out at a temperature of 325.2°C and pressure of 139.0 kpa. The sucrose (the bottom product) from the evaporator comes out at temperature of 325.2°C and presure of 139.0 kpa.

TABLE OF CONTENTS

CHAPTER ONE

1.0 Introduction

Recently many things have been developed concerning the new trends in engineering education; the most important of them is computer development. The increasing power and speed of computers allow the calculation of complex variable problems. In chemical engineering for example the need for simulation cannot be overemphasized especially in the areas of molecular simulation, microscopic simulations of fluid flow, heat transfer, mass transfer, kinetics, thermodynamics, molecular dynamics, neural networks, dynamic modeling, and others. In this way, commercial simulators are becoming very important in the undergraduate course. Simulation helps the students to develop the skills of analysis, synthesis and evaluation that are important to the engineers. Simulation in design projects brings sense of reality and students become more active and interested.

This research work is concerned with the computer aided design of a double effect evaporator for the concentration of sucrose solution using HYSYS Process Simulator. For the purpose of this work more emphasis is given to chemical engineering equipment design (with double effect evaporator as main case study) and the important role of computer softwares and process simulator application in chemical and process design engineering. Consequently, little attension is given to the minor case study i.e sucrose solution concentration. This is because, at present very little or no attention has been given to the use of computers together with the commercial simulators as an effective way to teach engineering concepts. In fact, the exciting world of computers and the interactive way in which the good commercial simulators were developed make an interesting combination that has to be added to the natural explorer feeling of the engineering student.

1.1 Computer Aided Design / Computer Aided Manufacturing

Computing hardware and software are tools-of-the-trade for engineers. The capabilities provided by computers for fast calculation, large storage, and logical decisions plus the available technical and mathematical software permit engineers to solve larger problems and to do it much more rapidly than ever before possible. The engineers' emphasis can therefore shift from problem solving to planning, conceiving, interpreting, and implementing with the information made

available. Design is one of the engineering functions that has been impacted by computers. Chemical engineering stresses the processes for manufacturing chemicals and chemical-based products. In this effort the emphasis of the chemical engineer tends to be on the process rather than on the product, and that emphasis is reflected in the contents of this project. The computer aids most useful to chemical engineers in design are process- rather than product oriented. The more widely known CAD/CAM (computer-aided design/computer-aided manufacturing) software is usually concerned with product-as object and is highly graphical and spatial. Chemical process computer-aided design, on the other hand, is much less graphical. It is more concerned with the performance of process units (such as the classical unit operations of chemical engineering) and the integration of these units into complete, consistent, efficient processes to produce chemical products. This project gives a practical application of computer software useful for process and plant design and takes advantage of the capabilities of computers and software.

1.2 Programming Language

An engineer may write a programming language code to solve a particular design problem. Before the explosive growth of software, this commonly was done. There is still a place for it when appropriate software is not available or as a learning technique. Because program writing and debugging is usually quite time consuming, it is recommended that available software be used and that a specific design program be written only after determining that appropriate software is not available. Many programs useful for chemical engineers have been published. Spread-sheet software has become an indispensible tool to engineers because of the availability on personal computers, ease of use, and adaptability to many types of problems. Hundreds, even thousands, of programs have been written to solve problems commonly encountered by chemical engineers. Many of these have become available for purchase. In turn, many of these programs are for the design of individual units of chemical process equipment. Design programs are available for virtually every unit operation and every type of common process equipment. *Chemical Engineering* provides a feature, "Chemputer," in each issue reporting on computer hardware and software developments and periodically publishes a comprehensive list of

programs useful to chemical engineers. The "Software" department of *Chemical Engineering Progress* likewise reports on software of interest to chemical engineers. The Computer Aids for Chemical Education (CACHE) Corporation makes available several programs intended mainly for educational use, but provides them at modest cost to anyone. CACHE is a not-for-profit organization whose purpose is to promote computer- and technology-based aids for chemical engineering education. The critical need for chemical and physical property data is apparent to anyone who has worked on process-design projects. Property storage or prediction is an enormous task because of the large number of substances and mixtures of possible interest and the virtually unlimited conditions (of temperature, pressure, and composition) at which they may be needed. SoftWare to supply these properties is one of the most useful of all computer aids to chemical engineers. There are many computer programs available for supplying or predicting properties, primarily for pure components.

1.3 Process synthesis and flow-sheeting

This programs are those most specifically intended for design use. Process synthesis (or invention) involves generating a flow sheet for a process to produce a particular product or slate of products from specified raw materials. The process flow sheet identifies the chemical reactors and unit operations required and their sequence, the material and energy streams in the process, those streams to be recycled, and some characteristics of the equipment. This flow sheet should be a reasonable approximation of the best economic flow sheet for the product slate. Process synthesis software, a type of expert system program, has begun to appear in the late 1980s. Process synthesis, though is used in this project, but rapid changes are to be expected in this field. "Flow-sheeting," as used in computer-aided-design, means performing on a specified flow sheet the calculations necessary to simulate the behavior of the process or to design the equipment and to determine values for key operating conditions. These calculations include mass and energy balances, process equipment parameters, and cost estimation for the equipment and plant as well as an economic analysis of the process. This is chemical process design; it is what this research project is all about.

1.4 Simulator Package

For the purpose of this design work the CAD system/module to be employed is a commercial process simulator- HYSYS process simulator- a product of HyproTech a subsidiary of AspenTech. HYSYS provides an intuitive and interactive approach toward process modeling, simulation and optimization. This software allows the plant designer to create detailed high-fidelity plant simulations for analyzing and optimizing the plant's operation. Through the completely interactive HYSYS interface, the plant designer has access to a fine level of equipment geometry, performance detail as well as the ability to completely customize the simulation.

1.5 Primary Problems in Evaporator Designs

Heat Transfer, this is the most important single factor in evaporator design, since the heating surface represents the largest part of evaporator cost. Other things being equal, the type of evaporator selected is the one having the highest heat-transfer cost coefficient under desired

operating conditions in terms of J/s·K (British thermal units per hour per degree Fahrenheit) per

dollar of installed cost. When power is required to induce circulation past the heating surface, the coefficient must be even higher to offset the cost of power for circulation.

CHAPTER TWO

2.0 Literature Review

Evaporation, a widely used method for the concentration of aqueous solutions, involves the removal of water from a solution by boiling the liquor in a suitable vessel, an evaporator, and withdrawing the vapour. If the solution contains dissolved solids, the resulting strong liquor may become saturated so that crystals are deposited. Liquors which are to be evaporated may be classified as follows:

(a) Those which can be heated to high temperatures without decomposition, and those that can be heated only to a temperature of about 330 K.

(b) Those which yield solids on concentration, in which case crystal size and shape

may be important, and those which do not.

(c) Those which, at a given pressure, boil at about the same temperature as water, and those which have a much higher boiling point.

Evaporation is achieved by adding heat to the solution to vaporise the solvent. The heat is supplied principally to provide the latent heat of vaporisation, and, by adopting methods for recovery of heat from the vapour, it has been possible to achieve great economy in heat utilisation. Whilst the normal heating medium is generally low pressure exhaust steam from turbines, special heat transfer fluids or flue gases are also used. The design of an evaporation unit requires the practical application of data on heat transfer to boiling liquids, together with a realisation of what happens to the liquid during concentration. In addition to the three main features outlined above, liquors which have an inverse solubility curve and which are therefore likely to deposit scale on the heating surface merit special attention.

2.1 EVAPORATOR TYPES AND APPLICATIONS

Evaporators may be classified as follows:

1. Heating medium separated from evaporating liquid by tubular heating surfaces.

2. Heating medium confined by coils, jackets, double walls, flat plates, etc.

3. Heating medium brought into direct contact with evaporating liquid.

4. Heating by solar radiation.

By far the largest number of industrial evaporators employ tubular heating surfaces. Circulation of liquid past the heating surface may be induced by boiling or by mechanical means. In the latter case, boiling may or may not occur at the heating surface.

2.2 HEAT TRANSFER IN EVAPORATORS

2.2.1 Primary Problems in Evaporator Designs

This is the most important single factor in evaporator design, since the heating surface represents the largest part of evaporator cost. Other things being equal, the type of evaporator selected is the one having the highest heat-transfer cost coefficient under desired operating conditions in terms of J/s·K (British thermalunits per hour per degree Fahrenheit) per dollar of installed cost. When power is required to induce circulation past the heating surface, the coefficient must be even higher to offset the cost of power for circulation.

2.2.2 Vapor-Liquid Separation

This design problem may be important for a number of reasons. The most important is usually prevention of entrainment because of value of product lost, pollution, contamination of the condensed vapor, or fouling or corrosion of the surfaces on which the vapor is condensed. Vapor-liquid separation in the vapor head may also be important when spray forms deposits on the walls, when vortices increase head requirements of circulating pumps, and when short circuiting allows vapor or unflashed liquid to be carried back to the circulating pump and heating

6

element. Evaporator performance is rated on the basis of **steam economy**—kilograms of solvent evaporated per kilogram of steam used. Heat is required (1) to raise the feed from its initial temperature to the boiling temperature, (2) to provide the minimum thermodynamic energy to separate liquid solvent from the feed, and (3) to vaporize the solvent. The first of these can be changed appreciably by reducing the boiling temperature or by heat interchange between the feed and the residual product and/or condensate. The greatest increase in steam economy is achieved by reusing the vaporized solvent. This is done in a **multiple-effect evaporator** by using the vapor from one effect as the heating medium for another effect in which boiling takes place at a lower temperature and pressure. Another method of increasing the utilization of energy is to employ a **thermocompression** evaporator, in which the vapor is compressed so that it will condense at a temperature high enough to permit its use as the heating medium in the same evaporator.

2.2.3 Selection Problems

Aside from heat-transfer considerations, the selection of type of evaporator best suited for a particular service is governed by the characteristics of the feed and product. Points that must be considered are crystallization, salting and scaling, product quality, corrosion, and foaming. In the case of a **crystallizing evaporator,**

the desirability of producing crystals of a definite uniform size usually limits the choice to evaporators having a positive means of circulation. **Salting,** which is the growth on body and heating-surface walls of a material having a solubility that increases with increase in temperature, is frequently encountered in crystallizing evaporators. It can be reduced or eliminated by keeping the evaporating liquid in close or frequent contact with a large surface area of crystallized solid. **Scaling** is the deposition and growth on body walls, and especially on heating surfaces, of a material undergoing an irreversible chemical reaction in the evaporator or having a solubility that decreases with an increase in temperature. Scaling can be reduced or eliminated in the same general manner as salting. Both salting and scaling liquids are usually best handled in evaporators that do not depend on boiling to induce circulation. **Fouling** is the

7

formation of deposits other than salt or scale and may be due to corrosion, solid matter entering with the feed, or deposits formed by the condensing vapor.

2.2.4 Product Quality

Considerations of product quality may require low holdup time and low-temperature operation to avoid thermal degradation. The low holdup time eliminates some types of evaporators, and some types are also eliminated because of poor heat-transfer characteristics at low temperature. Product quality may also dictate special materials of construction to avoid metallic contamination or a catalytic effect on decomposition of the product. **Corrosion** may also influence evaporator selection, since the advantages of evaporators having high heat-transfer coefficients are more apparent when expensive materials of construction are indicated. Corrosion and erosion are frequently more severe in evaporators than in other types of equipment because of the high liquid and vapor velocities used, the frequent presence of solids in suspension, and the necessary concentration differences.

2.3 Heat transfer coefficients

The rate equation for heat transfer takes the form:

$$Q = UA\Delta T \hspace{3cm} (2.1)$$

where: Q is the heat transferred per unit time,

U is the overall coefficient of heat transfer,

A is the heat transfer surface, and

ΔT is the temperature difference between the two streams.

In applying this equation to evaporators, there may be some difficulty in deciding the correct value for the temperature difference because of what is known as the *boiling point rise* (BPR). If water is boiled in an evaporator under a given pressure, then the temperature of the

8

liquor may be determined from steam tables and the temperature difference is readily calculated. At the same pressure, a solution has a boiling point greater than that of water, and the difference between its boiling point and that of water is the BPR. For example, at atmospheric pressure (101.3 kN/m2), a 25 per cent solution of sodium chloride boils at 381 K and shows a BPR of 8 deg K. If steam at 389 K were used to concentrate the salt solution, the overall temperature difference would not be *(389 − 373)* = 16 deg K, but *(389 − 381)* = 8 deg K. Such solutions usually require more heat to vaporise unit mass of water, so that the reduction in capacity of a unit may be considerable. The value of the BPR cannot be calculated from physical data of the liquor, though D¨uhring's rule is often used to find the change in BPR with pressure. If the boiling point of the solution is plotted against that of water at the same pressure, then a straight line is obtained, as shown for sodium chloride in Figure 2.1. Thus, if the pressure is fixed, the boiling point of water is found from steam tables, and the boiling point of the solution from Figure 2.1. The boiling point rise is much greater with strong electrolytes, such as salt and caustic soda.
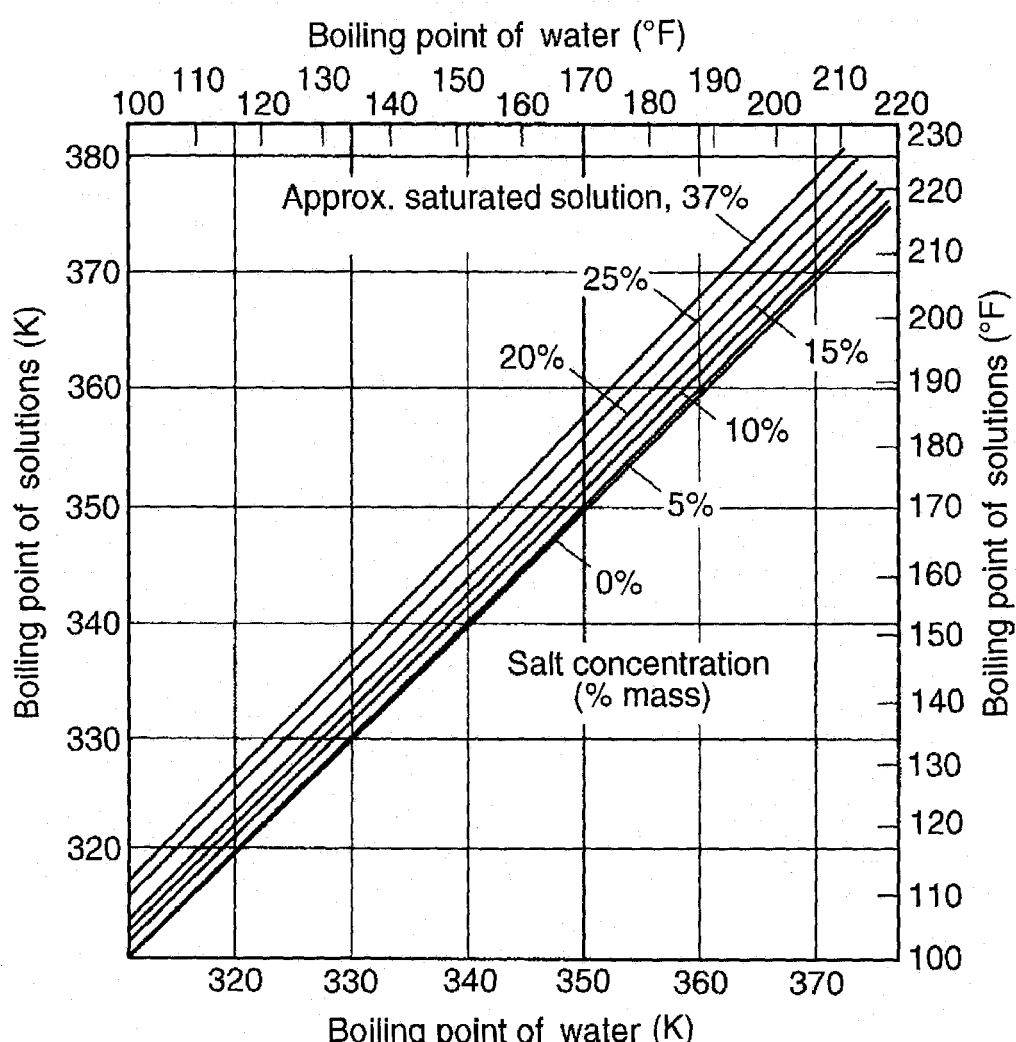
Fig 2.1 Boiling point of solutions of sodium chloride as a function of the boiling point of water. D'uhring lines.

Overall heat transfer coefficients for any form of evaporator depend on the value of the film coefficients on the heating side and for the liquor, together with allowances for scale deposits and the tube wall. For condensing steam, which is a common heating medium, film coefficients are approximately 6 kW/m2 K. There is no entirely satisfactory general method for calculating transfer coefficients for the boiling film.

2.4.1 Boiling at a submerged surface

The heat transfer processes occurring in evaporation equipment may be classified under two general headings. The first of these is concerned with boiling at a submerged surface. The second category includes two-phase forced-convection boiling processes occurring in closed conduits. In this case convection is induced by the flow which results from natural or forced circulation effects.
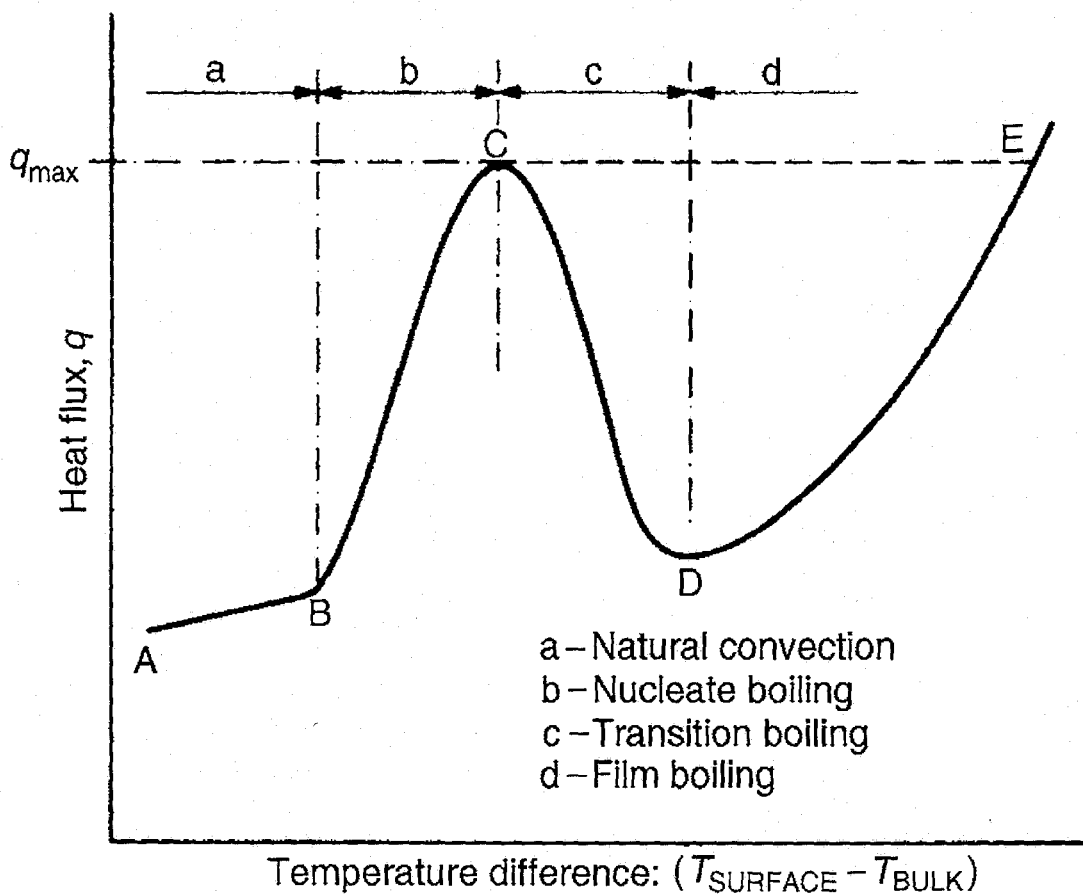

Figure 2.2 Typical characteristic for boiling at a submerged surface

The heat flux–temperature difference characteristic observed when heat is transferred from a surface to a liquid at its boiling point, is as shown in Figure 2.2. In the range AB, although the liquid in the vicinity of the surface will be slightly superheated, there is no vapour formed and heat transfer is by natural convection with evaporation from the free surface. Boiling commences at B with bubble columns initiated at preferred sites of nucleation centres on the surface. Over the nucleate boiling region, BC, the bubble sites become more numerous with increasing flux until, at C, the surface is completely covered. In the majority of commercial evaporation processes the heating medium is a fluid and therefore the controlling parameter is the overall temperature difference. If an attempt is made to increase the heat flux beyond that at C, by increasing the temperature difference, the nucleate boiling mechanism will partially collapse and portions of the surface will be exposed to vapour blanketing. In the region of transition boiling CD the average heat transfer coefficient, and frequently the heat flux, will decrease with increasing temperature difference, due to the increasing proportion of the surface exposed to vapour. This selfcompensating behaviour is not exhibited if heat flux rather than temperature difference is the controlling parameter. In this case an attempt to increase the heat flux beyond point C will cause the nucleate boiling regime to collapse completely, exposing the whole surface to a vapour film. The inferior heat transfer characteristics of the vapour mean that the surface temperature must rise to E in order to dissipate the heat. In many instances this temperature exceeds the melting point of the surface and results can be disastrous. For obvious reasons the point C is generally known as *burnout*, although the terms *departure from nucleate boiling (DNB point)* and *maximum heat flux* are in common usage. In the design of evaporators, a method of predicting the heat transfer coefficient in nucleate boiling *hb*, and the maximum heat flux which might be expected before *hb* begins to decrease, is of extreme importance. The complexity of the nucleate boiling process has been the subject of many studies. In a review of the available correlations for nucleate boiling, WESTWATER[1] has presented some fourteen equations. PALEN and TABOREK[2] reduced this list to seven and tested these against selected experimental data[3,4]. As a result of this study two equations, those due to MCNELLY[5] and GILMOUR[6], were selected as the most accurate. Although the modified form of the Gilmour

equation is somewhat more accurate, the relative simplicity of the McNelly equation is attractive

and this equation is given in dimensionless form as:

$$\left[\frac{h_b d}{k}\right] = 0.225 \left[\frac{C_p \mu_L}{k}\right]^{0.69} \left[\frac{qd}{\lambda \mu_L}\right]^{0.69} \left[\frac{Pd}{\sigma}\right]^{0.31} \left[\frac{\rho_L}{\rho_v} - 1\right]^{0.31}$$

....2.2

The inclusion of the characteristic dimension d is necessary dimensionally, though its

value does not affect the result obtained for hb.

This equation predicts the heat transfer coefficient for a single isolated tube and is not applicable

to tube bundles, for which PALEN and TABOREK(2) showed that the use of this equation

would have resulted in 50–250 per cent underdesign in a number of specific cases. The reason

for this discrepancy may be explained as follows. In the case of a tube bundle, only the lowest

tube in each vertical row is completely irrigated by the liquid with higher tubes being exposed to

liquid–vapour mixtures. This partial vapour blanketing results in a lower average heat transfer

coefficient for tube bundles than the value given by equation 2.2. In order to calculate these

average values of h for a tube bundle, equations of the form $h = Cshb$ have been suggested(2)

where the surface factor Cs is less than 1 and is, as might be expected, a function of the number

of tubes in a vertical row, the pitch of the tubes, and the basic value of hb. The factor Cs can only

be determined by statistical analysis of experimental data and further work is necessary before it

can be predicted from a physical model for the process. The single tube values for hb have been

correlated by equation 2.2, which applies to the true nucleate boiling regime and takes no

account of the factors which eventually lead to the maximum heat flux being approached. for

maximum flux, often a limiting factor in evaporation processes, have been tested by PALEN and

TABOREK(2), though the simplified equation of ZUBER(7) is recommended. This takes the

form:

$$q_{max} = \frac{\pi}{24} \lambda \rho_v \left[\frac{\sigma g(\rho_L - \rho_v)}{\rho_v^2}\right]^{1/4} \left[\frac{\rho_L + \rho_v}{\rho_L}\right]^{1/2}$$

.....2.3

12

where: q_{max} is the maximum heat flux,

λ is the latent heat of vaporisation,

ρL is the density of liquid,

ρv is the density of vapour,

σ is the interfacial tension, and

g is the acceleration due to gravity.

2.4.2 Forced convection boiling

The performance of evaporators operating with forced convection depends very much on what happens when a liquid is vaporised during flow through a vertical tube. If the liquid enters the tube below its boiling point, then the first section operates as a normal heater and the heat transfer rates are determined by the well-established equations for single phase flow. When the liquid temperature reaches the boiling point corresponding to the local pressure, boiling commences. At this stage the vapour bubbles are dispersed in the continuous liquid phase although progressive vaporisation of the liquid gives rise to a number of characteristic flow patterns which are shown in Figure 2.3. Over the initial boiling section convective heat transfer occurs with vapour bubbles dispersed in the liquid. Higher up, the tube bubbles become more numerous and elongated, and bubble coalescence occurs and eventually the bubbles form slugs which later collapse to give an annular flow regime in which vapour forms the central core with a thin film of liquid carried up the wall. In the final stage, dispersed flow with liquid entrainment in the vapour core occurs. In general, the conditions existing in the tube are those of annular flow. With

further evaporation, the rising liquid film becomes progressively thinner and this thinning, together with the increasing vapour core velocity, eventually causes breakdown of the liquid film, leading to dry wall conditions. For boiling in a tube, there is therefore a contribution from nucleate boiling arising from bubble formation, together with forced convection boiling due to the high velocity liquid–vapour mixture. Such a system is inherently complex since certain

13

parameters influence these two basic processes in different ways. DENGLER and ADDOMS*(8)* measured heat transfer to water boiling in a 6 m tube and found that the heat flux increased steadily up the tube as the percentage of vapour increased, as shown in Figure 2.4. Where convection was predominant, the data were correlated using the ratio of the observed two-phase heat transfer coefficient *(htp)* to that which would be obtained had the same total mass flow been all liquid *(hL)* as the ordinate.

The liquid coefficient *hL* is given by:

$$h_L = 0.023 \left[\frac{k}{d_t}\right] \left[\frac{4W}{\pi d_t \mu_L}\right]^{0.8} \left[\frac{C_p \mu_L}{k}\right]^{0.4}$$

....2.4

2.5 SINGLE-EFFECT EVAPORATORS

Single-effect evaporators are used when the throughput is low, when a cheap supply of steam is available, when expensive materials of construction must be used as is the case with corrosive feedstocks and when the vapour is so contaminated so that it cannot be reused. Single effect units may be operated in batch, semi-batch or continuous batch modes or continuously. In strict terms, batch units require that filling, evaporating and emptying are consecutive steps. Such a method of operation is rarely used since it requires that the vessel is large enough to hold the entire charge of feed and that the heating element is low enough to ensure that it is not uncovered when the volume is reduced to that of the product. Semi-batch is the more usual mode of operation in which feed is added continuously in order to maintain a constant level until the entire charge reaches the required product density. Batch-operated evaporators often have a continuous feed and, over at least part of the cycle, a continuous discharge. Often a feed drawn from a storage tank is returned until the entire contents of the tank reach the desired concentration. The final evaporation is then achieved by batch operation. In essence, continuous evaporators have a continuous feed and discharge and concentrations of both feed and discharge remain constant.

The heat requirements of single-effect continuous evaporators may be obtained from

mass and energy balances. If enthalpy data or heat capacity and heat of solution data are not available, heat requirements may be taken as the sum of the heat needed to raise the feed from feed to product temperature and the heat required to evaporate the water. The latent heat of water is taken at the vapour head pressure instead of the product temperature in order to compensate, at least to some extent, for the heat of solution. If sufficient vapour pressure data are available for the liquor, methods are available for calculating the true latent heat from the slope of the D¨uhring line and detailed by OTHMER(11). The heat requirements in batch operation are generally similar to those in continuous evaporation. Whilst the temperature and sometimes the pressure of the vapour will change during thecourse of the cycle which results in changes in enthalpy, since the enthalpy of water vapour changes only slightly with temperature, the differences between continuous and batch heat requirements are almost negligible for all practical purposes. The variation of the fluid properties, such as viscosity and boiling point rise, have a much greater effect on heat transfer, although these can only be estimated by a step-wise calculation. In estimating the boiling temperature, the effect of temperature on the heat transfer characteristics of the type of unit involved must be taken into account. At low temperatures some evaporator types show a marked drop in the heat transfer coefficient which is often more than enough to offset any gain in available temperature difference. The temperature and cost of the cooling water fed to the condenser are also of importance in this respect.

2.6. MULTIPLE-EFFECT EVAPORATORS

The single effect evaporator uses rather more than 1 kg of steam to evaporate 1 kg of water. Three methods have been introduced which enable the performance to be improved, either by direct reduction in the steam consumption, or by improved energy efficiency of the whole unit. These are:

(a) Multiple effect operation

(b) Recompression of the vapour rising from the evaporator

(c) Evaporation at low temperatures using a heat pump cycle.

2.7. EQUIPMENT FOR EVAPORATION

2.7.1. Evaporator selection

The rapid development of the process industries and of new products has provided many liquids with a wide range of physical and chemical properties all of which require concentration by evaporation. The type of equipment used depends largely on the method of applying heat to the liquor and the method of agitation. Heating may be either direct or indirect. Direct heating is represented by solar evaporation and by submerged combustion of a fuel. In indirect heating, the heat, generally provided by the condensation of steam, passes through the heating surface of the evaporator. Some of the problems arising during evaporation include:

(a) High product viscosity.

(b) Heat sensitivity.

(c) Scale formation and deposition.

Equipment has been developed in an attempt to overcome one or more of these problems. In view of the large number of types of evaporator which are available, the selection of equipment for a particular application can only be made after a detailed analysis of all relevant factors has been made. These will, of course, include the properties of the liquid to be evaporated, capital and running costs, capacity, holdup, and residence time characteristics. Evaporator selection been discussed in chemical engineering handbooks by MOORE and HESLER(20) and PARKER(21). Parker has attempted to test the suitability of each basic design for dealing with the problems encountered in practice, and the basic information is presented in the form shown in Figure 2.5. The factors considered include the ability to handle liquids in three viscosity ranges, to deal with foaming, scaling or fouling, crystal production, solids in suspension, and heat sensitive materials. A comparison of residence time and holding volume relative to the wiped film unit is also given. It is of interest to note that the agitated or wiped film evaporator is the only one which is shown to be applicable over the whole range of conditions covered.

16

Operational category	Evaporator type	Feed condition[a]							Suitable for heat-sensitive products	Retention time[b] (s)	Holding volume[c] (m³)
		Very viscous (above 2000 mN s/m²)	Med. viscosity (100–1000 mN s/m²)	Low viscosity to water (max. 100 mN s/m²)	Foaming	Scaling or fouling	Crystal producing	Solids in suspension			
Recirculating	Calandria[d] (short vertical tube)		■	■	■	■	■	■	No	168	3.03
Recirculating	Forced circulation		■	■	■	■	■	▨	Yes	41.6	12.8
Recirculating	Falling film		▨	■					No[e]	Not available	Not available
Recirculating	Natural circulation (thermo-siphon)		▨	■	■				No[e]	16	10.1
Single pass	Agitated film (vertical or horizontal)	■	■	■	■	■	■		Yes	1.0	1.0
Single pass	Tubular (long tube) Falling film		▨	■					Yes	Not available	Not available
Single pass	Rising film		▨	■	■			▨	Yes		
Single pass special type	Rising-Falling concentrator	▨	■	■					Yes	0.45	0.79
Single pass special type	Plate (can be recirculating)	▨	■	■					Yes	Not available	Not available

■ = Applicable to conditions noted   ▨ = Applicable over lower portion of range noted

a. Viscosities are at operating temperatures
b. Based on agitated film evaporator = 1.0
c. Based on agitated film evaporator = 1.0, proportioned to equal surface
d. Special disengagement arrangement required for foamy liquids
e. May be used in special cases

2.7.2 Evaporators with direct heating

The use of solar heat for the production of Glauber's salt has been described by HOLLAND(22,23). Brine is pumped in hot weather to reservoirs of 100,000 m2 in area to a depth of 3–5 m, and salt is deposited. Later in the year, the mother liquor is drained off and the salt is stacked mechanically, and conveyed to special evaporators in which hot gases enter at 1150–1250 K through a suitable refractory duct and leave at about 330 K. The salt crystals melt in their water of crystallisation and are then dried in the stream of hot gas. BLOCH *et al.(24)*, who examined the mechanism of evaporation of salt brines by direct solar energy, found that the rate of evaporation increased with the depth of brine. The addition of dyes, such as 2-naphthol green, enables the solar energy to be absorbed in a much shallower depth of brine, and this

technique has been used to obtain a significant increase in the rate of production in the Dead Sea area.

2.7.3 Forced-Circulation Evaporators

Although it may not be the most economical for many uses, the forced-circulation (FC) evaporator is suitable for the widest variety of evaporator applications. The use of a pump to ensure circulation past the heating surface makes possible separating the functions of heat transfer, vapor-liquid separation, and crystallization. The pump withdraws liquor from the flash chamber and forces it through the heating element back to the flash chamber. Circulation is maintained regardless of the evaporation rate; so this type of evaporator is well suited to **crystallizing operation,** in which solids must be maintained in suspension at all times. The liquid velocity past the heating surface is limited only by the pumping power needed or available and by accelerated corrosion and erosion at the higher velocities. **Tube velocities** normally range from a minimum of about 1.2 m/s (4 ft/s) in salt evaporators with copper or brass tubes and liquid containing 5 percent or more solids up to about 3 m/s (10 ft/s) in caustic evaporators having nickel tubes and liquid containing only a small amount of solids. Even higher velocities can be used when corrosion is not accelerated by erosion. Highest heat-transfer coefficients are obtained in FC evaporators when the liquid is allowed to boil in the tubes. The heating element projects into the vapor head, and the liquid level is maintained near and usually slightly below the top tube sheet. This type of FC evaporator is not well suited to salting solutions because boiling in the tubes increases the chances of salt deposit on the walls and the sudden flashing at the tube exits promotes excessive nucleation and production of fine crystals. Consequently, this type of evaporator is seldom used except when there are headroom limitations or when the liquid forms neither salt nor scale. By far the largest number of forced-circulation evaporators are of the submerged-tube type. The heating element is placed far enough below the liquid level or return line to the flash chamber to prevent boiling in the tubes. Preferably, the hydrostatic head should be sufficient to prevent boiling even in a tube that is plugged (and hence at steam temperature), since this prevents salting of the entire tube. Evaporators of this type sometimes have horizontal heating elements (usually two-pass), but the vertical single-pass heating element is used

18

whenever sufficient headroom is available. The vertical element usually has a lower friction loss and is easier to clean or retube than a horizontal heater. The submerged-tube forcedcirculation evaporator is relatively immune to salting in the tubes, since no supersaturation is generated by evaporation in the tubes. The tendency toward scale formation is also reduced, since supersaturation in the heating element is generated only by a controlled amount of heating and not by both heating and evaporation. The type of **vapor** head used with the FC evaporator is chosen to suit the product characteristics and may range from a simple centrifugal separator to the crystallizing chambers and is frequently used for common salt. It is designed to circulate a slurry of crystals throughout the system.

2.7.4 Natural circulation evaporators

Whilst each of the previous types of evaporator is of considerable importance in a given industry, it is the steam-heated evaporator that is the most widely used unit in the process industries and this is now considered in detail. The movement of the liquid over the heating surface has a marked influence on the rate of heat transfer, and it is thus convenient to classify evaporators according to the method of agitation or the nature of the circulation of the liquor over the heating surface. On this basis evaporators may be divided into three main types:

(a) Natural circulation units.

(b) Forced circulation units.

(c) Film-type units.

The developments that have taken place have, in the main, originated from the sugar

and salt industries where the cost of evaporation represents a major factor in the process economics. In recent years, particular attention has been given to obtaining the most efficient use of the heating medium, and the main techniques that have been developed are the use of the multiple-effect unit, and of various forms of vapour compression units. With natural-circulation evaporators, circulation of the liquor is achieved by convection currents arising from the heating surface. This group of evaporators may be subdivided according to whether the tubes are

horizontal with the steam inside, or vertical with the steam outside. Rillieux is usually credited with first using *horizontal tubes*, and a unit of this type is shown in Figure 2.6. The horizontal tubes extend between two tube plates to which they are fastened either by packing plates or, more usually, by expansion. Above the heating section is a cylindrical portion in which separation of the vapour from the liquid takes place. The vapour leaves through some form of de-entraining device to prevent the carryover of liquid droplets with the vapour stream. The steam enters one steam chest, passes through the tubes and out into the opposite chest, and the condensate leaves through a steam trap. Horizontal evaporators are relatively cheap, require low head room, are easyto install, and are suitable for handling liquors that do not crystallise. They can be used either as batch or as continuous units, and the shell is generally 1–3.5 m diameter and 2.5–4 m high. The liquor circulation is poor, and for this reason such units are unsuitable for viscous liquors.
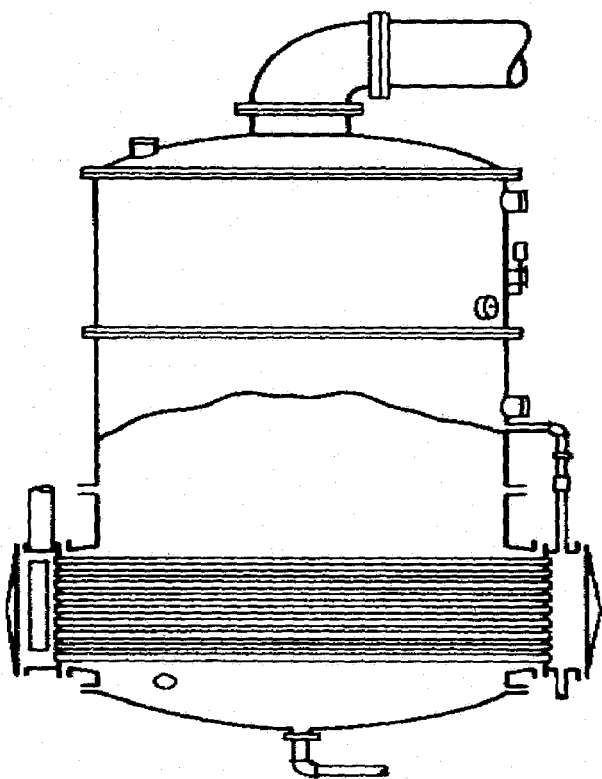

Figure 2.6. Natural circulation evaporator with horizontal tubes

The use of *vertical tubes* is associated with Robert, and this type is sometimes known as the Robert or Standard Evaporator. A typical form of vertical evaporator is illustrated in Figure 2.7,

in which a vertical cylindrical body is used, with the tubes held between two horizontal tube plates which extend right across the body. The lower portion of the evaporator is frequently spoken of as the calandria section shown in Figure 2.7. Tubes are 1–2 m in length and 37–75 mm diameter, giving ratio of length to inside diameter of the tubes of 20–40. In the basket type shown in Figure 2.7 vertical tubes are used with the steam outside, though the heating element is suspended in the body so as to give an annular downtake. The advantages claimed for this design are that the heating unit is easily removed for repairs, and that crystals formed in the downcomer do not break up. As the circulation of the liquor in the tubes is better, the vertical tube evaporator is used widely in the sugar and salt industries where throughputs are very large.
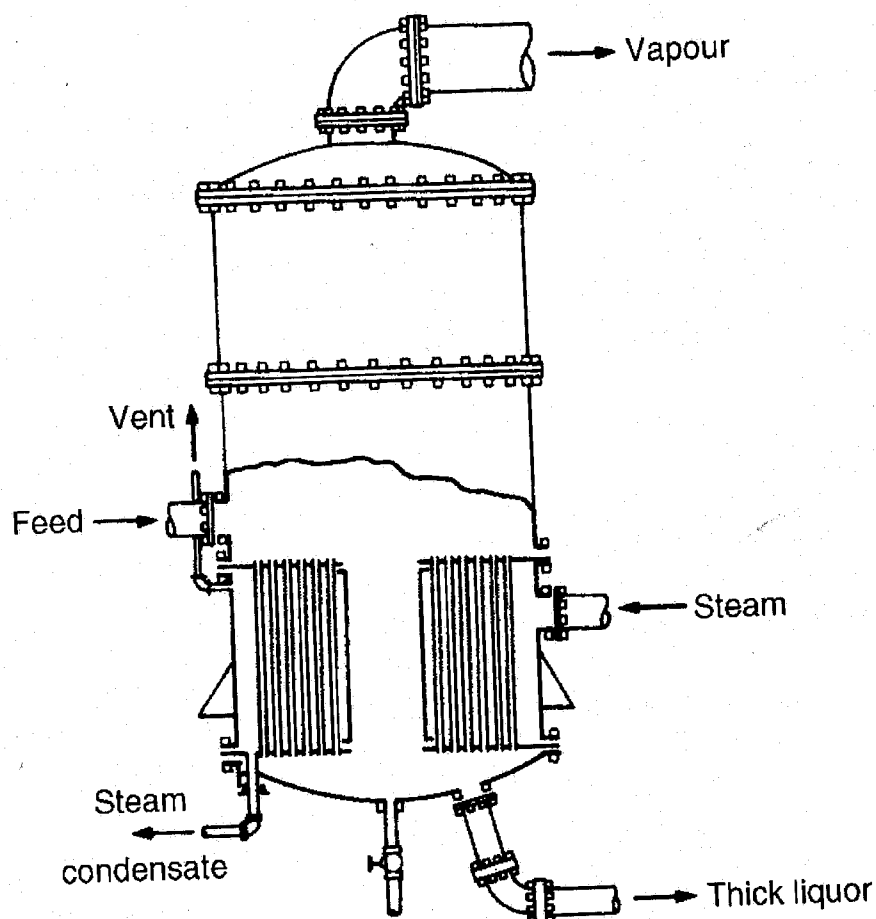

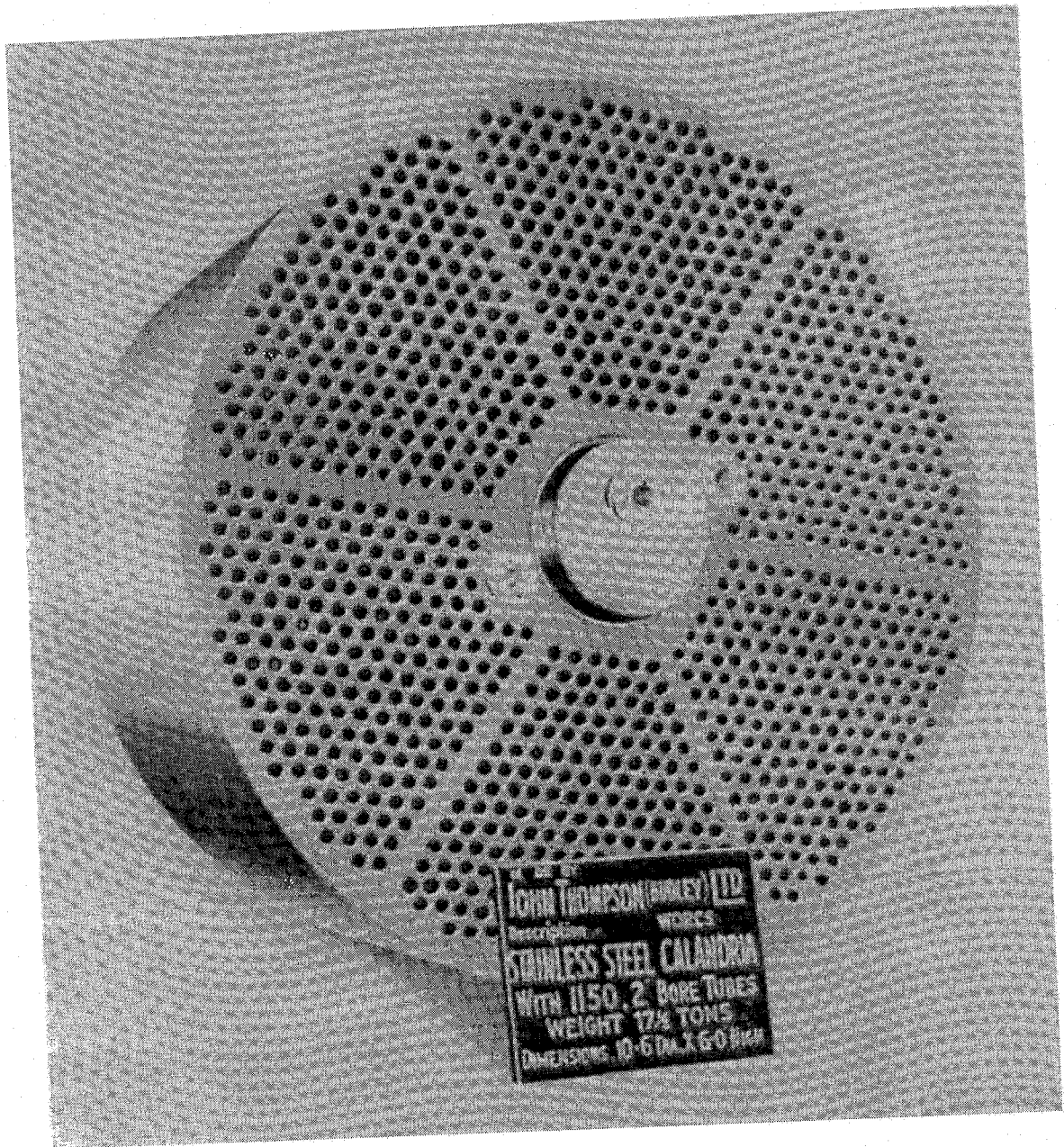Figure 2.5. Evaporator with vertical tubes and a large central downcomer.
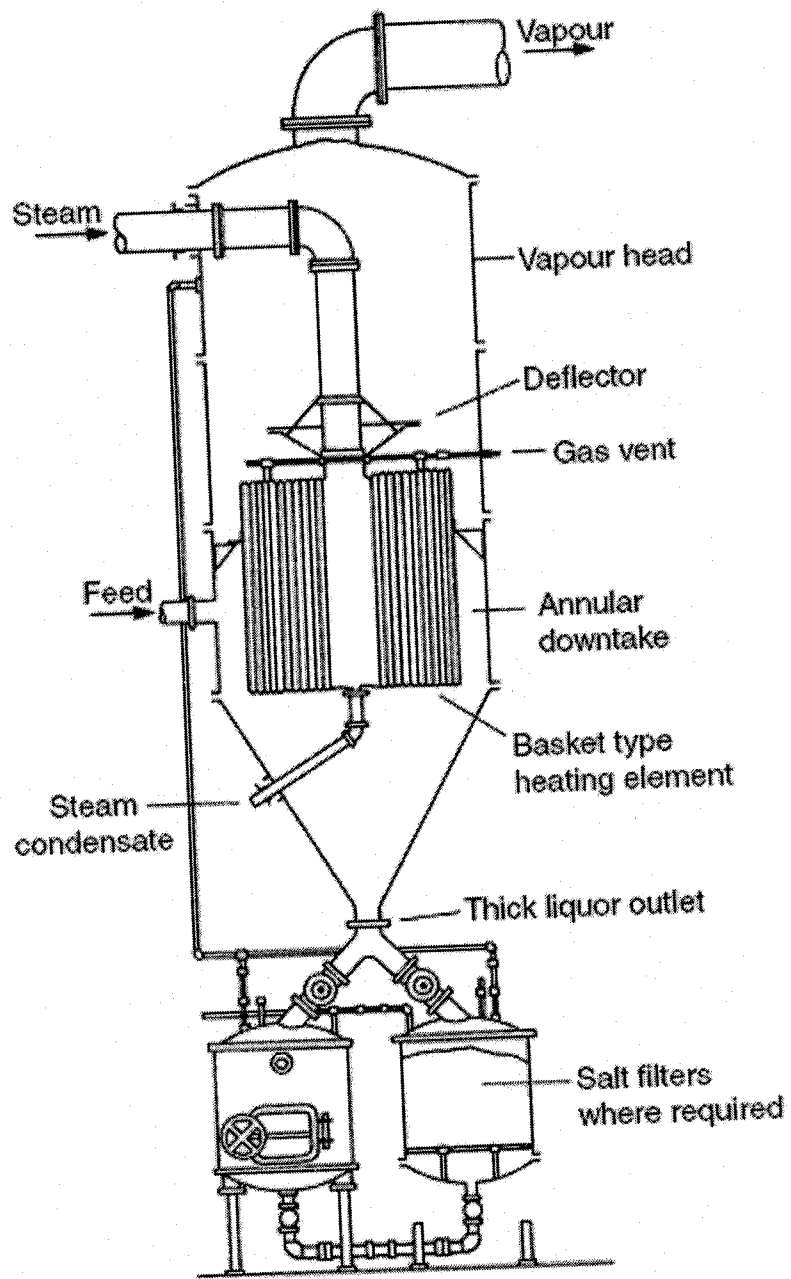
Figure 2.6. Calandria for an evaporator

Figure 2.7 Basket type of evaporator

CHAPTER THREE

3.0 METHODOLOGY

3.1 SAMPLE PROBLEM

Design of double effect evaporator to separate 1000kgmole/hr of a mixture of 76wt% of water

and 24wt% sucrose with specification

Concentration of 847.7kg/hr sucrose solution.

3.1.1 Creating a Fluid Package

Pressing the Add button, the new Fluid Package appears. HYSYS has created a Fluid Package

name Basis-1. This name can be changed by typing a new name in the **Name cell** at the button of

the view. For the Property Package to be used Peng Robinson is selected by scrolling down the

list of available property package and then click on i

3.1.2 Selecting Components

☐ Moving to the Components tab in the Fluid Package property by clicking on it.

☐ Selecting the components, i.e Sucrose, Water.

☐ Viewing Component Properties

Viewing the properties of one or more components, the component(s) are highlighted and press

the View Component; HYSYS will open the property view(s) for the component(s) selected. At

this stage, the Fluid Package is closed to return to the Simulation Basis Manager.

3.1.3 Procedure

To start a new simulation case the following steps were observed

. Selection of **New Case** from the **File Menu,** and press the **New Case button**. The Simulation

Basis Manager appears. The next step is creating a Fluid Package. A Fluid Package contains the

components and property method (for example, an Equation of State) to be used by HYSYS in

its calculations for a particular flow sheet.

3.1.4 Simulation Environment

☐ Press the Simulation Environment button on the button bar.

At Simulation Environment, the initial view that appears is dependent on the current performance setting for the initial Build Home View. Three initial views are available, namely the (Process Flow Diagram) PFD, Workbook and Summary. Any of them can be displayed at any time.

Case (Main) appears in the upper right corner instead of Basis.

. Menu, Button Bar, PFD and Object Palette are open on the Desktop.

Before proceeding any further to install streams or unit operations, the case is saved as follows:

If Object Palette is not open then F4 is pressed.

☐ The File button is clicked,

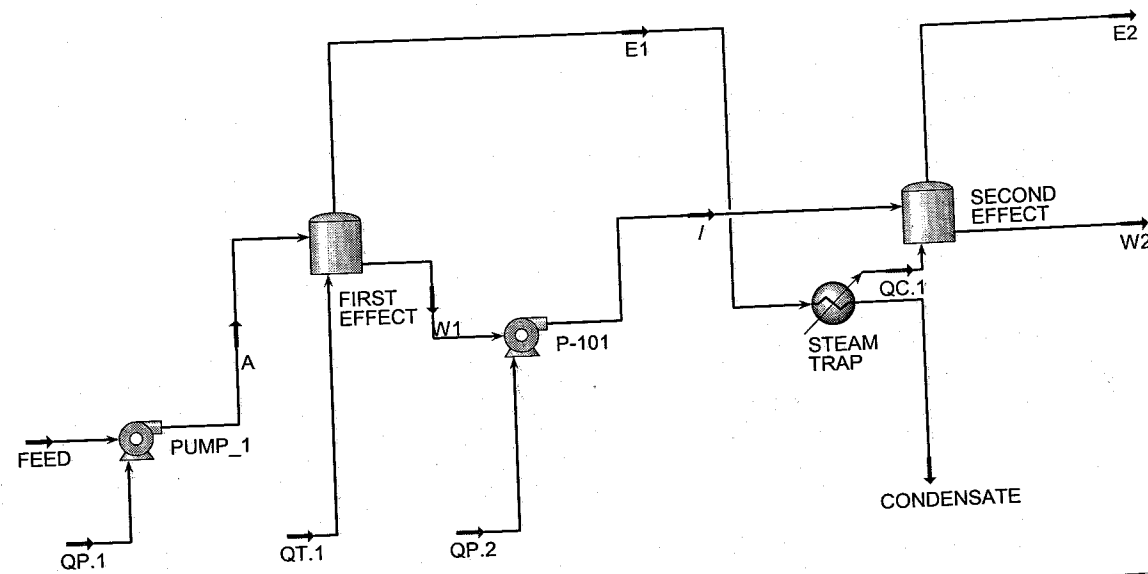. Save As is selected,

. A preferred name is typed, then **Save,** is selected

. Selecting Components

. Moving to **Components,** and typing Sucrose, Water one after the other and HYSYS will show their formula.

. **Add Pure** button is pressed.

		FEED	A	E1	W1	I	E2	W2	CONDENSATE
Vapour Fraction		0.0000	0.0000	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Temperature	C	25.00	25.00	110.0	110.0	110.0	325.2	325.2	25.00
Pressure	kPa	120.0	130.0	130.0	130.0	139.0	139.0	139.0	130.0
Molar Flow	kgmole/h	10.43	10.43	7.365	3.069	3.069	0.5573	2.511	7.365
Mass Flow	kg/h	1000	1000	132.7	867.3	867.3	19.56	847.7	132.7
Liquid Volume Flow	m3/h	0.7092	0.7092	0.1330	0.5762	0.5762	1.617e-002	0.5600	0.1330
Heat Flow	kJ/h	-8.045e+006	-8.045e+006	-1.755e+006	-5.839e+006	-5.839e+006	-1.825e+005	-5.313e+006	-2.098e+006

Material Streams

Fig 3.2 Flowsheet of material balance

SUMMARY OF ENERGY BALANCE ACROSS THE EFFECTS

Table 4.7:

SUMMARY OF ENERGY BALANCE FOR UNIT ONE (PUMP_1)

	INPUT	OUTPUT
Components	Heat Flow (kJ/hr)	Heat Flow (kJ/hr)
Sucrose	-1930919.18	-1930917.391
Water	-6114577.403	-6114571.737
Total	**-8045496.583**	**-8045489.128**

DUTY=	**7.45521155**	**kJ/hr**

Table 4.8:

SUMMARY OF ENERGY BALANCE FOR UNIT TWO (FIRST EFFECT)

	INPUT	OUTPUT
Components	Heat Flow (kJ/hr)	Heat Flow (kJ/hr)
Sucrose	-1930917.391	-1822344.293
Water	-6114571.737	-5770756.927
Total	**-8045489.128**	**-7593101.22**

HEAT LOAD=	**452387.9079**	**kJ/hr**

Table 4.9:

SUMMARY OF ENERGY BALANCE FOR UNIT THREE (PUMP P-101)

	INPUT	OUTPUT
Components	Heat Flow (kJ/hr)	Heat Flow (kJ/hr)
Sucrose	-4764353.917	-4764348.096
Water	-1074238.14	-1074236.827
Total	**-5838592.057**	**-5838584.923**

DUTY=	**7.133220821**	**kJ/hr**

Table 4.10:

SUMMARY OF ENERGY BALANCE FOR UNIT FOUR (STEAM TRAP)

Components	INPUT Heat Flow (kJ/hr)	OUTPUT Heat Flow (kJ/hr)
Sucrose	-1.03E+01	-1.24E+01
Water	-1754498.822	-2097534.503
Total	**-1754509.163**	**-2097546.867**

HEAT LOAD=   -343037.7039   kJ/hr

Table 4.11:

SUMMARY OF ENERGY BALANCE FOR UNIT FIVE (SECOND EFFECT)

Components	INPUT Heat Flow (kJ/hr)	OUTPUT Heat Flow (kJ/hr)
Sucrose	-4764348.096	-4484425.64
Water	-1074236.827	-1011121.579
Total	**-5838584.923**	**-5495547.22**

HEAT LOAD=   343037.7039   kJ/hr

CHAPTER FIVE

CONCLUSION

From the resach conducted using double effect evaporator it was found that the sucrose solution was concntrated to 24wt% of sucros.with the aid of simulation model i.e HYSYS.

RECOMENDATION

This desing of double effect evaporator for concentration of sucrose solution could be use by another method such as :designII,mathcard,aspen+.

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