Designing and Costing of Heat Exchanger & Extraction Column

Internship Report

Submitted for the partial fulfillment of the degree of

Bachelor of Technology

In

Chemical Engineering

Submitted By

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0901CM201013

UNDER THE SUPERVISION AND GUIDANCE OF

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माधव प्रौद्योगिकी एवं विज्ञान संस्थान, ग्वालियर (म.प्र.), भारत

MADHAV INSTITUTE OF TECHNOLOGY & SCIENCE, GWALIOR (M.P.), INDIA

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Jan-May 2024

DECLARATION BY THE CANDIDATE

I hereby declare that the work entitled **"Designing & Costing of Heat Exchanger and Extraction Column"** is my work, conducted under the supervision of **Prof. Shivangi Sharma, Assistant Professor,** during the session Jan-May 2024. The report submitted by me is a record of bonafide work carried out by me.

I further declare that the work reported in this report has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

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Date: 24/05/2024
Place: Gwalior

This is to certify that the above statement made by the candidates is correct to the best of my knowledge and belief.

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CERTIFICATE

Date: 13-05-2024

To whomsoever it may concern,

This is to certify that Ms. Ayushi Jain, B.Tech. in Chemical Engineering (4th year) from Madhav Institute of Technology & Science, Gwalior has undergone 4 months unpaid internship in our organization from 18-12-2023 to 18-04-2024.

During his internship, she completed the project titled "Designing & Costing of Heat Exchanger & Extraction Column" with compassion and diligence.

We wish Ms. Ayushi success in all his future endeavours as she progresses in his professional career.

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This is to certify that I, a student of B.Tech. in Chemical Engineering have checked my complete report entitled **"Designing & Costing of Heat Exchanger & Extraction Column"** for similarity/plagiarism using the "Turnitin" software available in the institute.

This is to certify that the similarity in my reportis found to be 16% which is within the specified limit (20%).

The full plagiarism report along with the summary is enclosed.

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ABSTRACT

The design and costing of heat exchangers and extraction columns are critical components in various industries where efficient heat transfer and separation processes are essential.

For heat exchangers, the abstract would focus on optimizing the heat transfer surfaces, fluid flow patterns, and materials selection to enhance thermal performance while minimizing energy consumption and costs.In the case of extraction columns,the design parameters that influence the efficiency of separating components in a mixture, such as column height, packing materials, and solvent selection, all aimed at achieving the desired extraction efficiency with cost-effective operations.Both the heat exchanger and extraction column designs involve a balance between performance requirements, operational efficiency, and cost considerations to ensure sustainable and reliable processes in chemical, petrochemical, and other related industries.Efficient design and accurate costing methodologies are crucial for achieving optimal performance and cost-effectiveness in these critical process equipment.

Designing& costing of heat exchanger and extraction column have successfully fulfilled the market demand. Additionally, it has followed other aspects to make operation economical &environmental friendly.

Keywords: Cost effectiveness,Design parameters,Efficiency, Methodologies.

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ACRONYMS

HE	Heat Exchanger
HTC	Heat Transfer Coefficient
DQ	Distribution Quality
HVAC	Heating, Ventilation & Air Conditioning
ANSYS	Analysis System
NTU	Number of Transfer Unit
RDC	Rotating Disc Contactor
HTU	Height of Transfer Unit
CFD	Computational Fluid Mechanics
HETP	Height Equivalent to a Theoretical Plates

NOMENCLATURE

LMTD	Log Mean Temperature Difference
TH2	Hot fluid outlet section
TC2	Cold fluif outlet section
TH1	Hot fluid inlet section
TC1	Cold fluif inlet section
Q	Heat duty
C_p	Specific Heat
A	Area
N_t	No. of tubes
ID	Inner Diameter
m	Mass flow rate
U	Overall HTC
l	Length
DO/OD	Outer Diameter
K	Thernal conductivity
Re	Reynold no.
G_s	Mass Velocity
P_t	Tube Pitch
S	Solvent
R	Raffinate
A_n	Net Area
A_s	Surface Area
Db	Bundle Diameter
D_s	Shell Diameter
D	Diameter

Ut	Velocity
C	Clearance
Pr	Prandtl Number
D_s	Shell Diameter
F	Feed
E	Extract
Z	Height of Tower
A_t	Tube Area
Y_s	Raffinate Phase
M_{avg}	Mass Average

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CHAPTER 1: INTRODUCTION

This project focuses on optimizing the cost and making operation easy to handle chemical engineering equipments such as heat exchanger , extraction column & Distillation .A heat exchanger is a system designed to efficiently transfer heat from one place to another. These two medium are generally separated by a solid wall to prevent mixing or they may be in direct contact. HE are globally used in various industries such as chemical processing, power production, heating & cooling in buildings and vehicles, refrigeration, and air conditioning systems.Heat exchangers and extraction columns are crucial elements in industrial processes that necessitate the control of thermal energy and the separation or purification of mixtures. They are constantly improving their designs to maximize effectiveness, cut expenses, and lessen environmental impact.There are several types of HE, but in most of the industries shell and tbe heat exchanger is used

1.1 **Heat Exchanger (Shell &Tube)**

The most popular and often used unfired heat exchangers are shell and tube heat exchangers, in all of their various variations. In this kind of HE, one fluid travels inside the tubes while the other travels over or beside them.Consists of multiple tubes running through a sealed cylindrical shell. One fluid runs through the tubes while another fluid flows over the tubes within the shell.The major parts of a shell and tube heat exchanger are the shell and shell cover, tube and tube sheets, channel and channel cover, baffles, floating head cover, and nozzles.It represent in figure1.1(a)

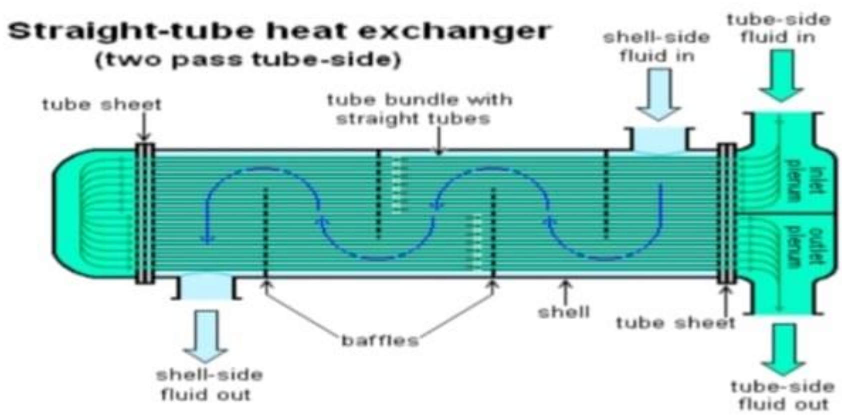

Fig. 1.1(a) Shell & Tube Heat Exchanger (i)

There are different Types of Shell & Tube Heat Exchanger, includes Tie rods, spacer , pass partition plates, impingement plates, longitudinal baffle , supports are the other component.Itshows in figure 1.1(b).

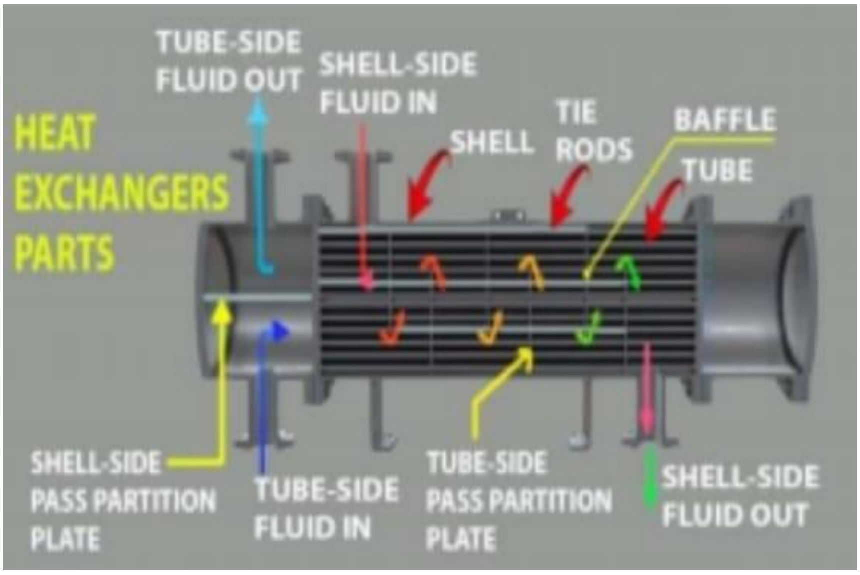

Fig. 1.1(b) – Parts of Shell & Tube Heat Exchanger(ii)

Tube Bundle

The tube bundle, the central component of the shell and tube unit, is made up of components such as tubes, tube sheet, baffles, floating heat cover, split ring, tie rods, spacers, impingement baffle, longitudinal baffle, and sealing & sliding strips. It shows in figure1.1(c).

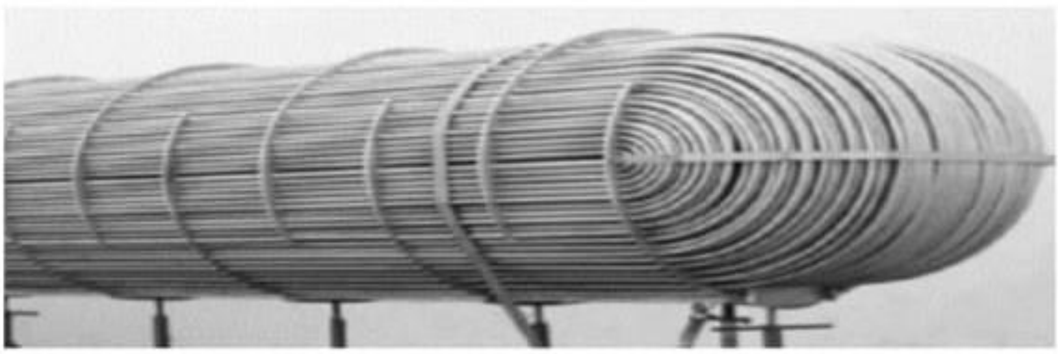

Fig. 1.1(c) Pictorial Viw of Tube Bundle (iii)

Tubes

The tube wall is where heat is really transferred, tubes are the most crucial part. While one fluid flows over or along the outside of the tubes, another flows inside the tubes. Normal tube parameters are wall thickness and outer diameter (OD).

Carbon steel, low and high alloy steels, special SS, admiralty brass, bronze, metals like copper and nickel and their alloys in different quantities.When the shell side fluid is not dirty, low fin tubes can be used effectively in circumstances where the shell side heat transfer coefficient is very controlling.It shows in figure 1.1(d).

Fig. 1.1(d) Pictorial View of Tubes(iii)

Tie Rod

Tie rods also do this. Tie rods are metal rods that are locked into place at the farthest baffle by lock nuts after being put into the fixed tube sheet. The shell diameter indicates the quantity of tie rods needed.

Baffles

Baffles are the very important part of HE. It provides support for tubes & also increases shell HTC. The next baffle is mounted after the baffles have been guided along the tie rods and two spacers have been positioned above the tie rods.

Channel Cover & Pass Partition Plates

The fluid that flows inside the tube and into and out of the exchanger is introduced and guided by the channel. The heat specialist uses pass partition plates inside the channel to guide the tube side fluid along the tubes.They are made to firmly fit into the grooves at the channel cover and tube side, stopping fluid loss on the tube side from moving from one area to another.It represent in figure 1.1(e).

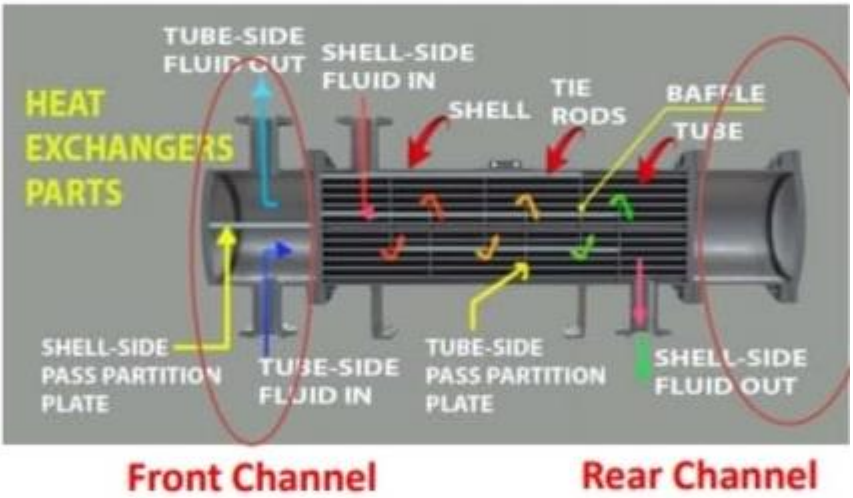

Fig.1.1(e) Pictorial View of Channels(ii)

1.2 Extraction Column

A specialist piece of apparatus used in the extraction process, which involves separating chemicals according to how differently they dissolve in two immiscible liquids—usually water and an organic solventis called an extraction column. Chemical engineering, pharmaceutical manufacture, and the food industry all frequently use extraction columns.Mixing and separation zones are separated by revolving internal components in extraction columns. Stirrers are positioned on a vertical shaft in the mixing zones to provide intense contact between the phases of countercurrent flow. The phases coagulate in the separating zones before moving on to the subsequent mixing zone.Packing columns or sieve tray columns are examples of pulsed columns.

To ensure efficient dispersion of the moving phases across sieve trays or packings in columns, vibration is applied. When comparing columns with and without this pulsation, those with pulsation show superior separation effects. This pulsation can be achieved using additional devices dedicated to vibration, or by harnessing the strong pulsing of high-pressure pumps.It shows in figure 1.2(a).

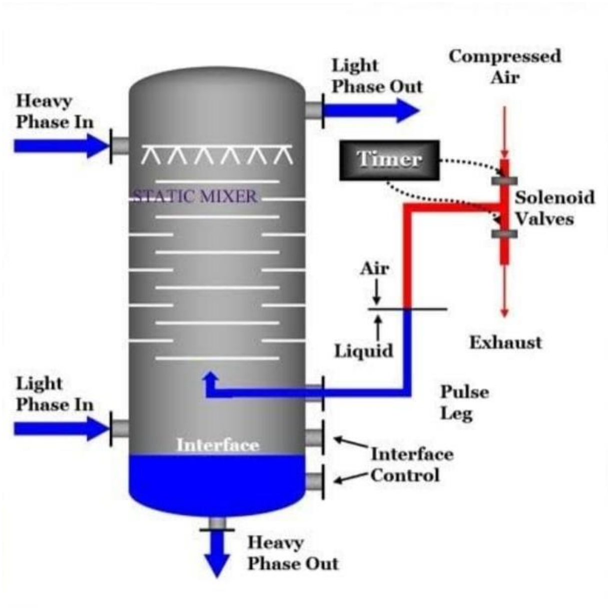

Fig.1.2(a) Pictorial View of Extraction Column(iii)

There are many types of Extraction Column, includes,

Packed Column:A packed column is one that is filled with random or structured packing material. The two phases' surface area is greatly increased by this packing.

Plate Column: Contact between the liquid phases is made possible by a sequence of perforated trays.

Rotating Disc Contactor(RDC):RDCis a device that allows the phases to mix and separate by agitating the fluid with its moving discs.

To improve the solute's transfer to the solvent, droplets of one fluid—typically the aqueous phaseare distributed into anotherthe organic phaseduring the extraction process. The effectiveness of contact between the two liquids.

Column Design: Packed columns, whether filled with random or structured packing, require several essential internal components to ensure their proper functioning. These components encompass vapor and liquid feed distributors, packing support and hold-down plates, entrainment separators, and liquid draw-off trays. Each of these elements needs to be meticulously designed to meet the specific operational needs of the column.

There are some components used in column design .

Liquid distributors: In packed tower design, achieving equal liquid and gas superficial velocity throughout the column section is paramount. The pressure drop across the packing facilitates uniform distribution of the upward flowing gas across the column area. Unlike gas, liquid tends to exhibit poorer cross-mixing tendencies and thus requires meticulous management for consistent distribution at the top of the bed. Liquid distributors, positioned above the packed bed, fulfill this crucial role by ensuring a uniform liquid distribution in discrete streams, achieved through orifices or V-weirs, while also facilitating passage for the upward flowing gas.Upon entering the bed, the packing tends to disperse the liquid, leading to a redistribution process. As the liquid traverses the distributor, albeit less effectively compared to its initial entry into the bed.

Distribution Quality: To assess the uniformity of liquid dispersion across packed beds, it's essential to calculate the distribution quality (DQ) of the distributor.Additionally, calculations are conducted to determine the irrigated, overlapping, and un-irrigated areas of these circles.An ideal distributor should achieve a DQ of 100%, but practical constraints typically limit this to around a maximum of 96%. A lower DQ indicates a higher degree of maldistribution, where some parts of the column area receive substantially different liquid flows compared to others. In larger diameter columns, ensuring proper irrigation of areas near the column wall becomes critical for maintaining a good DQ.A distributor with a high DQ is crucial for realizing the full separation efficiency of the bed. As the distribution quality decreases, the number of stages achievable from the packed bed also decreases. The impact of a poor distribution depends on the number of theoretical stages generated by the packing.

Drip Points: Drip points represent the number of irrigation points per square meter of the column area. They are primarily influenced by factors such as the size of the packing, the liquid load, and the desired distribution quality (DQ). Smaller or more efficient packing, which yield a lower height equivalent to a theoretical plate (HETP), require a larger number of drip points, whereas the opposite holds true for larger packing.In addition to the quantity of drip points, their arrangement and ensuring equal flow are essential for achieving uniform liquid distribution across the column area.

Hydraulic Design: The critical aspect of distributor design lies in the decisions made by the designer regarding various dimensional parameters to ensure its effectiveness across a range of operating conditions.Distributors can operate by feeding liquid under pressure, as seen in pressure feed distributors, or by allowing liquid to flow through due to gravity, as in gravity flow distributors.Pressure feed distributors typically come in ladder arm or spray nozzle types and are utilized for specific applications such as heat transfer services. Due to their operation under pressure, these distributors often feature small orifice sizes. One significant advantage of pressure feed distributors is their ability to thoroughly wet the surface of the packed bed. However, they may be prone to drawbacks like high variations in flow from point to point and higher associated costs.

CHAPTER 2: LITERATURE SURVEY

In the past few years we have faced the challenges and advancements in meeting cooling demands through the design of heat exchangers. It's crucial to continuously review and analyze recent developments in this field to enhance heat transfer efficiency and optimize the design of heat exchangers. By summarizing and surveying existing design methodologies proposed in literature, researchers can expand their understanding of heat transfer calculation methods and pave the way for advanced research in this area. Critically analyzing reports published by different researchers provides valuable insights for future research endeavors aimed at improving the design of heat exchangers. This iterative process of review and analysis contributes to ongoing progress in meeting cooling demands efficiently [1,12,13]. A heat exchanger serves as a fundamental component for transferring heat between fluids at varying temperatures. Diverse types of heat exchangers exist, categorized by factors like construction, flow arrangement, and heat transfer mechanism. They are tailored to specific applications, with optimization criteria typically revolving around parameters such as initial cost, operational expenses, effectiveness, pressure drop, heat transfer area, weight, or material. Through data modeling, the optimization process for a heat exchanger can be framed as a constrained optimization challenge and tackled using contemporary optimization algorithms.

This chapter focuses on elucidating the thermal design and optimization principles pertinent to shell and tube heat exchangers[2] .The increasing energy consumption demands in industries have prompted designers to focus on constructing efficient heat transfer exchangers. Among these, shell and tube heat exchangers stand out for their effectiveness in transferring heat. They are particularly prevalent in HVAC industries, notably in chiller plants, owing to their ample surface area for heat exchange. Material selection significantly influences the design of these chillers. Baffles, crucial elements in these heat exchangers, are studied to enhance their heat transfer efficiency. The paper investigates the impact of baffle spacing on heat transfer through both theoretical and computational fluid dynamics (CFD) analyses. The heat exchanger design and modeling are performed using Creo Parametric, with ANSYS Fluent employed for CFD analysis, considering copper, aluminum, and steel as potential materials. The analysis indicates that copper outperforms aluminum and steel, particularly with minimal baffle spacing, showcasing superior heat transfer performance[3].

A design was conducted for an extraction column aimed at separating water-acetic acid-acetone using chloroform as the solvent. Key outcomes of the design include the determination of mass flow rates and compositions for both the extract and raffinate phases. Additionally, the theoretical and actual number of stages, column diameter, column height, stage efficiency, and tray spacing were established. Stainless steel was chosen as the material of construction for the column[4].The methodology proposed involves a model-based approach for concurrently screening solvents and sizing extraction columns. It integrates a rate based model with a distillation model for solvent recovery and product purification, thereby encompassing the entire extraction process. Specifically, it determines the optimal operating point and column dimensions for each solvent candidate to minimize total costs, serving as the basis for solvent ranking.The application of this methodology is demonstrated from an aqueous feed, with particular attention to the impact of mutual solubility between the solvent candidates and water[5].

It's highlighted that considering mixture properties, accounting for mutual solubility significantly influences fluid dynamics and mass transfer calculations, consequently affecting the required extraction column height.

Moreover, the economic evaluation of solvents is strongly influenced by additional costs associated with solvents solubilized in the aqueous raffinate[6]. Starting with a theoretical model designed using Kern's method, you then validated the design through steady-state thermal analysis using ANSYS 14.0. Subsequently, you constructed a practical model matching the derived dimensions and conducted experiments under different flow conditions, insulation materials, ambient temperatures, and turbulence levels.This thorough approach allows for a holistic understanding of how the heat exchanger operates under real-world conditions and how its performance is affected by different variables. The discussions on these observations likely provide valuable insights into expanding heat exchanger design and operation for practical applications[7]. This literature review provides a comprehensive survey of various heat exchangers (HEs) and their design upgradation through advanced optimization techniques. The primary focus is on optimizing the parametric design of different types of HEs using these advanced algorithms. It's noteworthy that only research works related to advanced optimization techniques are included, making it the first paper to exclusively summarize such works in the context of HE design.The review covers various types of HEs, including shell-and-tube HEs, plate-fin HEs, fin-tube HEs, and different configurations of HE networks[8]. Parametric design upgradation of HEs involves numerous structural and physical parameters, making it highly complex. Hence, there's a preference for advanced optimization techniques in HE design.Previously, there hasn't been an attempt to review parametric design optimization across various types of HEs comprehensively. Therefore, this review paper serves as a consolidated resource, providing valuable information in one place[9]. It is likely to be beneficial for industrial designers and researchers alike, aiding them in choosing the direction of their research in the field of parameter optimization of HEs using advanced optimization algorithms. This paper introduces a method aimed at facilitating the extraction of design knowledge from biological information for bio-inspired design. By combining dependency parsing and keyword extraction techniques, the proposed method aims to identify structures and functions relevant to the subject matter. The dependency parsing establishes relationships between words in sentences, enabling the identification of potential knowledge, while keyword extraction helps filter out terms specifically related to the subject.The evaluation of this method suggests its promise in extracting structure-function knowledge. Additionally, a case study demonstrates its application in improving fan noise reduction through bio-inspired design. Furthermore, an experiment conducted with three different groups indicates that the method not only saves time in extracting design knowledge but also has the potential to generate novel ideas.In summary, the paper presents a structured approach that could significantly aid designers in leveraging biological information for innovative engineering solutions[10].

CHAPTER 3:COMPANY PROFILE

"Myriadly Engineering & Business Solutions Pvt. Ltd." are dedicated to provide Engineering & Business Solutions to the Chemical & Pharmaceutical Industries. Our working principal is to provide Engineering Solutions for Pharmaceutical & Chemical Industries to best of our knowledge. Our all products are customizing as per client need. Our motive is to provide finest quality services to the industries. Our products are manufactured as per Indian and International standards.

Our Company has achieved desired growth in last 4 years due to appreciation and goodwill that customers have showered on it from all over the India. Our Company is putting all its sincere efforts at keeping up to customer satisfaction and demands.

A product that manufactures under Myriadly Engineering & Business Solutions Pvt. Ltd. Issued objected to severe testing & quality checks before dispatch under various stages as Raw material Inspection:- Inspection of raw material has to be done as per requirement &schedule fixed.

Inspection during production:- Inspection of the molding, fabrication, galvanizing & machining has to be done to minimize the rejection & quality production.

Pre dispatch Inspection:- A pre dispatch inspection has to be done after assembly or production of the products to ensure proper fitment of all the accessories.

Drawings & Test Certificates:- All the Drawings & Test Certifications will be provided with the machine. The also provide Engineers to commission the machine.

Our motto is to provide economical solutions without compromising on quality. Infact all our products that include hastelloy coating, glove box,labscale reactors, halar coating, heat exchanger and hastelloy coating heat exchanger are of international standards and undergo stringent quality checks before they reach the end user.

CHAPTER 4: PROBLEM FORMULATION

In whole chemical engineering curriculum, I have found that heat exchanger holds much importance in most of the industries. It is not used only in chemical plant but also has uses in other mechanical works. Designing of unit operation equipments are first step to achieve the desired results. If the equipment has not designed properly it can led dangerous situati on. Several past accidents such as chernoboyl accident is an example of equipment failure that caused loss of live sand property. Moreover economic design of an equipment is the secondary factor that needs to be fulfilled.

Problem 1. Design a heat exchanger of the following duty.

(i) Fluid specification : Water

(ii) Purpose : To cool Hot Fluid stream

(ii) Temperature data

Hot fluid , Inlet section = 90℃,Outlet section = 50 ℃

Cold fluid , inlet section = 32 ℃ Outlet section = 40.889 ℃

(iv) flow rate : Hot fluid(Tube) = 5.528 kg/s, Cold fluid (Shell) = 24.875 kg/sec

Keep important points while designing the heat exchanger: (1) How protected is your heat exchanger against pressure & flow rate variations ? (2) How much safety margin should be used during the construction? (3)Will this heat exchanger be economical to used for the given system ?

Problem 2 . Extraction columns are an important part of chemical process industries. Caffeine extraction is a well-known example. Design a column to obtain 99% purity of the extract for the provided parameters(Water in feed – 97.5%, Volumetric flow rate – 3m^3/hr, Raffinate – 1% allowable, Caffeine in feed – 2.5%, equilibrium relation(Y_e) = 1.2* X_r). Include the following points in your design a.) The quality of the extract cannot be compromised. b.) Provide importance of various parameters used c.) Would the proposed design be suitable for %x changes in parameters i.e. mention the assumptions used and limitations of the columns.

Problem 3 Oil extraction from meal using benzene in a continuous countercurrent extractor is planned to treat 1000 kg of meal per hour. The untreated meal consists of 400 kg of oil and is contaminated with 25 kg of benzene. The fresh solvent mixture contains 10 kg of oil and 655 kg of benzene. After extraction, the exhausted solids are expected to contain 60 kg of unextracted oil. Experiments conducted under conditions identical to those of the projected setup demonstrate that the amount of solution retained depends on the concentration of the calculated the concen. Of the strong solution. (2) Concentration of the solution adhering to the extracted solids. (3) the mass of solution leaving with the extracted meal. (4) mass of extract solution. as shown in Table 1. (1). (4) Also calculated number by using Mccabe Thiele diagram.?

S.No.	**Concentration Kg oil/ kg solution**	**Solution retained Kg/kg solid**
1.	0	0
2.	0.0	0.500
3.	0.1	0.505
4.	0.2	0.515
5.	0.3	0.530
6.	0.4	0.550
7.	0.5	0.571
8.	0.6	0.595
9.	0.7	0.620

Table 1. Solution Retained Data

CHAPTER 5:METHODOLOGY

5.1Method 1.

Heat Exchanger Design

We have used kern's Method to solve our heat exchanger problem.the advantage associated with this method is that it is easy to apply and accurate enough for design calculation.

This problem has been solved in following steps .

1. First of all, the type of heat exchanger has been selected (for a given duty in the problem shell & tube heat exchanger is suitable) .
2. Then the selction of fluids, either in tube side or shell side.
3. To achieve maximum heat transfer counter current mode of heat exchanger is selected.
4. Fluid properties at bulk mean temperature is to be determined.
5. Log mean temperature is calculated with the help of below given formula

$$LMTD = \frac{(TH1 - TC2)-(TH2 - TC1)}{ln\left(\frac{TH1 - TC2}{TH2 - TC1}\right)}$$

6. Temperature correction factor has used to correct the LMTD.
7. Heat duty is calculated as

$$Q = m * Cp * \Delta T \; or \; Q = m * Lambda$$

8. With the help of literature for given system universal heat transfer coefficient is assumed .
9. Now, the area is calculated as

$$A = \frac{Q}{U * LMTD}$$

Tube side calculation

10. Then tube length & diameter is specified .
11. No. of tubes is calculated as

    No. of tubes Nt = A/pi*do*l
12. Based on our problem No. of passes has been selected.
13. Baffle spacing is calculated and head type is selected.
14. Tube pitch is to be selected (for given problem triangular pitch has been used).

15. Then based on the the fluid parameters the reynold and prandtl no. can be calculated as

$$Re = \frac{D*Gs}{\mu} \qquad pr = \frac{\mu*Cp}{K}$$

16. For given reynold no. and selected head the parameters such as j_h and j_v have determined.
17. Now finally we can calculate heat transfer coefficient for tube side fluid using nusselt no. correlation.

<u>For shell side calculation</u>

1. Same above procedure has been repeated for the shell side fluid.
2. Shell diameter is calculated.
3. Shell side parameters like shell side reynold no. ,prandtl no. ,heat transfer is then calculated.
4. Now with the help of tube side htc and shell side htc overall htc is to be determined and if calculated overall htc is less than the assumed htc then process will again be repeated from 8^{th} step.
5. If the calculated overall htc is grater than the assumed htc then our designing parameters are efficient for particular heat duty.
6. Then the pressure drop calculation is verified once again for the both fluids.

7. This completes the designed part .Now with the help of given data cost analysis is to be done to check the disgn is economical or not.

Method for Extraction Column 2 & 3

1. **Problem Identification and Representation:**
   - Begin by understanding the problem you need to solve.
   - Draw the phase diagram to represent the components involved (solvent, extract, and raffinate).
2. **Identify the Solvent and Extract Phases**:
   - Determine the solvent (S) and extract (E) phases.
   - Read the problem carefully to identify the solute to be extracted.

3. **Convert Fractions and Flow Rates to Solute-Free Basis**:
    - Express flow rates and fractions in terms of moles of solute per moles of other constituents.
    - For example, use the ratio X = X / (1 - X), where X represents the moles of solute per moles of other constituents, and x is the mole fraction of solute.
    - Define Fs as the solute-free feed rate and F as the total feed rate with solute.
4. **Mode of Operation**:
    - Check if the mode of operation (e.g., countercurrent) is specified.
    - If not, use countercurrent operation for maximum purity of the extract.
5. **Material Balances**:
    - Apply general material balances across stages (F + S = E + R).
    - Component balance: F * Xr + S * Ys = E * Ye+ R * Xr
    - For solute-free basis, F and R flow rates will be equal for each stage.
6. **Equilibrium Relationship**:
    - Ensure that the equilibrium relationship is given between the extract and raffinate phases.
7. **Pure Solvent Case**:
    - If the solvent is pure, the raffinate phase (YS) will be zero.
8. **Calculate Minimum Number of Stages**:
    - Use the Kremser equation to regulate the minimum number of equilibrium stages required.
9. **McAbe-Thiele Plot**:
    - Find the stages from the McCabe-Thiele plot.
10. **Efficiency of the Column**:
    - Determine the efficiency of the column for practical situations.
11. **Actual Number of Stages**:
    - Calculate the actual number of stages using the theoretical plates and efficiency from literature.
12. **Calculate Height of the Tower (Z)**:
    - Z = HTU (Height Transfer Unit) * Number of actual stages.

13. Flooding Velocity:

- Find the flooding velocity for the given operation and select 60-65% of it.

14. Then calculate net tower cross section area with the help density , mass flow rate and operating velocity.

15. Then find total tower area as An=0.90At

16. Then further calculation will depend on the type of valve selected for the operation.

Bubble cap provides maximum pressure drop with very less weeping problem.

17. Safety factor must also involved during designing.

5.2 Analysis

Solution (1) Given,

Solvent : Hot water(Tube side), Cold Water(shell side)

Mass flow rate = 24.875 kg/s

Cp(Hot) = 4.2 J/g°C

Temperature (Hot fluid)

Inlet section – 90°C , Outlet - 50°C

Temperature (Cold fluid)

Inlet section - 32°C , Oulet – 40.889°C

Passes - 2 , OD = 0.02 m, ID = 0.016m

Clearance – 25%, baffle spacing – 7inch

(i) Log mean Temperature difference

LMTD = 28.863°C

Q = 1393.00 KW

(ii) Area – 48.26 m^2

(iii) No of Tubes – 194

Using split ring floating head Type HE

Bundle Dia(mm)- 408.502

Db Clearance – 56 mm

Shell dia. = 464 mm

Temperature difference

ΔT = 26.88°C

(iv) Cold terminal difference

Tc = 36°C (Mean Shell side Temp.)

tc = 70°C (Mean tube side Temp.)

shell side calculation

(i) Bundle crossflow per area $(As) - 0.5 * \frac{ID*C*B}{144*Pt}$

Baffle spacing (mm) = 929 mm

$As = 86315.9 \ mm\text{^}2$

(ii) Mass Velocity (G_s) $- 116 \frac{kg}{s} * m^2$

(iii) At temperatature , Tc = 36°C

Viscosity (µ) – 0.8 Ns/m^2

Specific heat(C_p) – 4.2 J/$g°C$

k – 0.59 w/m*k

(iv) D_e – 14.201 mm

(v) Reynold No. (R_e) – 5115.653

(vi) Prandtl No. – 5.695

baffle cut % - 25 %

(vii) Heat Transfer factor (J_h) - 0.0028 (from graph)

(viii) HTC outside bundle (h_o) – 1056 w/$m^2°C$

Tube side calculation

Method 1

Mean hot temp. = 70$°C$

(v) Tube cross section Area = 201.062 mm^2

(vi) Tube per pass = 97

Total Flow Area = 19503.007 m^2

(vii) Water linear velocity = 0.285 m/s

Density = 995 kg/m^3

(viii) Tube side Coeff. h_i = 2429.175 W/m^2$°C$

Heat Exchanger method -2

(v) At temp tc –70°C

µ - 0.8 Ns/m^2

(vi) K = 0.59 W/m°C

(vii) Reynold No.= 5668

(viii) Prandtl No. – 5.695

(ix) L/di – 250

(x) Heat transfer factor , J = 0.0038

(xi) Tube side Coeff., hi = 1410.28 W/m^2°C

(xii) Outside dirt factor – 3000 W/m^2°C

(xiii) Inside Dirt factor – 5000 W/m^2°C

(xiv) Overall HTC = 1200 W/m^2°C

Solution 2 Given,

Water – 97.5%

Caffeine(feed) – 2.5%

Volumetric flow rate – 3 m^3/hr

Raffinate (R) – 1% (allowable)

Molar mass of caffeine – 194.19

Density (caffeine) – 1230 $\frac{kg}{m^3}$

Density of water – 1000 $\frac{kg}{m^3}$

Average density of feed – 1005.75 $\frac{kg}{m^3}$

(i) Mass flow rate (m) = 3017.25 kg/hr

(ii) Mavg(feed) = 22.4047

(iii) Molar flow rate (M) = 134.670103 kmol/hr

(iv) X_f - 0.025

(v) Mole of caffeine

In feed – 3.366 kmol

In extract – 3.33 kmol

In raffinate – 0.0336 kmol

(vi) Water

In feed – 131.303 kmol

In raffinate – 131.303 kmol

(vii) X_r – 0.00025641

(viii) Equilibrium relation $Y_e = 1.2* X_r$ (given)

Y_e – 0.0003072

(ix) Applying balance,

F+ S = E+R

$F*X_f + S*Y_s = E*Y_e + R*X_r$

S = 10847.08 kmol/hr

E = 10847.08 kmol/h

(x) Mole fraction of caffeine

in extract – 0.000307

(xi) Mole fraction of $CHCL3$ – 0.9997

(xii) Mole fraction of caffeine in raffinate – 0.00025634

(xiii) Mole fraction of water in raffinate – 0.9997

(xiv) Density(feed) = 1000 $\frac{kg}{m^3}$

Column design

(xv) No. of stages - 3 (by kremerser equation)

Efficiency – 20% (given) (perforated plate column is used)

Actual no. of plates – 15

(xvi) Height of Tower – 15m

(xvii) Flooding Velocity – 0.5 $\frac{m}{s}$

(xviii) Net area (An) – 0.5680 m^2

A_t – 0.6311 m^2

(xix) Diameter – 0.897 m

Solution 3 Given,

Feed = 1000 kg of meal

Solute(oil) = 400 kg

Solvent (benzene) = 25 kg

Oil in extract = 10 kg

Benzene in raffinate = 655 kg

(i) In the solvent inlet,
Mass (V_b) = 665 kg solution/hr
Mole fraction (Y_b) = 0.01

(ii) If X_b = 0.1 , the solution retained, from table 1, is 0.505 kg/kg. then mass of solution leaving with extracted meal

L_b = 0.505*(1000)

= 505 kg/hr

Mole fraction (X_b) = 0.119

From table ,the solution retained is 0.507 kg/kg
L_b = 0.507*(1000)
= 507 kg/hr

X_b = 0.118

(iii) Benzene in the underflow at L_b is
= 507- 60
= 447 kg/hr

At the solid inlet ,
L = 425 kg solution/hr
X_a = 0.941

(iv) Oil in extract = 350 kg/hr
Benzene in extract = 233 kg/hr

(v) The mass of extract (V_a) = 583 kg/hr

Mole fraction (Y_a) = 0.60

(vi) Since X_1=Y_a= 0.60 solution retained is 0.595 kg/kg solid

(vii) Overall material balance

$$F+S = E+R$$

$$S = 753 \text{ kg/hr}$$

(viii) Mole fraction in extract = 0.408

Chapter 6: Result & Discussion

All the problems have been solved with the conditions provided.

1.The heat exchanger is designed in such a way that it can accommodate up to 5% variation in flow rate, this can be understood from the value of the overall HTC. The proposed designing of heat exchanger meets the demand. The construction of this exchanger design should be accomplished with a high safety margin of 1.5. This shows how safe the design is against equipment failure. Economic analysis has been conducted to examine its economic feasibility.Therfore, we can say that the heat exchanger is practically suitable for the given case.

Some important parameters obtained for given problem are

Overall htc assumed < calculated from individuals htc

$U=1200\ W/m_2k$, $U = 1000\ W/m_2k$

Heat duty = 1393 KW

2.The caffeine extraction is an important example mass transfer operations.The problem is solved accurately without compromising the quality (strictly follow at 99%). The amount of solvent can be changed to maintain caffeine extraction up to 99% with different feed flow rates and in that case the number of stage required will be more. A equilibrium between the extract and raffinate phase must be maintained in each stage. Additionally, the solvent must be low viscous and partially miscible with the carrier, so attention must be paid to temperature variations during the process. An increase in temperature will increase the solubility of the solvent with the carrier liquid and the operation will become less economical since solvent recovery units in this case will keep more charge.

For the given problem following results obtained

No. of stages obtained = 3

Height of column = 15m

Extraction of 99% of caffeine from feed

3.The important results of 2nd extraction problem are

(i) Although the calculations are lengthy the mass blance is easy to apply.

Oil extracted = 350 kg/hr

Solvent used = 750 kg/h

(ii) On solving No. of stages with the help of Mccabe Thiele plot . The graph is obtained . which is shows on figure no. 6.1

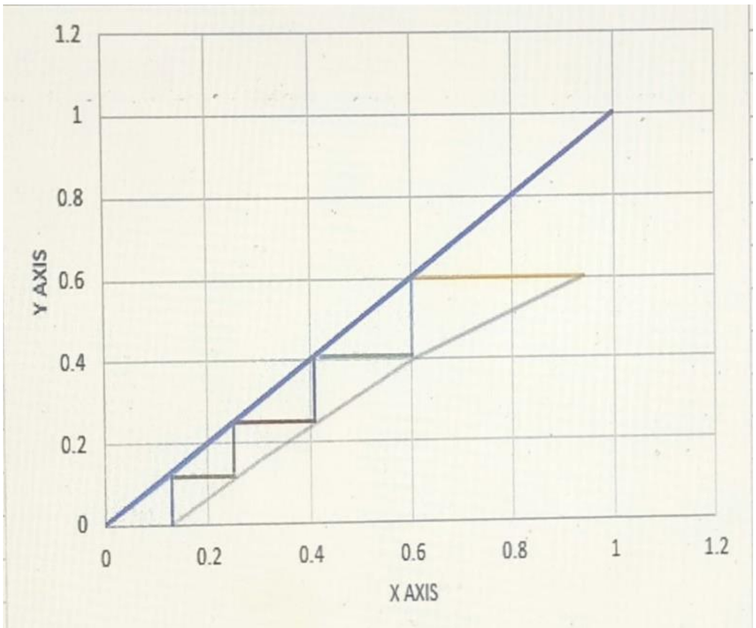

Fig.6.1 Mccabe Thiele Graph

Chapter 7: CONCLUSION

In chemical engineering , designing equipment like heat exchangers , extraction column involves considering factors like heat transfer rates, material compatibility, pressure drops, 7 energy efficiency . The conclusion often emphasize the importances of optimizing these parameters to ensure optimal performances , safety ansd cost effectiveness in industrial processes. It underscores the significance of thorough analysis, simulation & experimentation to achieve desired outcomes & meet industry standards and regulations . Additionally, it highlights the ongoing need for innovation and improvement in equipment design to address evolving challenges and requirements in the field of chemical engineering .

Designing and costing of a heat exchanger and extraction column would depend on various factors such as the specific requirements, operating conditions, material constraints. It's, and budget essential to thoroughly analyze the design parameters, consider various options, evaluate costs, and ensure the chosen design meets the desired performance criteria within the allocated budget. The design of a heat exchanger requires meticulous attention to detail, balancing various parameters such as heat transfer efficiency, pressure drop, material selection, and cost-effectiveness. Through thorough analysis, simulation, and iterative refinement, we have crafted a heat exchanger design that meets the specified requirements and optimizes performance. By leveraging advanced computational tools and engineering principles, we have achieved a design that not only enhances heat transfer rates but also ensures operational reliability and longevity. Moving forward, ongoing monitoring and maintenance will be essential to uphold performance standards and adapt to changing operational conditions. This design serves as a testament to the synergy of innovation, engineering expertise, and practical application in the pursuit of efficient thermal management solutions." A detailed cost-benefit analysis and comparison of different design alternatives would be necessary to make an informed decision. Additionally, considering factors like effisciency, maintenance requirements, and potential future scalability would contribute to be comprehensive conclusion

CHAPTER 8: PROJECT OUTCOMES

8.1 Achieved Outcomes

1. Design modular heat exchanger systems to adapt to varying production demands.

2. Design extraction column system to adapt to varying production demands.

3. Conduct a lifecycle analysis to assess the environmental impact and sustainability of the designed equipment, including factors such as energy consumption, material sourcing, and end-of-life disposal or recycling options.

4. Evaluate heat Exchanger & Extraction Column parameters.

5. Facilitates cost analysis in designing phase .

8.2 Societal Relevance

1. This project is based on 'safety first' principle. Hence during the designing much care is to be considered. There is always proper safety factor in designing all equipments. We all know that operability of these chemical engineering equipments are directly related to workers so that we can't ignore their safety. Many chemical disaster in the past are evident that failure of equipment causes immense loss to society.

2. Efficient heat exchanger design and costing directly impact operational expenses for industries and consumers alike. By optimizing designs and minimizing costs, businesses can improve profitability, which can lead to economic growth and job creation.

3. Advancements in heat exchanger design and costing lead to the development of new technologies and materials, driving innovation in various sectors. This innovation not only improves existing processes but also opens up new possibilities for applications in renewable energy, waste heat recovery, and sustainable manufacturing.

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<u>Image Reference</u>

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TURNITIN PLAGIARISM REPORT

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APPENDIX SECTION

1. **<u>Appendix A (</u>**Problem 1)

Given					
	Hot (tube	Cold (shell)			
Temp in (℃)	90	32		OD(mm)	20
Temp out (℃))	50	40.889		ID(mm)	16
Specific heat (Cp)	4.2	4.2	j/g *℃	Length(m)	4
Mass flow rate (kg/s	5.528	24.875			
overall HTC(U)	100	W/m^2℃	(assumed)		
parameters		counter current			
θ1		49.111			
θ2		18			
LMTD		28.863			
Heat duty(kw)		1393			
Area(m^2)		48.262			
Nt		194			
Using split ring floating head type HE					
Bundle diameter(mm)		408.532			
Db clearance (mm)		56			
Shell dia(mm)		464.532			

Fig.1 It shows the designing of Heat Exchanger

Tube Side Calculation	fluid = Water(Hot)
Method 1	
Mean hot Temp(°C)	70
tube cross Section area(mm^2)	201.062
Tubes per pass	97
Total flow area (mm^2)	19503.01
Density of Hot fluid(kg/m^3)	995
Water linear velocity (m/s)	0.285
tube side coeff.,hi(w/m^°C)	2429.175
Method 2	
Viscosity (ns/m^2)	0.8
Thermal Conductivity(w/m^2°C)	0.59
Reynold No.	5668.641
Prandtl No.	5.695
L/di	250
Heat transfer factor,J	0.0038
Tube side Coeff,hi(W/m^2°C)	1410.28

Fig. 2 It shows Tube side calculation

Shell Side Coefficient)	Fluid = Water(cold)
Baffle spacing(mm)	929.064
Cross flow area,As(mm^2)	86315.93
Mass velocity (kg/s.m^2)	116
Equivalent diameter(mm)	14.201
Mean shell side temp.(deg C)	36
Density (kg/m^3)	995
Viscosity(ms/m^2)	0.8
thermal cond.(w/m* deg c)	0.59
reynold No.	5115.653
prandtl No.	5.695
taking baffle cut %	25
heat transfer factor, J	0.0028
Shell Side Coefficient)	1056
SS- 316(W/m^2°C)	16.3
outside dirt Coefficient	3000
inside dirt coefficient (W/m^2°(	5000
Overall HTC	1200 W/m^2*°C

Fig. 3 It shows shell side Calculation

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1																	
2	Parts of HE		Quantity	Material	Size(mm)	thk(mm)	weight	Rate Rs. /Kg		Amount			Column1	Column2	Wt.Kg	Rate	Amount
3	1 Tubes		32	SS316	15.8 x 4876	1.65	22.88	950		21736			Labour		156	45	7020
4	2 Tubesheet		2	SS316	500 OD	20	62.8	300		18840			consumable		238	5	1190
5	3 Baffle		6	SS316	160 OD	3	17.163	410		7036.83			Tubesheet drilling		22	40	880
6	4 tie rod + spacer			SS316						6000			Baffle		198	25	4950
7	5 Shell / tube Nozzle			SS316									D/E forming		4	20	80
8	6 Shell		1	SS316	250 OD *	4.19	52.85	50		2642.5							
9	7 nuts & volts		2	SS316												Total	14120
10	8 Body Flange		2	SS316	300OD x 16	22	17.162512	300		5148.7535							
11	9 Gaskets		1	SS316						4000							
12	10 Earthing Boss		2	SS316						1000							
13	11 Channel Dish		2	SS316	265	4	4.4944	300		1348.32							
15												Material	68352.4				
16									total	68352.403		Labour	14120				
17												Total	82472.4				

Fig 4. It shows the costing of Heat exchangers parts

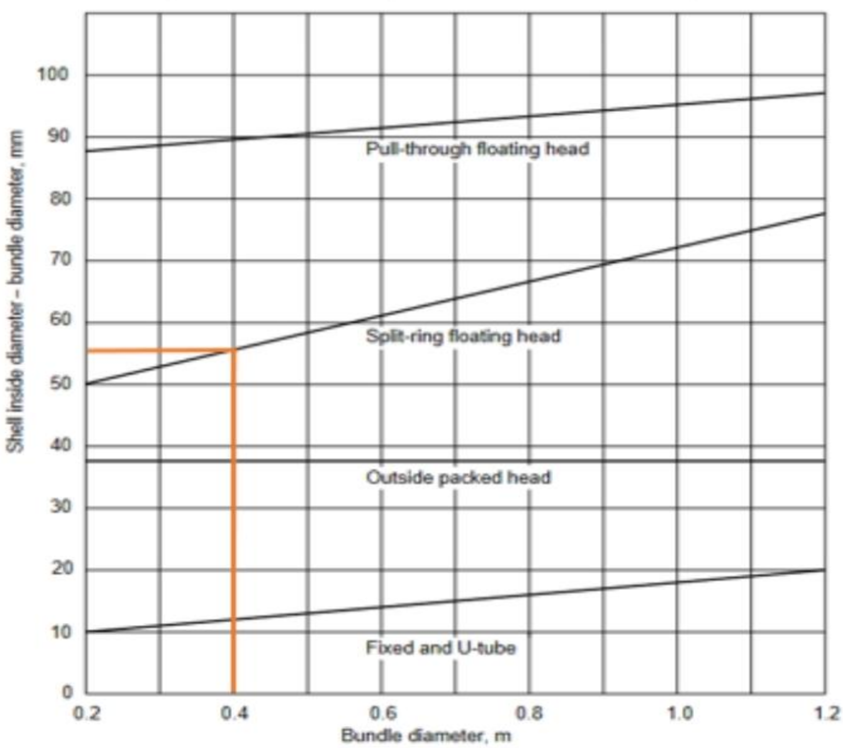

Fig. 5 Bundle Diameter Graph

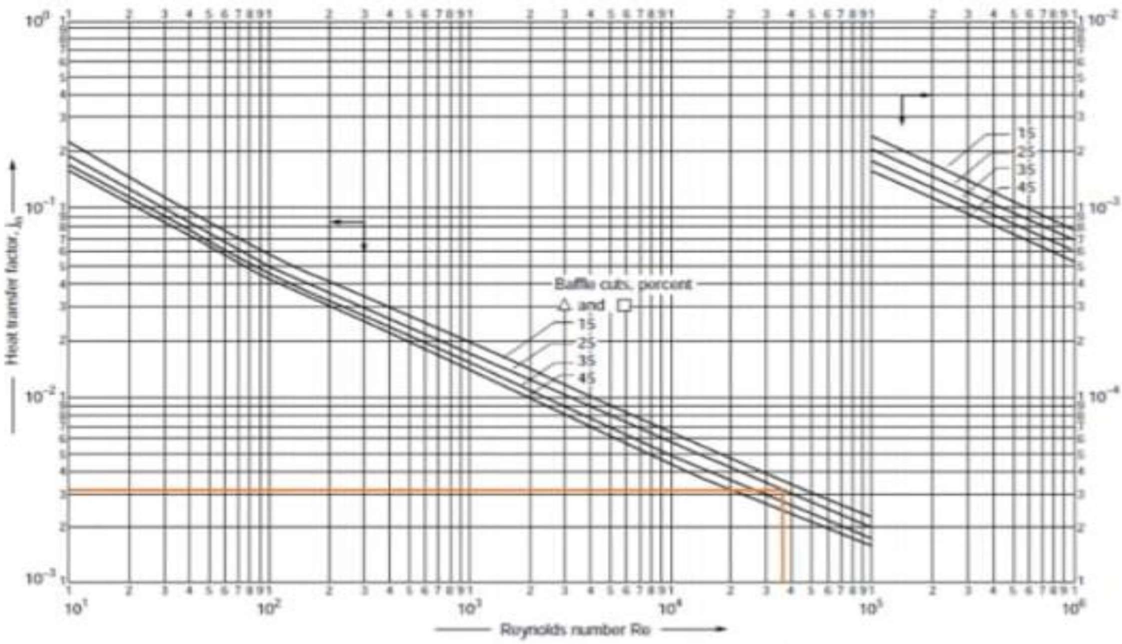

Fig. 6 Heat transfer factor J , Graph(shell)

2. **Appendix B** (Problem 2 & 3)

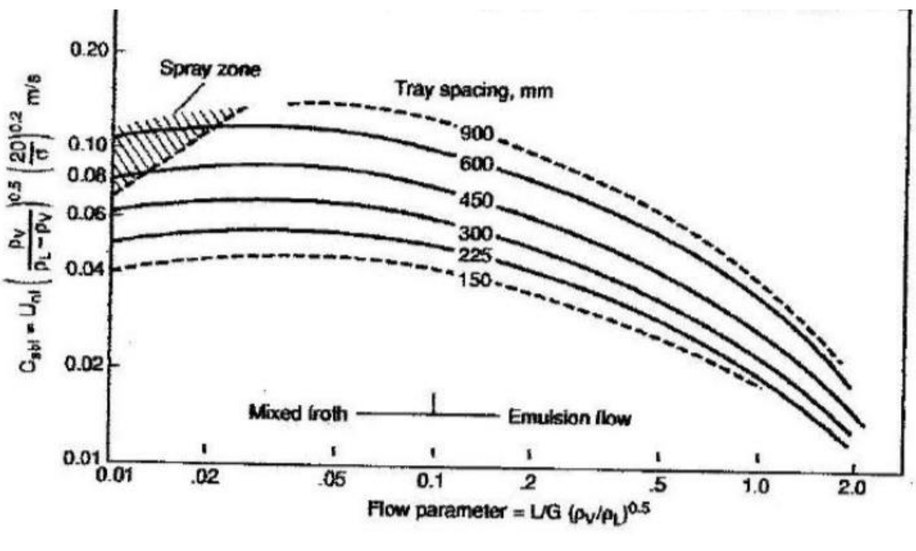

Fig.7 Flooding Velocity Graph

	B	C	D	E	F	G
1	Caffeine Extraction					
2						
3	Water (feed)			97.5	%	0.975
4	Caffeine(feed)			2.5	%	0.025
5	Vol. flow rate (feed)			3	m^3/hr	
6	Raffinate			1	%	Allowable
7	Caffeine(Mw)			194.19		
8	Chloroform(Mw)			119.38		
9	Density(caffeine)			1230	kg/m^3	
10	Density(water)			1000	kg/m^3	
11	Density(chloroform)			1490	kg/m^3	
12	Avg. Density(feed)			1005.75	kg/m^3	
13	Mass flow rate (feed)			3017.25	Kg/hr	
14	Mavg(feed)			22.40475		
15	Molar flow rate(feed)			134.670103	kmol/hr	
16	Xf			0.025		
17	Mole of caffeine (in feed)			3.36675259	kmol	
18	In extract			3.33308506	kmol	
19	In raffinate			0.03366753	kmol	
20						
21	Water (In feed)			131.303351	knol	
22	(In Raffinate)			131.3034	kmol	
23	Xr			0.00025641		
24	Equilibrium Relation			(Ye= 1.2*Xr)		
25		Ye		0.00030769		
26	Solvent (Flow rate)			10829.7249	kmol/hr	
27				1292852.56	Kg/hr	
28	Extract(E)			10829.72	kmol/hr	
29	Avg. Density (Rho S)			1490	kg/m^3	
30	Avg. Density (Rho f))			1000	kg/m^3	
31						
32	No. of stages			3	(kremerser eqn)	
33	Efficiency			0.2	(perforated plate coiumn (6-	
34	Actual no. of plates			15		
35	HTU			1	(PPC (1-20))	
36	Height (H)			15	m	
37						
38	An			0.56711522	m^2	
39	At			0.63012802	m^2	
40	Diameter(D)			0.89594132	m	
41						

Fig. 8. Extraction Column Design (Problem 2)

	B	C	D	E	F	G	H
11	Given ,	Feed	(A+B+C)				
12		Meal	1000	kg			
13		oil	400	kg			
14		Benzene	25	kg			
15							
16		Solvent	Benzene	(Ben. + oil)			
17		Benzene	655	kg			
18		Oil	10	kg			
19							
20		Unextracted oil		60	kg		
21		solvent (					
22							
23		Solvent flow rate (Vb)			665	kg/hr	
24		mole fraction of solute (Yb)			0.01503759		
25		concen. Kg/kg (xb)			0.1		
26		mass of sol.leaving extracted meal(Lb)				507	kg/hr
27		concentration of sol. To extract solid(Xb)				0.1183432	(very close to xl
28		Benzene in solid		447	kg/hr		
29		At solid inlet (oil flow rate La)			425	kg sol/hr	
30		mole fraction (xa)		0.94117647			
31		Oil in extract		350	kg/hr		
32		benzene in extract		233	kg/hr		
33		The mass of extract (Va)			583	kg/hr	
34		Conce. Of strong sol or extract(Ya)			0.60034305		
35		for calculating no. stages					
36		X1= Ya	0.6				
37		retained sol.		0.595	(from table)		
38		L1	595				
39		Overall Material Balance ,					
40							
41		V2	753	kg/hr			
42							
43		Oil Balance ,					
44			La*xa + V2*y2 =				
45			L1*x1 + Va*va				
46			y2*753	306.8			
47			y2	0.40743692			
48							
49	5	No of stages		4			
50							
51	6	Efficiency		0.8			
52	7	No. of Actual plates		5	(NTU)		
53	8	HTU		1			
54	9	Height of tower		5			
55	10	density (feed)		307.224	kg/m^3	(oil)	
56	11	density (Solvent)		525.6	kg/m^3	(Benzene)	
57	12	Mass of Solvent		rho (v) * An*0.85*flooding velocity			
58				19.7422142	An		
59	13	An	0.01407024	m^2			
60	14	An	0.90*At				
61	15	At	0.0156336	m^2			
62	16	At	pie*d^2/4				
63	17	D	0.14	m			

Fig.9 Extraction Column Design (problem 3)

3. Appendix C (Daily Diary)

Daily Diary

Date - 18/12/2023 to 23/12/2023.

- Orientation Programme
- Visit to the industry, workshop and various other parts of industry.
- Observed the working of industry
- Learnt the work culture of the industry.
- Communicate with colleagues.

Date - 24/12/2023 to 30/12/2023.

- Firstly, Asked to study about different types of Heat Exchanger.
- Studied for the same.
- Got my first project on designing a Heat Exchanger for Ethanol + Water Syste
- Studied about the problem and understood about the same.
- In starting phase, i got some difficulties but my industrial mentor explained & helped me well with it.

Daily Diary

Date - 31/12/2023 to 6/01/2024

- Solved the problem and designed the heat Exchanger.
- calculated overall heat Transfer coefficient and its Area.
- At instant, i started with calculation by hand but then i learnt the excel.
- In excel, i calculated the same afterwards correctly.

Date - 7/01/2024 to 13/01/2024

- After solving # the problem, my industrial ~~gu~~ mentor taught me the drawing practically.
- In this, I learnt the mechanical design of heat Exchanger.
- Observed the making of tube bundle and parts of heat Exchanger.

Daily Diary

Date - 14/02/2024 to 20/02/2024

- I solved the extraction problem given by my guide at the industry.
- I Analyzed the problem carefully and derived the solution
- I have learned to plot the graph of the solution in excel.
- I visited the workshop in industry and learned about tube bundle used in HE and my guide explained about mechanical design of that tube bundle.

Date - 21/02/2024 to 27/02/2024

- I observed the working in AutoCAD
- I got my next problem on extraction of caffeine from water.
- My guide explained me about the problem and we had a discussion.
- I started working on the problem by analyzing it and studying about it.

Date - 20/03/2024 to 28/03/2024

- I researched about the calculation for distributor.
- In this, there is calculation of pressure drop and its dimensions.
- Main work of distributor is to balance the vapour and liquid in extraction coloumn.
- I learnt that, without distributor there is no means of coloumn.

Date - 29/03/2024 to 04/04/2024

- Also, my mentor asked me to study P&ID Diagram for extraction coloumn designing.
- P&ID Diagram is very important to study for designing because it gives the representation of extraction coloumn at prior stage which makes the designing easy.
- P& ID Diagram is like a mind map for designing.