Modelling, and Optimization of Plate Type Heat Exchanger through Scaling Reduction

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Certificate

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Dedications

This project, thesis and all related work is dedicated firstly to our beloved parents, who taught us that the best kind of knowledge to have is that which is learned for its own sake and without whom none of this would have been possible. They are the reason we have reached thus far and continue to prosper in life, so we dedicate this project to them. We also dedicate this work to our Department, the School of Chemical and Materials Engineering, and to our university, National University of Sciences and Technology for providing us with not only the opportunity to carry out this project in the most supportive of environments, but for also grooming us to avail that opportunity to the fullest. Lastly, we dedicate this project to our Project and Industry supervisors, who have made this project possible through their guidance, support and constant encouragement.

Abstract

Fouling in process equipment has been regarded as one of the major issues in any industry because it leads to massive loss of time, energy in the form of heat in heat transfer equipment and efficiency of the unit. Heat exchangers are of primary use in almost every industry for heat transfer applications. But with the cooling water having calcium carbonate present in it which causes scaling on heat exchanger surface, the efficiency of heat exchanger is greatly lowered because of decrease in heat transfer and cleaning is needed on a weekly basis. At ICI Soda ash plant one Plate heat exchanger is shut down for cleaning every single day and this is causing great harm to heat transfer requirement.

This Project is focused on modelling of Plate heat exchanger in Aspen Exchanger Design and Rating (EDR) and optimization through manipulation of process conditions and by devising a Scale Prevention technique to reduce the cleaning requirement as this technique will mitigate the scale formation. A plate heat exchanger was designed in Aspen Exchanger Design and Rating (EDR) and then optimized it by manipulating process variables. Afterwards a scheme was devised for the process that uses scale inhibitors in water. The scale inhibitor will cause 74% inhibition and will increase the heat transfer by 20% which is lost due to fouling in heat exchanger and increases the life of heat exchanger.

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Nomenclature and Abbreviation:

- TPA   Tonnes per annum
- PHE   Plate Heat Exchanger
- ppm   Parts per million
- LSI   Langelier Saturation Index
- Ca   Calcium
- T_{H1}^{IN} Hot fluid inlet temperature
- T_{H1}^{OUT} Hot fluid outlet temperature
- T_{C1}^{IN} Cold fluid inlet temperature
- T_{C1}^{OUT} Cold fluid outlet temperature
- q   Heat transfer
- Q   Heat transfer rate'
- m   Mass flow rate
- Cp   Heat capacity at constant pressure
- Δh Change in enthalpy
- U   Overall heat transfer coefficient
- A   Exchanger area
- ΔT_m Temperature difference
- ε Effectiveness
- q_{max} Maximum heat transfer
- C_{min} Minimum heat capacity rate
- $T_{h,I}$ Inlet temperature of hot fluid
- $T_{h,o}$ Outlet temperature of hot fluid
- $T_{c,I}$ Inlet temperature of cold fluid
- $T_{c,o}$ Outlet temperature of cold fluid
- C_h Heat capacity rate of hot fluid
- C_c Heat capacity rate of cold fluid
- C_{max} Maximum heat capacity rate
- U   Overall heat transfer coefficient
- A   Effective heat transfer area
- C^* Heat capacity ratio
- NTU   Number of transfer units

- P   Temperature effectiveness
- C_1 Heat capacity rate of fluid 1
- ΔT_{max} Maximum temperature difference
- R   Heat capacity ratio
- ΔT_{lm} Log mean temperature difference
- TDS   Total dissolved solids
- Re   Reynolds number
- D   Diameter of fluid
- μ   Viscosity of fluid
- ρ   Density of fluid
- u   Speed of fluid
- Pr   Prandtl number
- K   Thermal conductivity
- Nu   Nusselt number
- h   Heat transfer coefficient
- R_{fl} Fouling factor for weak liquor
- R_{fw} Fouling factor for water
- x   Thickness
- E   Thermal Effectiveness
- N_p Power number of agitator of mixer
- N   Agitator speed
- P   Power
- H   Head
- Q   Volumetric flowrate
- h_w Heat transfer coefficient of water
- h_l Heat transfer coefficient of weak liquor

Chapter No 1:

Introduction

1.1 About ICI Soda Ash

ICI Soda Ash Plant was established in 1929 and it starts its production in 1944. This plant was go through many expansion projects, objective of that was to increase production. Initially it was producing 18000 TPA (tonnes per annum) but after various expansion projects its capacity is 350000 TPA these days. They are working on a project to increase its production to 500000 TPA.

Main Product is Sodium Carbonate (Soda Ash), other products are dense soda ash and refined sodium bicarbonate. ICI soda ash is meeting 70% of country requirement. Most customers from Pakistan are relying on ICI Soda Ash as trusted supplier. Soda ash has varied applications which includes soap, detergents and glass industry.

Figure 1 ICI plant

1.2 Problem Statement

In ICI Soda Ash plant, we have variety of process streams which are heated or cooled by means of different heat exchangers. They are using plate type heat exchangers (PHE). The reason behind using PHE is they are highly efficient and can transfer heat at low pressure.

Heat exchanger they use are from ALFA-LAVAL company. These heat exchangers offer high heat flux at comparatively low pressure. These designs are the most efficient design. The calcium carbonate ions present in water have inverse solubility property so when the cooling water enters exchanger and its temperature increases the solubility of calcium ions decrease and they start to precipitate out of cooling water and start to accumulate on the surface of plates of exchanger which result in deposition and scaling of plates. This scaling issue is causing decrease in heat transfer and loss of time and cost.

1.3 Background

As the whole soda ash production process involves so many process streams. At some stages we also need to cool them by mean of PHEs. Cooling water they used is mainly obtain from ground water source or Jehlum. That water contains high amount of impurities including bicarbonates, carbonates, chlorides and sulphates of Magnesium and calcium.

This water is treated in various ways. Temporary hardness is removed by clarifier. But few amount of dissolved calcium carbonate left behind. It varies from 500 to 1500 ppm.

1.4 Issue

This amount looks like very small. But the issue arises when we use this water for cooling purpose in plate type heat exchangers. With rise of temperature solubility of calcium carbonate in water starts decreasing and precipitation starts occurs which leads to fouling.

1.5 Plate Type Heat Exchanger

A large number of industries are using PHEs. PHEs are famous due to their compactness and brilliant performance in transferring heat. PHEs are famous due to their high effectiveness, light weight and reasonable price.
Although they are used by industries from many years, The PHE technology and its manufacture remain limited to a few companies in some of most developed nations.

The PHEs regularly comprises of corrugated plates amassed into an edge. The weak liquor with high temperature travels in one course in substituting chambers whereas the chilly liquid flows in genuine counter-current flow in the other rotating chambers. The liquids are coordinated inside their appropriate chambers by two ways, by reasonable gasket or by using weld contingent upon the sort of exchanger picked.

Customarily, PHEs have been utilized only for the fluid to fluid heat exchange. The finest illustration is in the Milk industry. Now a days, numerous varieties of the plate innovation have demonstrated valuable in uses where a stage change happens too. This incorporates duties regarding condensing and in addition duties regarding vaporization.

Figure 2 Plate Heat Exchanger

PHEs are famous for having general heat exchange coefficients in overabundance of 4 times the U in a shell & tube intended for a similar administration.

1.5.1 Why Plate Heat Exchangers

PHE is an appealing alternative in term of most economical material of construction. The fundamentally higher heat transfer co efficient value brings about quite less region for required application. The higher heat transfer co efficient value qualities are gotten by initiating turbulence between different plate surfaces.

The idea driving this type of exchanger is utilization of channels or any other suppression vessels necessity to rise temperature or decrease temperature of any fluid by transporting heat amongst it & to other fluid.

The majority of these heat exchangers utilized as a part of production Industries are of shell & tube type or PHE. Generally, PHEs are utilized for fluid exchange at small to normal weights. Be that as it may, without gasket these types of HEs can safely operate at higher temperatures & weights. PHEs offer adaptability because plates can not only have added or compacted for each extraordinary condition.

PHEs are comprise of corrugated plates inside frame. It creates very high turbulence & higher wall shear stretch, Due to these properties we can achieve larger heat transfer coefficient plus resistance due to fouled surface. Fluids flow inside the exchanger. Both streams travels alternatively in alternative plates. The high temperature fluid moves down on first plate while the low temperature fluid flow up another plate.

This alignment and presence of gasket guaranteed that both low temperature and high temperature fluids don't blend together. Alternatives to this gasket is welding & brazing .

These plates are attached in interchanging manner to produce the counter current stream. Numerous plates are held together & sealed at the boundaries. The outline helps two fluids to not mix together. Be that as it may, heat will transmit from one fluid to other fluid through these plates.

Because Gasket PHEs are way simple to clean, they are valuable for nourishment and pharmaceutical preparing, where large grades of sanitation needed.

1.5.2 How Things Work

These type of heat exchangers consists of a Precise plates arranged between pressure and the fixed-frame. These plates are of different type of designs which helps to enhance surface area of the Plate heat exchanger. As we know maximum the surface area maximum will be heat transfer.

These Heat exchangers can movable within the frame. The plates are generally opposite in direction and their pattern is like honey comb especially when we view it from sides. This pattern increases the fluid turbulence and as a result we observe increase in the overall heat transfer.

Fixed and pressure plate are held with the help of secondary column. Plates are attached to each other with the help of gasket which evade the material from coming out sideward and also through the holes located on the plates. Setting of gasket is such that it allows only one type of fluid.
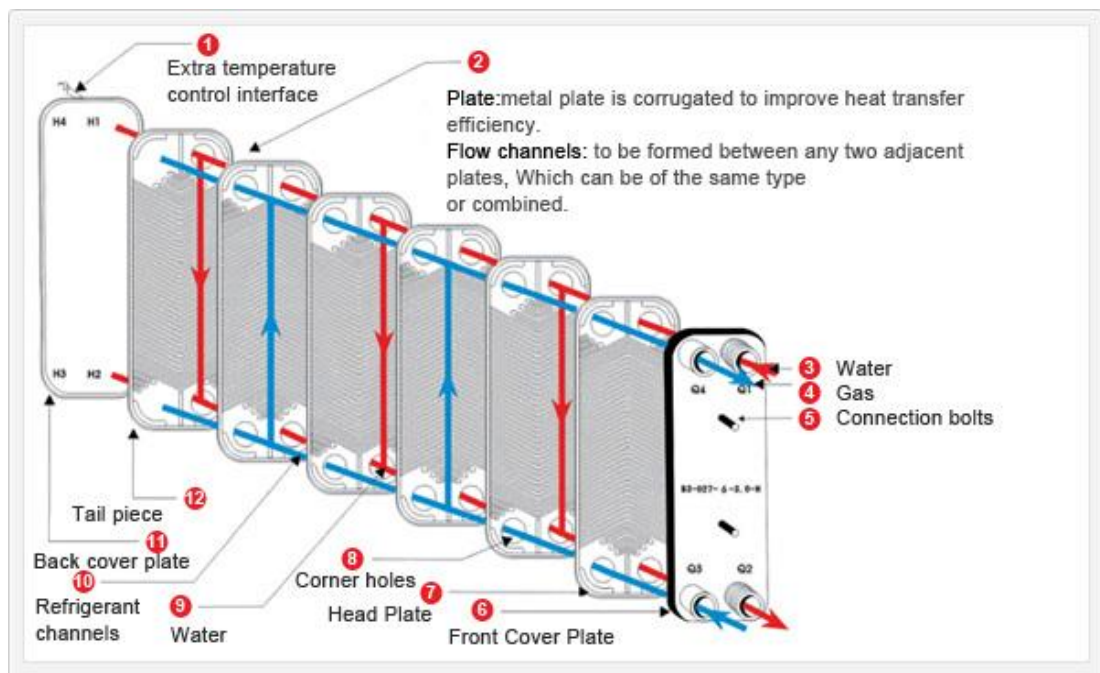
Figure 3 Working of plate heat exchanger

1.5.3 Material of Construction

We have variety of construction materials for plate heat exchanger. Basically it depends on application where we are going to use it. We have different materials for different applications for example Aluminium can be used in cryogenic and aerospace due to their light weight.

But there are some places where we have to deal much higher temperatures we can use stainless steel, copper and nickel alloys with aluminium too.

1.6 Types of PHEs

Generally, we have two types

- Gasket type PHEs
- Brazed type PHEs
- Welded type PHES
- Semi-Welded type PHEs

1.6.1 Gasketed Plate Heat Exchangers:

Also referred as Plate and frame heat exchangers(PHE). They consist of sum of thin rectangular plates made of metals sealed by gaskets & held organized in the frame. The frame of these plates has a cover which is static and fitted with joining ports & has a portable cover.

The plates are held in the air from an top conveying bar & guided by a base-conveying bar to guarantee appropriate arrangement. For this reason, every plate is indented at the focal point of it's top & base ends. The plate pack with settled & mobile end spreads are clasped collected by long jolts, subsequently compacting the gaskets and framing a seal.

Gasket material of construction includes Natural rubber, neoprene, nitrile, Butyl (resin cured), Ethylene propylene, compressed asbestos fiber and Fluorinated rubber.

Gasketed plate heat exchangers have gaskets as sealing on the edges of plates to avoid leakage of liquid stream. Its a counter-current flow heat exchanger with 2 fluids flowing side by side in opposite direction to allow heat transmission to take place through plates.

The two streams enter through ports of the exchanger and flow through channels and spread on alternate sides of the plate. Plates are usually packed together to have a compact structure thus allowing high performance and small pressure drop.

The raw materials of gaskets are imported from Netherlands and are more durable.

Rubber gasket adopts latch-locked design, with observation holes of leakage.
The fixed and seal functions are separate; therefore, even if there are some problems in fixed function, its seal function can still work.
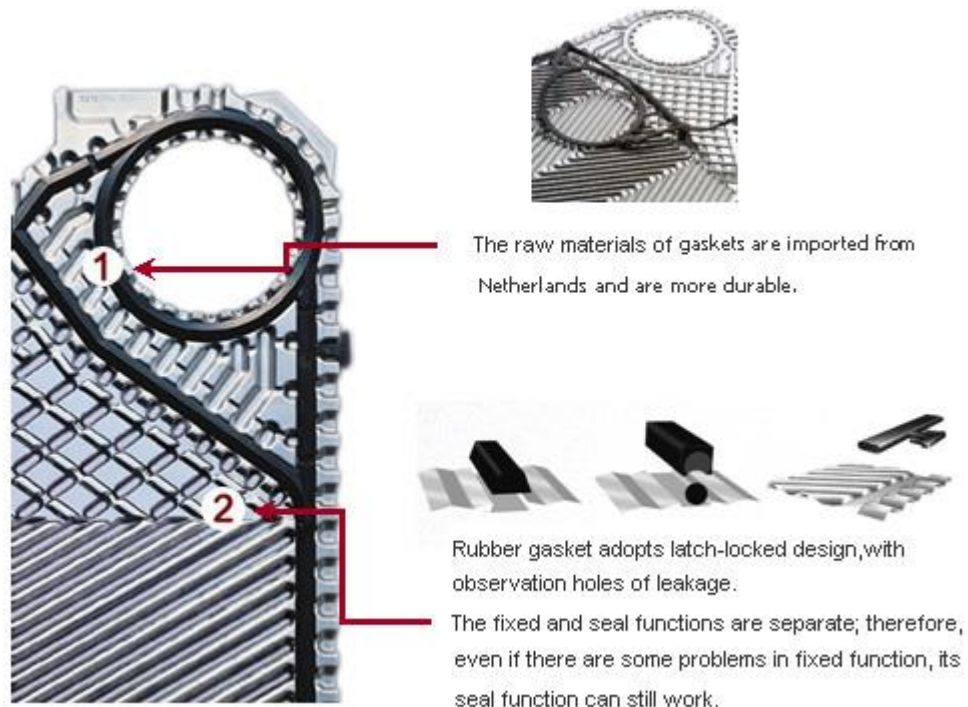
Figure 4 Gasketed PHE

1.6.2 Brazed Type PHEs

These type of PHEs are utilized as a part of numerous commercial uses. Because of stainless-steel plate made with brazed copper, these are exceptionally impervious to oxidization. Brazed type PHEs are effective & dense, settling on them a phenomenal financial idea.
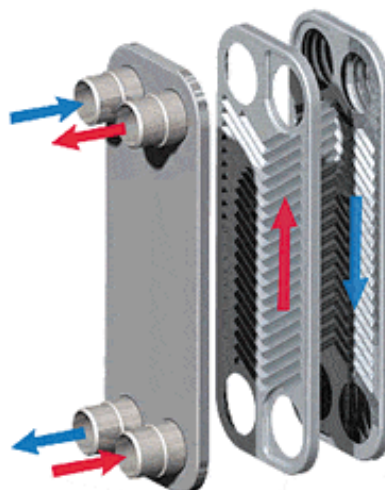
Figure 5 Brazed type PHE

1.6.3 Welded and Other Plate Heat Exchangers

A various scheme has raised with welded sets of plates on either one side or both liquid sides. In order to diminish the large welding expenses, Plates use in these type of PHEs are normally larger than that of the gasket type PHEs.

The impediment of such a plan is the loss of dismantling adaptability on the liquid sides where the welding is finished.

Essentially, laser welding is completed around the total boundary, whereas the gasket is typically put.

Welding on all two sides at that point brings about higher breaking points on working temperatures & pressures [350C and 4.0 Megapascal] & permits the utilization of destructive liquids perfect with the plate material. Welded type PHE have ability to suit multiple passes and more than 2 liquid streams. Plate heat exchanger can suit 4 liquid streams.

Figure 6 Welded PHE

1.6.4 Semi-Welded Type PHEs

Semi-Welded type PHEs consist of a blend of welded & gasket plates. A pair of 2 plates welded to each other which are then gasketed to different pairs, in this manner one track is welded & other track is gasketed.

This results more heat transfer and this alignment also avoid fluid loss. This type of PHEs needs very less cleaning as well.
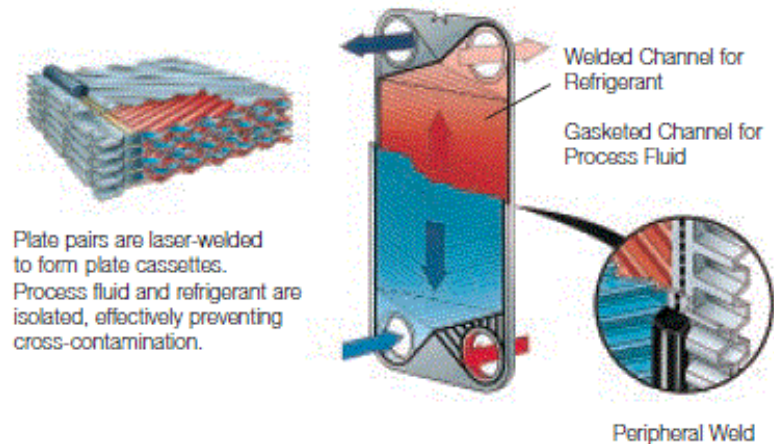
Figure 7 Semi-Welded type PHE

1.7 Applications:

- Initially PHEs were introduced for milk pasteurization applications.
- Useful in the dairy, juice, beverage.
- Alcoholic goods production also require PHEs
- Food processing Industry
- They are also used in alcoholic drink, general food processing.
- Pharmaceutical industries.
- Another major applications are synthetic rubber industry, paper mills.
- Other use includes heat drain to seawater. But here titanium plates are used.

1.8 Advantages/ Disadvantages

1.8.1 Advantages

Overall heat transfer coefficient value larger than other types of Heat exchangers for similar liquids, a PHE has a:

- They are easy to remove / easy to make changes

- Quite easy to clean

- They are expandable

- Very High efficiency at low pressure

- They can perform multiple duties in single unit

1.8.2 Disadvantages

- Chances for leakage − There is a chance of leakage despite the plates and gasket are solidly attached to each other.

- Higher weight drop

- Not useful for large fluid temperature contrasts

- Fouling may occur due to high pressure drop.

1.9 Alternatives Of Plate Type Heat Exchangers

PHEs are not good decision for all uses. It is generally more cost effective to utilize a Shell and two fluids, Tube heat exchanger in situations where there is an outrageous temperature distinction between use which need a low weight loss may want to consider a Shell and Tube heat exchanger.

Gasket type PHEs are constrained in high fluid temperatures, by the temperature restrictions of the gasket. In spite of these restrictions, PHEs are the most proficient decision for a many of uses.

PHEs are presently normal & small brazed adaptations are utilized as a part of the high temp water segments of a large number of grouping boilers. The high heat transfer proficiency in tiny volume made it more attractive for household applications.

1.10 Insulating plate and frame heat exchangers

Usually, In shell and tube heat exchangers heat transfer takes place between one fluid coursing through the tubes whereas another fluid streams over the tubes in the shell.

Plate heat exchangers are presently normal and small brazed adaptations are utilized as a part of the high temp water segments of a large number of combination boilers. The high heat transfer proficiency for such a small physical size has increased the household high temp water stream rate of combination boilers. The small plate heat

exchanger has made a great impact in residential heating and boiling hot water. Larger commercial variants utilize gaskets between the plates, whereas smaller renditions have a tendency to be brazed.

Chapter No 2:

CaCO₃ Fouling and its Effects

2.1 Mechanism for Fouling of Calcium Carbonate

It involves five steps including initiation, transport and attachment. After that we have Removal and aging.

2.1.1 Initiation and Precipitation

In this step, first of all surface is set for the fouling. Induction period is effected by three factors which includes surface temperature, material and roughness. With rise in temperature precipitation starts occurring.

2.1.2 Transport

The transport of precipitate happens via diffusion and sedimentation

2.1.3 Attachment

Calcium carbonate transported start attaching to the surface and characteristics of material such that density and surface conditions have major role in fouling rate.

2.1.4 Removal

Due to shear force between fluid and fouling layer, attached fouling material starts removing. Removal rate depends on the mass velocity of fluid. Maximum will be velocity of fluid maximum will be removal.

2.1.5 Aging

When rate of attachment is more than rate of removal, Calcium carbonate starts depositing on the surface and aging begins. Thickness of fouling depends on time.

2.2 Saturation Index

The chemical formula portraying the arrangement of calcium carbonate crystals is seen beneath. The reactant ions originate from minerals in water and join to frame calcium carbonate which solidifies on the dividers of heat exchangers.

2.2.1 Langelier Saturation Index

The potential for overload of fouling material in water can be stated by the Langelier Saturation Index (LSI).

Langelier Saturation Index (LSI) = **pH – pHs**

pH = pH of the water

pHs = pH of the water at saturation

We have three conditions here

If Langelier Saturation Index > 0: Fouling will occur

Langelier Saturation Index < 0: No chance of scaling

Langelier Saturation Index = 0: Scale will not form but may if temperature.

pH of the water at saturation (pHs) can be calculated as

pHs = (9.3 + P + Q) - (R + S)

where:

P = (Log [Total solid dissolved] - 1) / 10

Q = -13.119 x Log (water temperature) + 34.55

R = Log [Calcium(ion) as calcium carbonate] - 0.4

S = Log [alkalinity as calcium carbonate]

2.3 Cost of Fouling

It influences both capital & working expenses of exchangers. The additional surface region required because of fouling in the plan of heat exchangers can be very

significant. The aggregate fouling related expenses can be divided into four principle territories:

Higher capital cost for larger than usual plants which incorporates overabundance surface region (10- half), costs for additional space, expanded transport and establishment costs.

Vitality misfortunes because of the decline in thermal efficiency and increment in the weight drop.

Creation misfortunes amid arranged and spontaneous plant shutdowns for fouling cleaning.

Support including cleaning of heat exchange gear and utilization of antifoulants.

2.4 How it effects Heat Exchangers Networks

The nearness of fouling in a one of a kind heat exchanger has significantly genuine impacts on its execution. On account of heat exchanger networks (HEN), these impacts turn out to be more sensational in which they exchanged starting with one exchanger then onto the next growing up and increasing all through the network.

2.4.1 Effect on Single Heat Exchanger
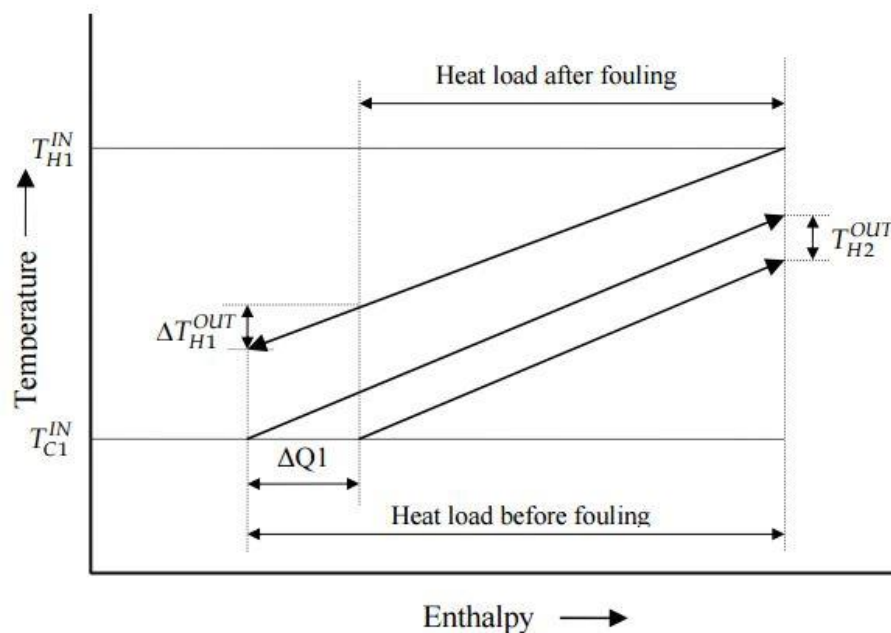
Figure 8 Enthalpy vs Temperature Graph

2.4.2 Effect on HEN with Two Heat Exchangers and Four Streams
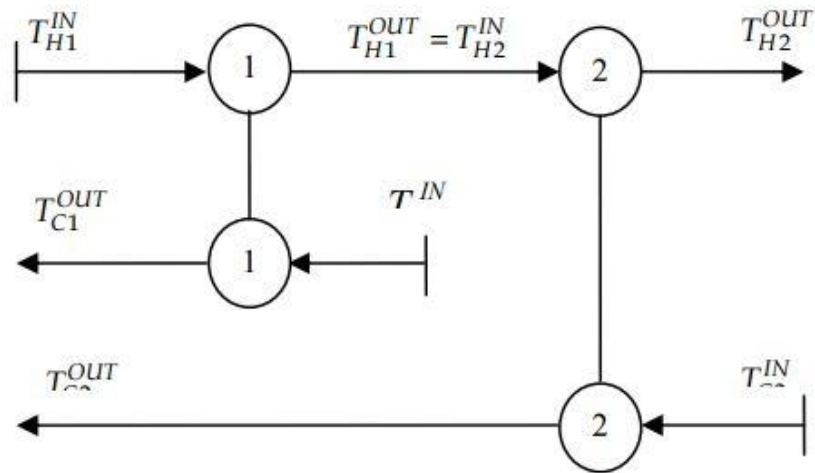
Figure 9 Network of heat transfer with 2 heat exchangers and 4 streams

2.5 Traditional Cleaning Methods

As a rule, the strategies used to expel the scales present in the heat exchanger surfaces can be comprehensively arranged into two classes, namely mechanical and chemical cleaning. These cleaning procedure might be utilized while when plants run , that is called, online cleaning, yet most of the time, the shutdown of the units to clean the exchangers called off-line cleaning will be crucial.

In a few occurrences blends of these cleaning strategies might be fundamental. Every technique for cleaning has points of interest and weaknesses with particular hardware sorts and materials of development.

2.5.1 Selecting the Suitable Cleaning technique:

The need should be deliberately analysed, before cleaning a heat exchanger, Consider the accompanying components for choosing a cleaning technique: -

- Degree of fouling.
- Scalant nature, observed through store analysis
- Ecological releases regulations
- Accessibility of the surfaces for cleaning.
- Cost components.
- While cleaning precautions to be taken.

2.5.2 Manual Cleaning Methods

Following are some of manual cleaning methods

Manual cleaning method

Soot blowing method

Jet cleaning method

Thermal cleaning method

Turbining method

Blasting method

2.5.3 Advantages/Disadvantages

The benefits of mechanical method techniques incorporate straightforwardness and simplicity of operation, and capacity to clean even totally blocked tubes. In any case, the negative marks of this technique might be because of the harm of the gear, especially tubes, it doesn't create a chemically clean surface & the utilization of high weight water stream or air fly may bring about damage and/or mishaps to faculty occupied with the cleaning operation henceforth the work force are tobe well secured against wounds.

2.5.4 Chemical Method

The standard practice is to turn to chemical cleaning of heat exchangers just when other techniques are not attractive. Chemical cleaning includes the utilization of chemicals to break down or slacken stores. The chemical cleaning strategies are for the most part off-line.

Procedure for Chemical Cleaning

1. First of all it is Flushed to remove loose debris material.

2. After that it is Heated and then circulated

3. Addition of chemical or inhibitor

4. After some time, cleaning solution is discharged and flush the system thoroughly.

5. Passivation is done on the metal surfaces.

6. All traces of cleaning chemicals are removed by flushing

Chapter 3:

Heat Exchanger Design Methodology

Design is an action meant at giving complete explanations of an manufacturing system or part of a system. For successive engineering and utilization these explanations characterize an explicit specification of the size, and performance, system/component structure, and other characteristics are important.

Heat exchangers design methodology is rather complex process due to some qualitative judgments and quantitative calculations that must be done. Some of the major design considerations are listed that must be followed while designing heat exchanger.

- Design and process specifications
- Hydraulic and thermal design
- Mechanical designing
- Cost and manufacturing concerns
- System centred optimization and Trade-off aspects.

3.1 Process and Design Considerations

To design a heat exchanger the first most consideration is design basis. After that the study of performance at design conditions and off-design situations. Design considerations require operating conditions and the environment where it will be operated. Design considerations include

- Mass flow rates of fluid (including fluid types)
- Thermo-physical properties
- Pressures of fluids and Inlet temperatures
- Required heat duty
- Maximum permitted pressure drop
- Corrosiveness of fluids
- Properties regarding fouling

3.2 Thermal and Hydraulic Design

This is the heart of design of Heat exchanger. Hydraulic and thermal design includes the exchanger sizing and exchanger rating which further include measureable heat transfer & decrease in pressure calculation. In exchanger rating all the heat transfer calculations are done that include heat transfer rate on both cold and hot stream sides, overall heat transfer coefficient & overall heat transfer rate.

Some of important relations are listed here.

3.2.1 Enthalpy rate equations

Enthalpy rate equation is used to calculate the enthalpy rate of both side fluids.

$$q = q_j = \dot{m}_j \, \Delta h_j \qquad (1)$$

$$\dot{m}_j \, \Delta h_j = (\dot{m} c_p)_j \, \Delta T_j = (\dot{m} c_p)_j \left| T_{j,i} - T_{j,o} \right| \qquad (2)$$

Value of j represents fluid 1 and 2.

Q = rate of heat transfer

Δh = enthalpy change

3.2.2 Heat transfer rate equation

To calculate overall heat transfer rate, simple equation of rate of heat transfer can be used.

$$Q = U \, A \, \Delta Tm$$

Q = overall rate of heat transfer

U= coefficient of overall heat transfer

A=exchanger area

ΔTm=Temperature difference

3.2.3 Sizing Problem

In sizing problem size (height, length, width and surface areas on every portion) of an PHE are determined. Selection of type of plate and dimensions, gasket type, passes arrangements number of plates, and so on are involved in sizing problem for a plate exchanger. Surface geometries (including their pressure drop characteristics and dimensionless heat transfer), fluid flow rates, fouling factors, in and out fluid temperatures, and decrease in pressure in every side are contributions to the sizing problem. It is also called as the design problem.

3.2.4 Hydraulic and Thermal design strategies

There are mainly three methods that are used for thermal and hydraulic design.

- ε-NTU technique
- p-NTU technique
- MTD technique

3.2.5 ε-NTU Method

$$\epsilon = \frac{q}{q_{max}} \qquad (3)$$

$$q_{max} = C_{min}(T_{h,i} - T_{c,i}) \qquad (4)$$

It is used in calculation of rate of heat transfer in exchangers. ε represents the effectiveness.

Where q_{max} is

$$q = C_h(T_{h,i} - T_{h,o}) = C_c(T_{c,o} - T_{c,i}) \qquad (5)$$

q is given by

$$NTU = \frac{UA}{C_{min}} \qquad (6)$$

Where NTU is described by this relation

C* is given by

$$C^* = \frac{C_{\min}}{C_{\max}} = \frac{(\dot{m}c_p)_{\min}}{(\dot{m}c_p)_{\max}} \qquad (7)$$

3.2.6 p-NTU Method

$$q = P_1 C_1 \, \Delta T_{\max} = P_2 C_2 \, \Delta T_{\max} \qquad (8)$$

Important relations that are used in p-NTU method are listed below.

Where P = effectiveness in temperature for 1st and 2nd fluid.

P_1 and P_2 are given by these formulas and their values will always be less than are

$$P_1 = \frac{T_{1,o} - T_{1,i}}{T_{2,i} - T_{1,i}} \qquad (9) \qquad\qquad P_2 = \frac{T_{2,i} - T_{2,o}}{T_{2,i} - T_{1,i}} \qquad (10)$$

$$P_1 = P_2 R_2 \qquad P_2 = P_1 R_1 \qquad (11)$$

$$P_1 = \frac{C_{\min}}{C_1} \varepsilon = \begin{cases} \varepsilon & \text{for } C_1 = C_{\min} \\ \varepsilon C^* & \text{for } C_1 = C_{\max} \end{cases} \qquad (12)$$

$$P_2 = \frac{C_{\min}}{C_2} \varepsilon = \begin{cases} \varepsilon & \text{for } C_2 = C_{\min} \\ \varepsilon C^* & \text{for } C_2 = C_{\max} \end{cases}$$

equal to ε.

Now calculate NTU number transfer units for both fluids separately.

$$NTU_1 = NTU \frac{C_{\min}}{C_1} = \begin{cases} NTU & \text{for } C_1 = C_{\min} \\ NTU\ C^* & \text{for } C_1 = C_{\max} \end{cases} \qquad (9)$$

$$NTU_2 = NTU \frac{C_{\min}}{C_2} = \begin{cases} NTU & \text{for } C_2 = C_{\min} \\ NTU\ C^* & \text{for } C_2 = C_{\max} \end{cases}$$

$$NTU_1 = \frac{UA}{C_1} \qquad NTU_2 = \frac{UA}{C_2} \qquad (10)$$

Heat capacity rate ratios are given by

$$R_1 = \frac{C_1}{C_2} = \frac{T_{2,i} - T_{2,o}}{T_{1,o} - T_{1,i}} \qquad R_2 = \frac{C_2}{C_1} = \frac{T_{1,o} - T_{1,i}}{T_{2,i} - T_{2,o}} \qquad (11)$$

$$R_1 = \frac{1}{R_2} \qquad (12)$$

3.2.7 Log Mean Temperature Difference (MTD)

According to this procedure heat transfer rate q is calculated by the following

$$q = UAF \, \Delta T_{\text{lm}} \qquad (13)$$

formula.

For measuring Counter flow & co current flow heat exchanger value of F is 1. Whereas F is given by

$$F = \frac{\Delta T_m}{\Delta T_{\text{lm}}} \qquad (14)$$

Log mean temperature can be calculated using

$$\text{LMTD} = \Delta T_{\text{lm}} = \frac{\Delta T_{\text{I}} - \Delta T_{\text{II}}}{\ln(\Delta T_I / \Delta T_{\text{II}})} \qquad (16)$$

Temperature differences ΔT_1 and ΔT_2 for counter and parallel flow is calculated

$$\Delta T_{\text{I}} = T_{h,i} - T_{c,o} \qquad \Delta T_{\text{II}} = T_{h,o} - T_{c,i} \qquad \Delta T_{\text{I}} = T_{h,i} - T_{c,i} \qquad \Delta T_{\text{II}} = T_{h,o} - T_{c,o} \qquad (15)$$

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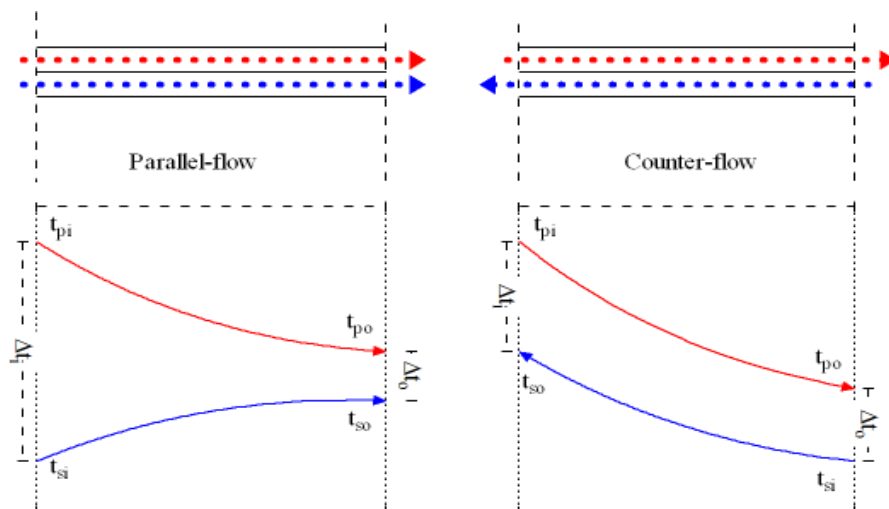
Figure 10 LMTD chart for Parallel and Counter flow

3.3 Mechanical Design

In mechanical design heat exchanger fundamental is modelled for the preferred physical strength built on the working temperatures, pressures & degree of corrision. To compute the width of most important parts in the exchangers thermal/force stress calculations are achieved, Including the fin, plate thickness, tube and shell dia, and tube sheet. The proper selection of the material and the method of connection of fins and plates or tubes is completed depends on the working pressures, temperatures, kinds of fluids used, scaling and corrosion ability and design age. Made check to minimize flow-induced vibrations.

Heat exchanger must Obey with applicable state, native, state, and/or international codes and principles

- Pressure container codes of ASME
- Standard of TEMA

3.4 Manufacturing Concerns and Cost Estimations

3.4.1 Manufacturing Concerns

- **Equipment Considerations** (accessibility & boundaries of dies, and apparatuses, machines, kilns engineering space; funding for capital investment and production versus offline setup)

- **Processing Considerations** (Processing thoughts are linked how discrete units, parts of a PHE are produced & ultimately gathered)

3.4.2 Costing

- **Capital Cost**

  Material, Production, (apparatus, overhead & labour), installation, transportation, & reduction

- **Operating Cost**

  fluid pumping power, maintenance, repair, warranty, cleaning, price of energy related with the utilities in aggregation with the heat exchanger in the grid.

3.5 Heat Exchanger Design Calculations

Overview of process streams:

Fluids are not pure solutions of a certain compound but they are mixture of different components used in process that include brine, water, ammonium carbonate, ammonium bicarbonate and calcium carbonate. Water is being used as a cooling agent to cool down the other hot fluid which is also called as week liquor. Week liquor has many components in it. Temperature of week liquor is 75 degree Celsius which has to be cool down before it enters absorption tower for efficient absorption. Water has TDS, $CaCO_3$ and traces of Cl_2 and Zinc.

Composition of water is given in following table.

Table 1 Composition of Water

Composition and Property	Value
pH	6.8-7.6
TDS	1500-3000ppm
M Alk as $CaCO_3$	50-150ppm
Mg as $CacO_3$	200-400ppm
Cl as NaCl	500-1500ppm
Cl_2	0.2-0.5ppm
PO_4	3-6ppm
Zinc	0.5-1.5ppm
Hardness	500-100ppm
Ca as $CaCO_3$	300-800ppm

Composition and some of the properties of the hot fluid also known as week liquor are listed in following table.

Table 2 Composition of weak liquor

Components	Amount in %
NH_3	3-3.5%
NaCl	26-28%
NH_4HCO_3	4-5%
H_2S	Traces
H_2O	64-66%

Stream Conditions:

Stream conditions such as temperature, pressure and flowrates are given in table below.

Table 3 Stream Conditions

Stream	Inlet Temp.	Outlet Temp.	Pressure Drop	Flowrate	Liq. Volume
Weak Liquor	75 C	35 C	7.708 kPa	102800 kg/hr	288 dm3
Water	32.5 C	50 C	29.4 kPa	188300 kg/hr	290 dm3

Heat Capacities:

Heat capacities of both hot and cold stream is given in following table.

Table 4 Heat Capacities

Stream	Heat Capacity
Weak Liquor	3.37 joule/g.K
H_2O	4.19 joule/g.K

3.6 Heat Balance

Now we have flowrates, heat capacities and temperature differences of both fluids, so heat transfer rate for both fluids separately can be calculated using simple equation of enthalpy. That equation is

$$Q = mCp\Delta T \qquad (17)$$

Where, ΔT = Outlet temperature – Inlet Temperature

According general rule, heat in must be equal to heat out. According to law of conservation of energy heat must travel from hot fluid to cold fluid as energy travels from higher potential to lower potential. Balance must be zero.

Heat released by weak liquor = Heat taken by water + Heat Loss

Heat rate on Water side:

T_{ic} = Temperature of inlet side of cold stream

T_{oc} = Temperature of outlet side of cold stream

Q_1 = Heat attained by cold stream

$$Q_1 = m_c * C_{pc} * (T_{oc} - T_{ic})$$

Q_1 = 188300 * 4.19 * (50-32.5)

Q_1 = 3835.3 kW

Heat Rate on Weak Liquor side:

T_{ih} = Temperature of inlet side of hot stream

T_{oh} = Temperature of outlet side of hot stream

Q_2 = Heat lost by the high temperature stream

$$Q_2 = m_h * C_{ph} * (T_{oh} - T_{ih}) \quad\quad (22)$$

Q_2 = 102800 * 3.37 * (35-75)

Q_2 = 3849.2 kW

$$Q_2 - Q_1 = Heat\ Lost \quad\quad (23)$$

Heat Lost = 3849.2 – 3835.3 = 13.9 KW

3.7 Heat Transfer Calculation's

To calculate overall heat transfer coefficient, we have to find convective coefficient (h) for both hot and cold fluid side. To find convective heat transfer coefficient we will use this approach.

- First, we will calculate Reynold number for both fluids.

$$Re = \frac{Du\rho}{\mu} \quad\quad (24)$$

- Calculate Prandtl number for both fluids.

$$Pr = \frac{\mu C_p}{k} \qu\quad\quad (25)$$

- Use a correlation to find Nussle number using both Reynolds number and Prandtl number

$$Nu = 0.5666 * Pr^{0.33} * Re^{0.8} \left(\frac{\mu}{\mu_s}\right) \quad\quad (26)$$

41

- Using formula for Nussle number, calculate convective heat transfer coefficient

$$Nu = \frac{hl}{k}$$

3.7.1 Convective Heat Transfer Calculation for Water

Reynold's Number:

First, we calculated velocity using the given data and equation of continuity. After that we used that velocity to calculate Reynolds number.

μ = 0.890*10-3 Kg/ms

A = 0.60 m^2

u = m/ρA

u = 188300/1000*0.60*3600

u = 0.1m/s ,

$$Re = \frac{Du\rho}{\mu} \quad (\text{Eq. 24})$$

Re = 1.606 * 0.1 * 1000 / (0.798 * 10^{-3})

= 201253.1

Prandtl Number:

Prandtl number can be calculated using its formula as given below.

k = 0.615 W/mK

$$Pr = \frac{\mu C_p}{k} \text{ (Eq. 25)}$$

Pr = $0.798 * 10^{-3} * 4.19 * 10^3 / .615$

   = 5.43

Nussle Number:

Following empirical relation is used for the calculation of Nussle number.

$$Nu = 0.5666 * Pr^{0.33} * Re^{0.8} \left(\frac{\mu}{\mu_s}\right) \text{ (Eq. 26)}$$

Nu = $0.5666 * (5.43)^{0.33} * (201253.1)^{0.8} * (.67)$

Nu = 11610

$$h_w = \frac{Nul}{k} \text{ (From Eq. 27)}$$

h$_w$ = $11681.5 * 0.643 / 1.606$

   = 4648 W/m²K

3.7.2 Convective Heat Transfer Calculation for Weak Liquor

Reynold's Number:

First, we calculated velocity using the given data and equation of continuity. After that we used that velocity to calculate Reynolds number.

μ = $0.676*10-3$ Kg/ms

u = 0.22 m/s

$$Re = \frac{Du\rho}{\mu} \text{ (Eq. 24)}$$

Re = $1.606 * 0.22 * 391.2/0.676 * 10^{-3}$

   = 204465.6

Prandtl Number:

Prandtl number can be calculated using its formula as given below.

$$K = 0.603 \text{ W/mK}$$

$$Pr = \frac{\mu C_p}{k} \text{ (Eq. 25)}$$

$$Pr = 0.676 * 10^{-3} * 3.37 * 10^3 / 0.603$$

$$= 5.6$$

Nussle Number:

Following empirical relation is used for the calculation of Nussle number.

$$Nu = 0.5666 * Pr^{0.33} * Re^{0.8} \left(\frac{\mu}{\mu_s}\right) \text{ (Eq. 26)}$$

$$Nu = 0.5666 * (5.6)^{.33} * (204465.6)^{0.8} (.88)$$

$$Nu = 15601.1$$

$$h_l = \frac{Nul}{k} \text{ (From Eq. 27)}$$

$$h_l = 15585.4 * 0.603 / 1.606$$

$$h_l = 5857.7 \text{ W/m}^2\text{K}$$

3.8 Overall Heat Transfer Coefficient

Fouling resistance factors are taken from literature and are written below:

Fouling factor for Weak Liquor = R_{fl} = 0.00018 m²K/W

Fouling factor for Water = R_{fw} = 0.00053 m²K/W

$K_{Titanium}$ = 21 W/Mk

3.8.1 Overall Heat Transfer Coefficient for Clean Surface

To calculate U_c, following formula is used.

$$\frac{1}{Uc} = \frac{1}{h_w} + \frac{1}{h_l} + \frac{x}{K_{Titanium}} \tag{28}$$

$$\frac{1}{Uc} = 1/4648 + 1/5857.7 + 0.50*10^{-3}/21$$

U_c = 2440.98 W/m²K

3.8.2 Overall Heat Transfer Coefficient for fouled Surface

To calculate U_f , following formula is used. As this is for fouled surface so it includes the fouling resistance factors.

$$\frac{1}{Uf} = \frac{1}{h_w} + \frac{1}{h_l} + \frac{x}{K_{Titanium}} + R_{fw} + R_{fl} \qquad (29)$$

U_f = 1/4648 + 1/5857.7 + 0.50*10⁻³/21 + 0.00018 + 0.00053

U_f = 893.12 W/m²K

3.9 Log Mean Temperature Difference (LMTD)

Find the temperature differences ΔT_1 and ΔT_2 using counter current flow. After that apply formula of MTD to calculate LMTD.

ΔT_1 = $T_{ol} - T_{iw}$

= 36 - 32.5

= 3.5⁰C

ΔT_2 = $T_{il} - T_{ow}$

= 75 - 50

= 25⁰C

$$LMTD = \frac{[\Delta T1 - \Delta T2]}{ln\left(\frac{\Delta T1}{\Delta T2}\right)} \qquad (30)$$

LMTD = (25-3.5)/ln(25/3.5)

LMTD = 10.93⁰C

3.10 Overall Heat Transfer Rate

Now that we have everything needed for overall heat transfer rate we can simply put values and calculate overall heat transfer rate.

$$Q = UA\Delta T_m \tag{31}$$

$$= 2440.98 * 142.6*10.93$$

$$= 3804.55 \text{ KW}$$

No. of plates = Area of exchanger / Effective area of one plate

No. of plates = 142.6/0.61

No. of plates = 232

3.11 Rating (Knowing UA)

Now for rating we use NTU approach. In this approach, we will find number transfer units NTU. NTU tells us about the performance of heat exchanger.

3.11.1 NTU Approach:

$$Cw = \dot{m}_w * Cpw \tag{32}$$

$$= 188300*4.19*1000/3600$$

$$= 219160 \text{ W/K}$$

$$C_l = \dot{m}_l * C_{pl} \tag{33}$$

$$= 102800*1000*3.37/3600$$

$$= 96232 \text{ W/K}$$

Now As $C_l < C_w$ So, C_l is C_{min} and C_w is C_{max}.

$C_{min} = C_l = 96232$ W/K

$C_{max} = C_w = 219160$ W/K

$$C^* = \frac{Cmin}{Cmax} \tag{33}$$

$$= 96232/21960$$

$$= 0.439$$

Number Transfer Unit (NTU):

$$NTU = \frac{UA}{Cmin} \qquad\qquad (34)$$

$$= 893.12 * 142.6 / 96232$$

$$= 1.323$$

3.11.2 Effectiveness(ϵ)

Following formula is the representation of effectiveness of heat exchangers.

$$\epsilon = \frac{1 - exp[-NTU(1-C*)]}{1 - C* \, exp[-NTU(1-C*)]} \qquad\qquad (35)$$

$$= \frac{1 - exp[-1.323\,(1-0.439)]}{1 - 0.439\, exp[-1.323\,(1-0.439)]}$$

$$\epsilon = 0.6624$$

Chapter 3 (Part-b)

Plate Heat Exchanger design in Aspen EDR (Exchanger Design and Rating)

Aspen Exchanger Design and Rating has been used for the designing of plate heat exchanger. It allows you to play with internal geometry and process data of heat exchanger.

The input information you provide are:

- Process data
- Streams composition and properties
- Exchanger geometry (plate detail, geometry summary)
- Construction Specifications
- Program options (Design options, thermal analysis, methods/ correlations

Actions performed:

- Design
- Rating/ checking
- Simulation

Output Data:

- Results summary
- Thermal/ hydraulic summary (performance, pressure drop, heat transfer).
- Mechanical Summary (Exchanger diagram, exchanger geometry, cost/ weights
- Calculation details.

3.12 Data

Data includes hot and cold streams properties.

Stream Properties:

Hot Stream Properties:
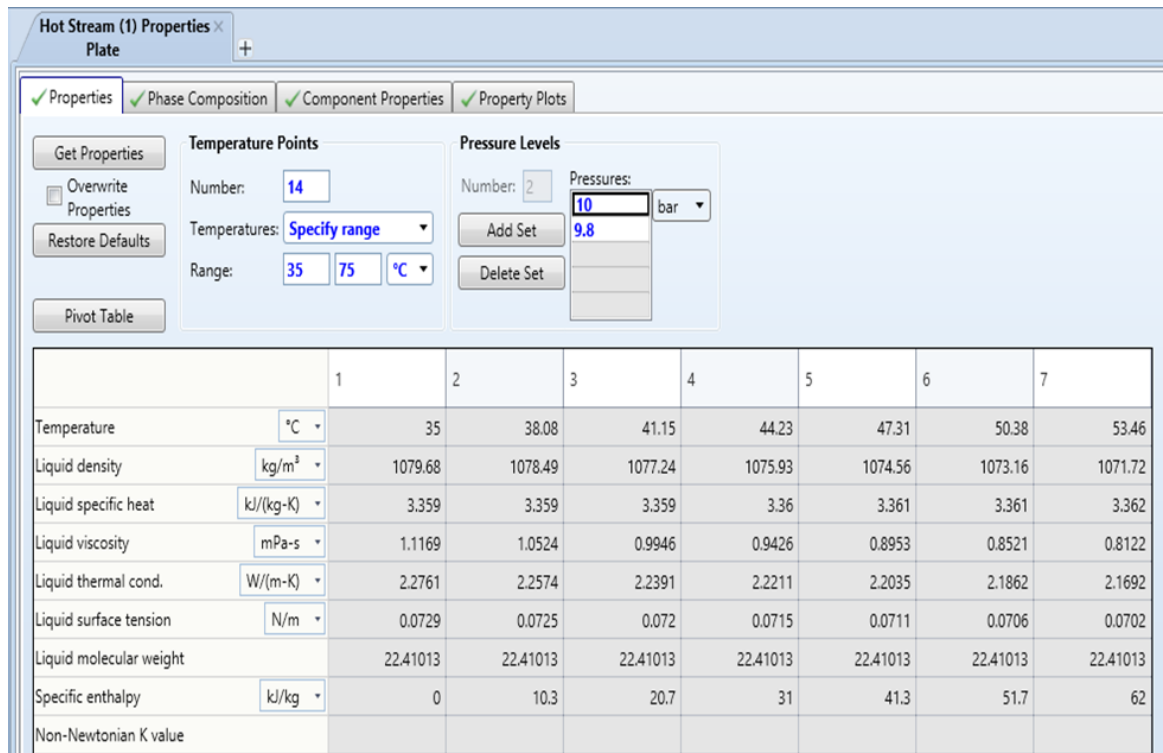
Figure 11 Hot stream properties

Cold Stream Properties:
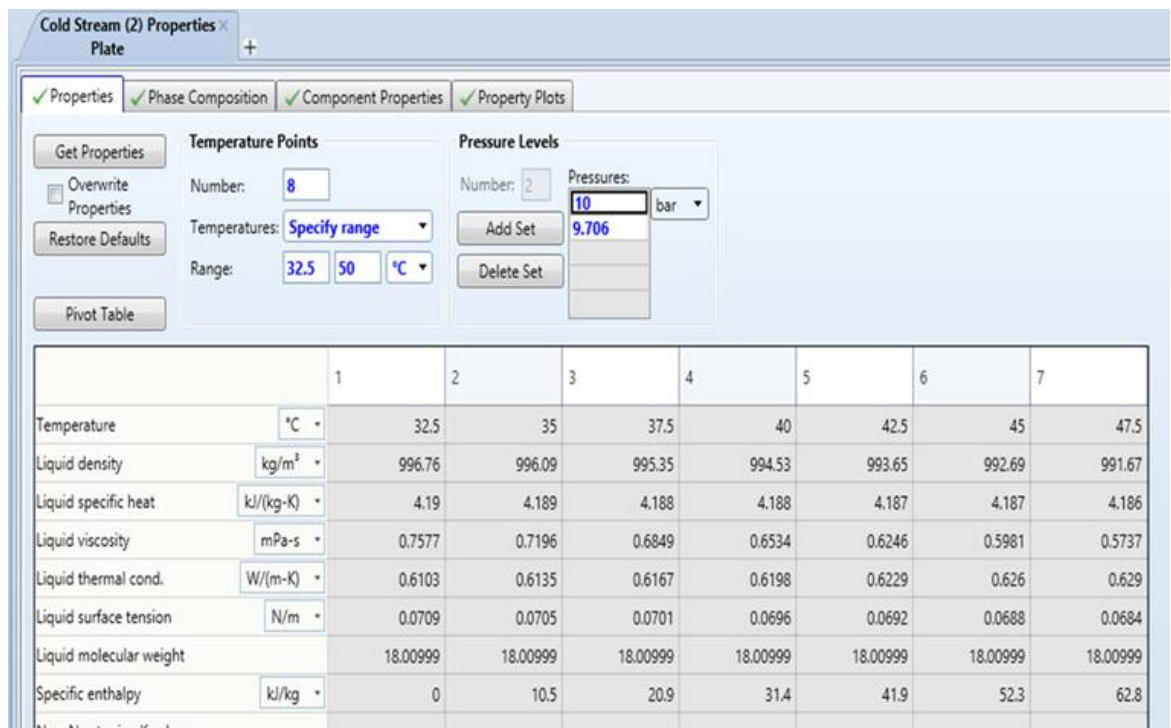
Figure 12 Cold stream properties

3.13 Exchanger Summary

Table 5 Exchanger Summary

	Hot Side	Cold Side
Number of Passes	1	1
Total Number of Channels	115	116
Plates	115	116

Total number of plates = 115+116+1 pressure plate = 232

3.14 Plate Details

Table 6 Plate Details

Plate property/ parameter	Type/Value
Plate Material	Titanium
Chevron angle	45˚
Plate Thickness	0.5mm
Plate Width	610mm
Compressed Plate Pitch	4.47mm
Plate Length	1941mm
Port diameter	136mm
Horizontal port centres distance	298mm
Vertical port centre distance	1290mm
Plate area	$0.614m^2$

Figure 13 Total Data Summary

Total effective heat transfer area = 142.5m^2

3.15 Exchanger Design Results

3.15.1 Heat Transfer

This property table shows the heat transfer coefficient values as well as it uses them to calculate the Prandtl number and Reynolds number.

Figure 14 Heat Transfer

3.15.2 Pressure Drop:

The decrease in pressure on the hot side and cold side of the PHE are shown as below:

Pressure Drop	bar	Hot Side	Cold Side
Maximum allowable pressure drop		0.08	0.3
Total pressure drop		0.03713	0.12974
Total port pressure drop		0.02867	0.10357
Total plate pressure drop		0.00846	0.02617

Pressure drop distribution		m/s	bar	%dp	m/s	bar	%dp
Port for pass	1		0.02867			0.10357	
Plates for pass	1		0.00846			0.02617	

Figure 15 Pressure Drop

3.15.3 Exchanger Performance

Exchanger performance shows the results and summary of all the data given and the output information acquired like total heat exchanged, pressure drop, overall coefficient, design parameters etc that explain the performance of plate heat exchanger.

	A	B	C	D	E	F	G	H	I	J	K
2	Total mass flow rate		28.5556		kg/s		52.3056		kg/s		
3		In		Out		In		Out			
4	Vapour mass flow rate	0	kg/s	0	kg/s	0	kg/s	0	kg/s		
5	Liquid mass flow rate	28.5556	kg/s	28.5556	kg/s	52.3056	kg/s	52.3056	kg/s		
6	Vapour mass quality	0		0		0		0			
7	Temperature	75	C	35.92	C	32.5	C	49.63	C		
8	Pressure	10	bar	9.96279	bar	10	bar	9.87037	bar		
9											
10	Heat transfer coeff (mean)	5851.8	W/(m2*K)			4677.3	W/(m2*K)				
11	Fouling resistance	0	m2*K/W			0	m2*K/W				
12	Velocity (Port/Plate)	1.85	m/s	0.1	m/s	3.63	m/s	0.19	m/s		
13	Wall shear stress (mean)	2.11	N/m2			6.8	N/m2				
14	Pressure drop (allow/calc)	0.08	bar	0.03721	bar	0.3	bar	0.12963	bar		
15											
16	Total heat exchanged	3752.1	kW								
17	Overall coef. (dirty/clean)	2432.5	W/(m2*K)	2432.5	W/(m2*K)						
18	Effective surface area	141.2	m2								
19	Effective MTD	10.93	C								
20	Actual/Reqd. area (dirty/clean)	1		1							
21	Risk of maldistribution	Yes									
22											
23	No of Exchangers	1									
24	No of Plates	232									
25	Passes (hot/cold)	1		1							
26	Channels (hot/cold)	115		116							
27	Plate length	1606	mm								
28	Plate width	610	mm								
29	Plate pitch	4.47	mm								
30	Plate thickness	0.5	mm								
31	Port diameter	136	mm								
32	Chevron angle	45	Degrees								
33											

Figure 16 PHE Performance without fouling factors(Zero fouling, clean fluids)

3.15.4 Exchanger Diagram

It shows the design, geometry and dimensions of plate heat exchanger designed. Below shown is the Gasketed plate heat exchanger for weak liquor cooling.
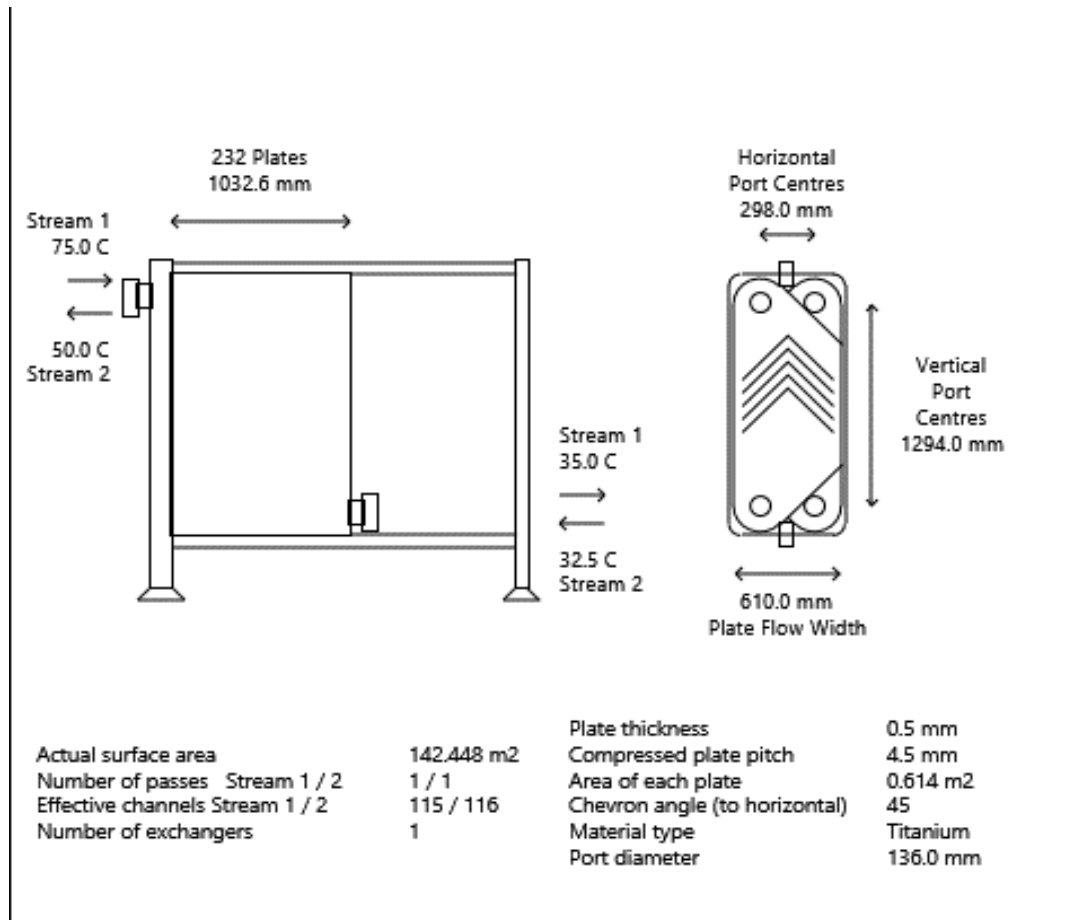
Figure 17 Exchanger Diagram

3.15.5   Cost/ Weight Calculation

The final cost and weight of Gasketed plate heat exchanger are as follows:

3.15.6   Calculation plot of plate

Figure 18 Cost/Weight Calculation

Hot side:
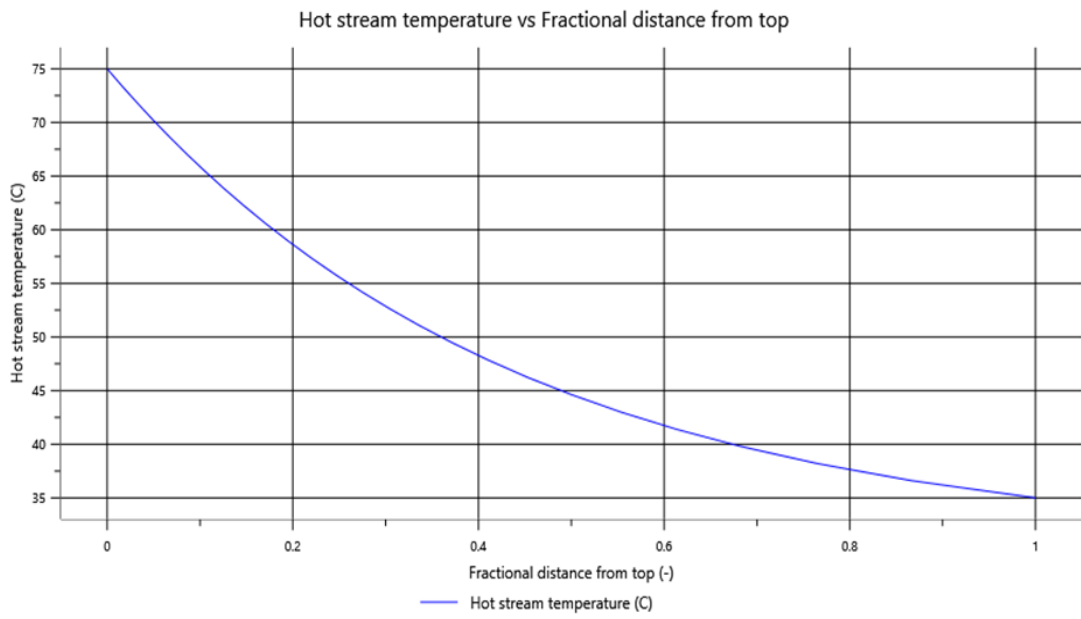
Figure 19 Hot stream temperature vs Fractional distance from top

Cold Side:
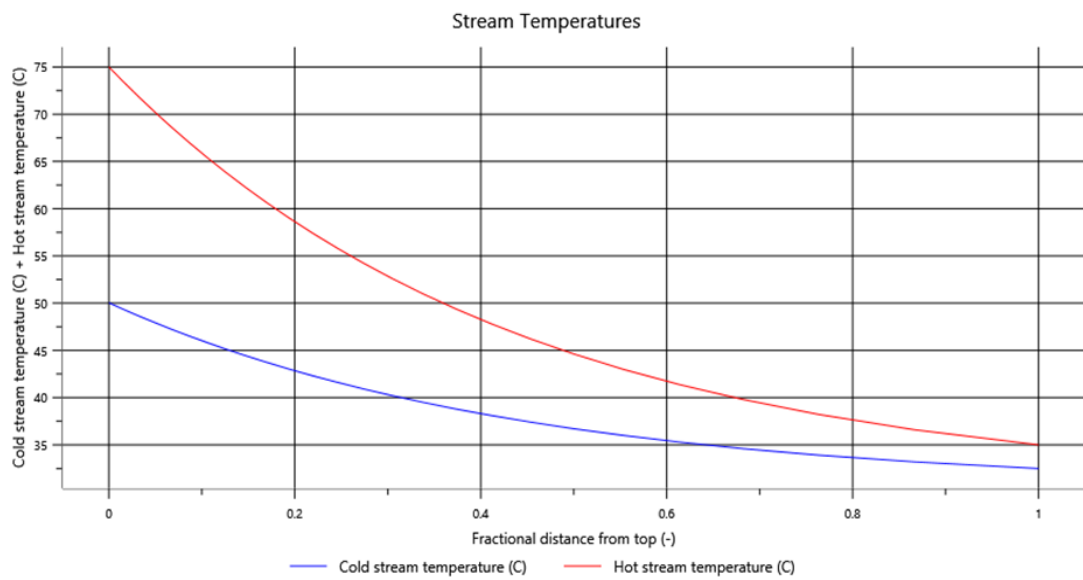
Figure 20 Stream temperature's vs Fractional distance from top

Chapter 4

Technique Used to Clean and Prevent Scaling

4.1 Selection of Cleaning Method

Following things are kept in mind while selecting a cleaning method for heat exchanger:

- Fouling resistant.

- Properties of the fouling material.

- Compatibility of the material of exchanger & system gears in connection with the washing chemicals.

- Rules and laws in contradiction of environmental ejections.

- Availability of surface for washing.

- Cost of method

4.1.1 Off-Line Mechanical Cleaning

Some of mechanical methods are

1. Manual method of cleaning

2. Jet method

3. Soot blowing

4. Thermal method of cleaning

1. Manual method of Cleaning

In manual method we have to open whole casing and we have to clean each and every plate individually. This method is simple but it need high precautions. Limitation of this process is it decrease efficiency of gasket with increase in number of cleanings. It also possess high labour cost.

2. Jet Cleaning method:

In this method we insert water jet of high pressure inside tubes or shell. This leads in removing of all foulant present at the surface. But this technique applies on those exchangers who can bear high pressure.

This way is composed of pointing high speed water jets at fouled surfaces through special guns or nozzles. Range of nozzles and tips are used to create effective hydraulic force.

3. Soot Blowing:

For boiler plants soot blowing is employed. In this technique particles are removed by steam or air blast. To remove carbon containing components water washing may also be used.

4. Thermal Cleaning:

It is steam method of cleaning, in presence or absence of chemicals, can referred as hydro-steaming. Cleaning of long chain hydrocarbons in condensers & heat exchangers are its uses.

4.1.2 Merits and Demerits of Mechanical Cleaning:

The benefits of mechanical method techniques incorporate straightforwardness and simplicity of operation, and capacity to clean even totally blocked tubes. In any case, the negative marks of this technique might be because of the harm of the gear, especially tubes, it doesn't create a chemically clean surface & the utilization of high weight water stream or air fly may bring about damage and/or mishaps to faculty occupied with the cleaning operation henceforth the work force are tobe well secured against wounds.

4.1.3 Chemical Cleaning

The standard practice is to turn to chemical cleaning of heat exchangers just when other techniques are not attractive. Chemical cleaning includes the utilization of chemicals to break down or slacken stores. The chemical cleaning strategies are for the most part off-line.

Procedure for Chemical Cleaning

1. First of all it is Flushed to remove loose debris material.

2. After that it is Heated and then circulated

3. Addition of chemical or inhibitor

4. After some time, cleaning solution is discharged and flush the system thoroughly.

5. Passivation is done on the metal surfaces.

6. All traces of cleaning chemicals are removed by flushing

4.1.4 Chemical Cleaning Solutions

Chemical cleaning solutions consists of mineral acids, organic acids, reducing agents, alkaline bases, complex agents, oxidizing agents, and organic solvents. Inhibitors and surfactant are added to decrease corrosion and to increase cleaning efficiency.

4.2 Fouling Mitigation Techniques

4.2.1 Electronic Anti-Fouling Technology

The method can used to avoid fouling in PHE. $CaCO_3$ has inverses properties of solubility. Boundary of HE have temperature larger as compare to pipes feeding the heat exchanger. Hence $CaCO_3$ will be precipitated out of the water and deposits on heat exchanger walls. This method forces the calcium carbonate to precipitate in the majority solution before entering the heat exchangers system.
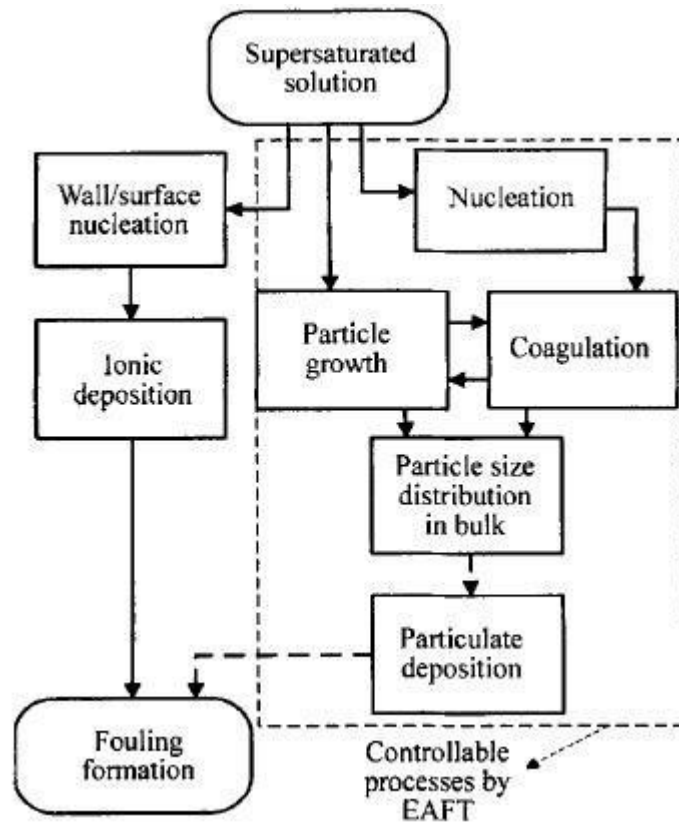
Figure 21 Principle How the EAF works (Xing Xiao-kai, wt al, 2006)

This device has a solenoid coil covered round the tube of feed. It is shown the figure below. An oscillating electing field is produced as a result of varying magnetic field. Agitation in the solution is produced, this forces the following reaction to happen which causes precipitation of $CaCO_3$ in the bulk solution.

$$Ca^{2+} + 2HCO_3^- \leftrightharpoons CaCO_3 + H_2CO_3$$
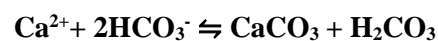
The bulk fluid enters and exits the exchanger with this precipitated calcium carbonate. The ability to precipitate on the wall of heat exchanger is greatly reduced because of precipitation before in the pipe feeding the exchanger.

4.2.2 Chemicals Used to Reduce Fouling

Some additives are used to decrease the fouling. Softening is used to remove the minerals from fluids in crystallization fouling. The solubility of the build-up is enhanced by acid and phosphates and then crystal modification is done by the chemical additive which allows to easily remove the deposits (Kakac 1991).

Scaling molecules and ions are also removed by ion exchange and chemicals like lime.

$$Ca(HCO^{3-})_2 + Ca(OH)_2 \text{ -------> } 2\ CaCO_3 + 2H_2O$$

$$CO2 + Ca(OH)_2 \text{ --------> } CaCO_3 + H_2O$$
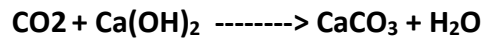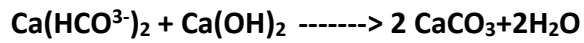
The calcium carbonate precipitates out as silt and some as particles.

(37)
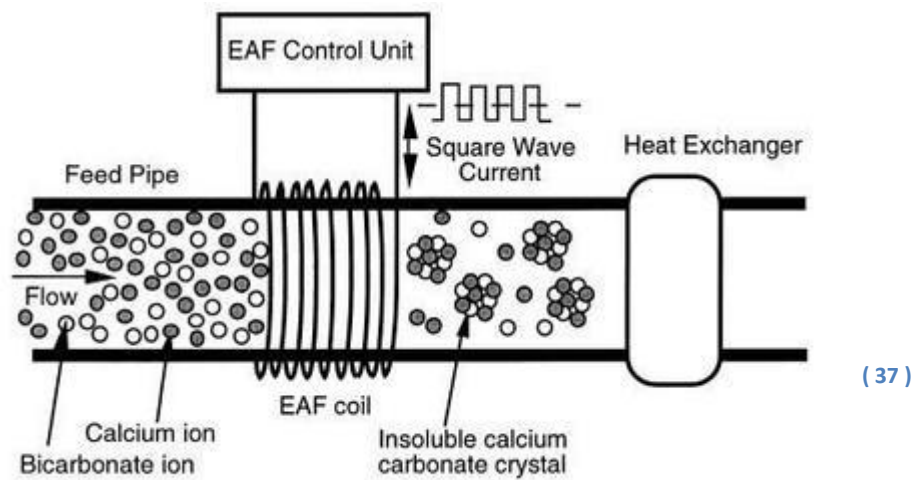
Figure 22 Schematic Of a EAF unit (Y.I. Cho & Byung Gap Choi, 1999)

4.2.3 Influences Caused by Operating Conditions on Fouling

- Concentration of the foulant in the fluid increases the fouling linearly
- Decrease in fouling resistance increases shear stress
- Increase in resistance of fouling will force us to increase flow velocity
- Increase in resistance of fouling will lead to increase temperature of surface exponentially.
- Increase in resistance of fouling will increase roughness too (Figure 7)
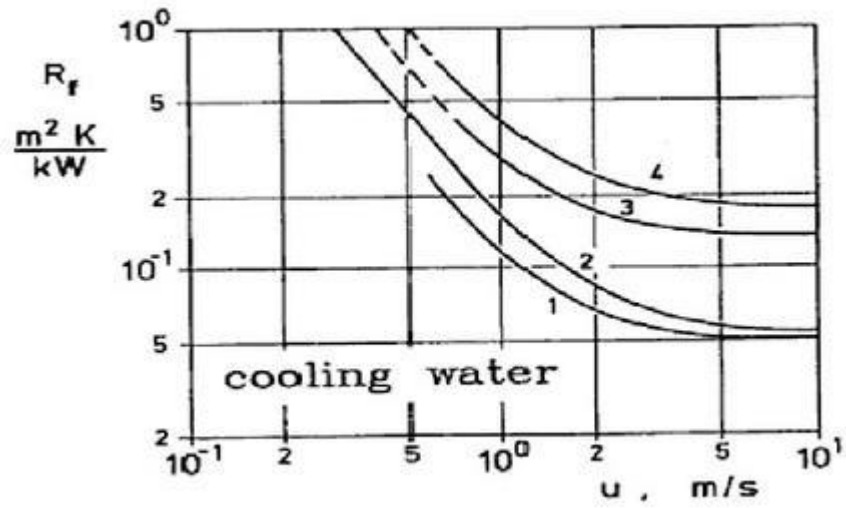
Figure 23 Fouling Resistance as a function of flow velocity and water quality
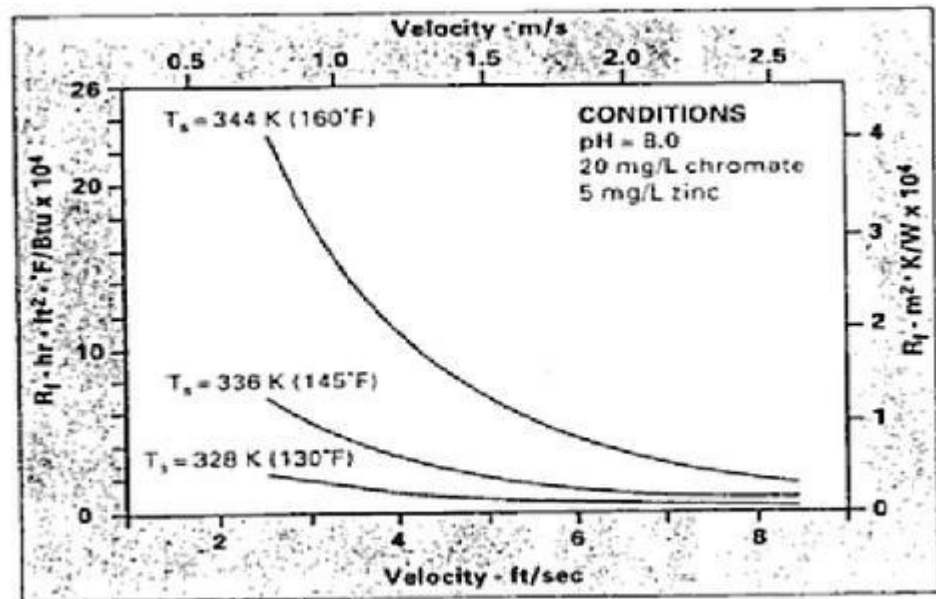
Figure 24 Fouling resistance as function of flow velocity and wall temperature
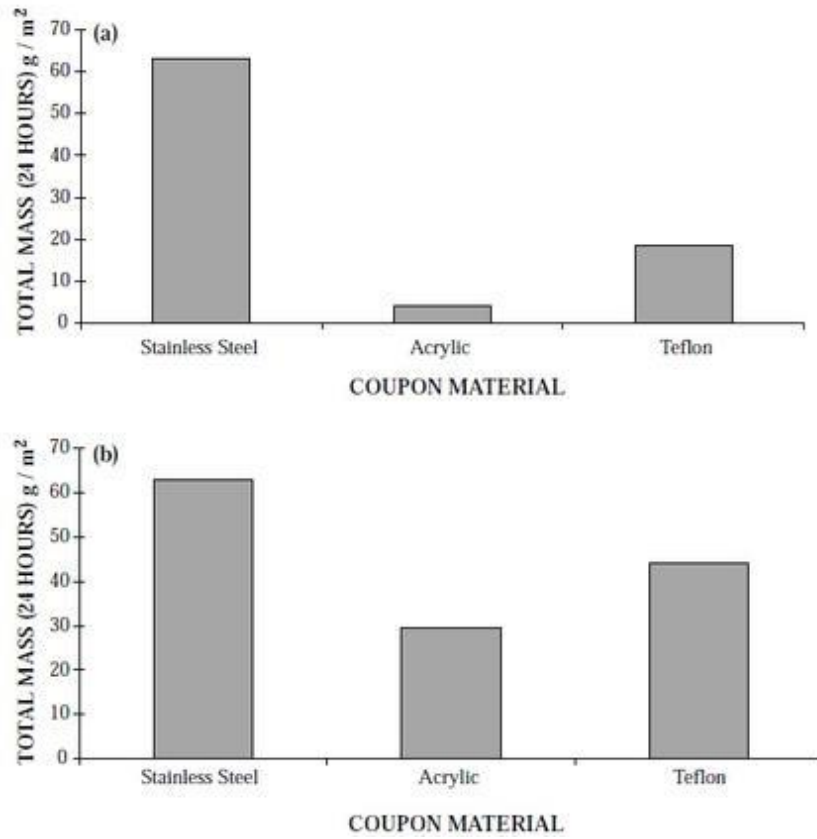
Figure 23 Effect of surface roughness on fouling.

(a) Smooth Surface(b) Rough surface (J. McAdam's & S. A. Parsons ,2004)

Chapter 5

Proposed Scale Inhibitor used in the mitigation of fouling in Gasket Plate Heat Exchanger and its effect on performance

5.1 Scale Inhibitor

Scale inhibitor use is a widely-recognized practice in which small amount of inhibitor is added to water to reduce fouling and increase mitigation. These inhibitors include phosphonate and/or carboxylate groups, and are monomeric or polymeric. They work at threshold levels, since the [Ca]:[inhibitor] concentration ratio is extremely high. It is said that they achieve "threshold inhibition" by a surface adsorption mechanism comprising Langmuir adsorption. Inhibition (or delay) of crystal growth at the very early stages happens because of adsorption onto the $CaCO_3$ crystal surface(s). Other changes involve alteration of crystal morphology as shown in figure.
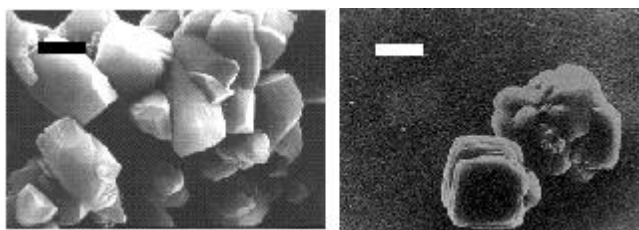
Figure 24 CaCO^3 precipitates from solutions containing no additives (left) and polyacrylate polymer (right). Bar = 20 μ

5.1.1 AMP (amino-tris-(methylenephosphonic acid))

AMP(amino-tris-(methylenephosphonic acid) a complex chemical solid is used as an inhibitor because of its effectiveness to lessen the scaling process and is blended with a polymer to enhance its performance.

Polymers **1** and **2** are Polyacrylate and Polyalkylsulfonate with different degree of sulfonate groups. **Polymer 2** has higher number of sulfonate and lower degree of acrylate groups than **1**.

5.1.2 Scale Inhibition Test

The performance of AMP as a CaCO3 scale inhibitor was investigated by the Scale Inhibition Test at high Ca^{2+} and CO_3^{2-} levels, as well as high temperatures and pH (see Table 1). The experiments were performed at 43 ℃ temperature. In industrial applications bulk water temperatures in the range 40-50 ℃ are commonly found. The synergism between AMP and certain dispersant polymers was also inspected.

According to results in Table 2, AMP is an effective scale inhibitor. It sustains 400 ppm (of 800 ppm) of soluble calcium at high super-saturation and temperature (run 1). Moreover, its performance is assisted by the dispersant properties of polymers 1 and 2. At Ca^{2+}/HCO_3^- of 800/800 $CaCO_3$ inhibition is assisted by both polymers 1 and 2. The result shows that AMP/polymer 1 achieves 64 % inhibition (run 4) and the blend AMP/polymer 2 is more effective with 74 % inhibition (run 5).

Table 7 Scale Inhibition Test Conditions

Run	Ca^{+2} (ppm)	HCO^{-1} (ppm)	Mg^{+2} (ppm)	AMP (ppm)	Polymer1 and 2 (ppm)
0	800	800	200	0	0
1	800	800	200	30	0
2	700	700	200	30	30 of 1
3	700	700	200	30	30 of 2
4	800	800	200	30	30 of 1
5	800	800	200	30	30 of 2
6	900	900	200	30	30 of 1
7	900	900	200	30	30 of 2

Table 8 Scale Inhibition Test Results

Run	Soluble Ca^{+2}(ppm,2h)	% Inhibition (2h)	Dispersed Ca^{+2} (ppm, 24h)	% Dispersion (24h)
0	5	<1	0	0
1	411	53	355	45
2	532	76	693	98
3	574	83	714	101
4	512	66	718	91
5	595	72	729	92
6	553	63	737	85
7	552	65	759	87

There are obvious differences in the morphology of $CaCO_3$ scale deposits upon examination. $CaCO_3$ solids that precipitate from solutions containing AMP and polymer 1 are mostly amorphous (non-crystalline) spheres and have little affinity to adhere to each other. 6 μ is there approximate size. While $CaCO_3$ crystals from AMP and polymer 2 solutions (Figure 5, left column) have precise crystalline morphology, and, seemingly, tend to agglomerate to larger aggregates with size ~ 10 μ. With AMP scale inhibition both polymers 1 and 2 show virtually the same good synergistic effects. But polymer 1 and polymer 2 causes the precipitated $CaCO_3$ to form amorphous (and, consequently, more easily removed) scale and larger agglomerates composed of crystalline micro particles respectively
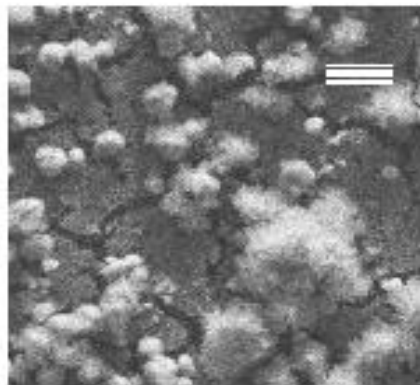
polymer 1
Bar = 20 μ
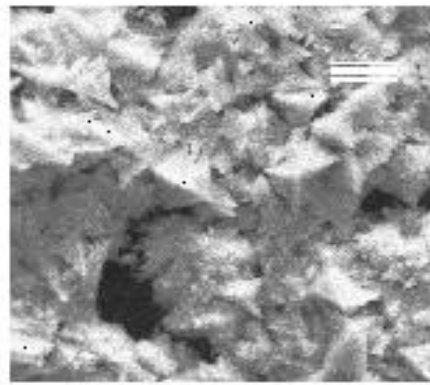
polymer 2
Bar = 20 μ
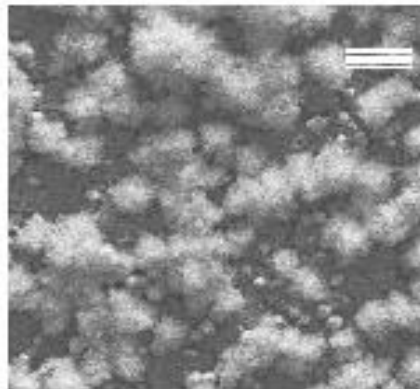
polymer 1
Bar = 40 μ
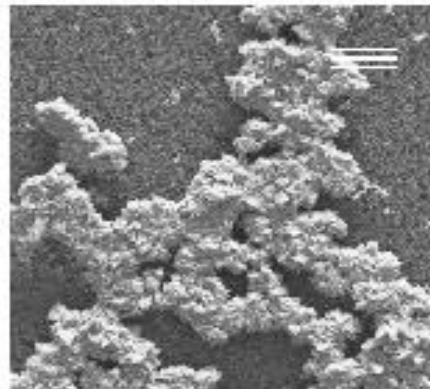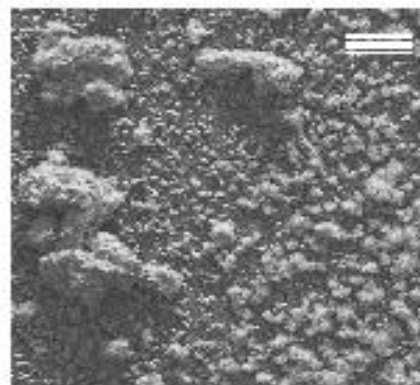
polymer 2
Bar = 40 μ
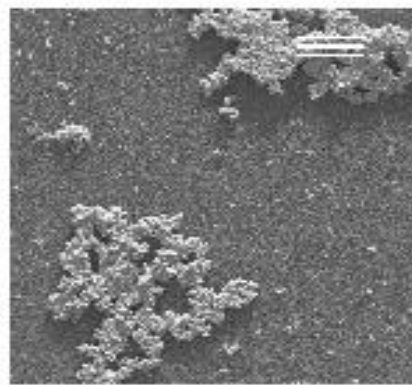
polymer 1
Bar = 100 μ

polymer 2
Bar = 100 μ

**Figure 25 CaCO3 precipitates from solutions containing
AMP and polymers A or B as additives. Bar = 20 μm**

5.2.1 Material Balance of Scale Inhibitors for one exchanger:

Composition of cooling water is:

Table 9 Composition Of Water

Composition and Property	Value
pH	6.8-7.6
TDS	1500-3000ppm
M Alk as CaCO3	50-150ppm
Mg as CacO3	200-400ppm
Cl as NaCl	500-1500ppm
Cl2	0.2-0.5ppm
PO4	3-6ppm
Zinc	0.5-1.5ppm
Hardness	500-100ppm
Ca as CaCO3	300-800ppm

The hot cooling water moves to cooling tower for its cooling. The temperature, flowrate and pressure drop of water and weak liquor are given in table:

Table 10 Process and streams data

Stream	Inlet Temp.	Outlet Temp.	Pressure Drop	Flowrate	Liq. Volume
Weak Liquor	75 C	35 C	7.708 kPa	102800 kg/hr	288 dm3
Water	32.5 C	50 C	29.4 kPa	188300 kg/hr	290 dm3

According to this table, composition of water and the results of scale inhibitor for 800ppm calcium ions 30ppm AMP and 30ppm polymer1/polymer2 are required.

1) Material Balance for AMP Polymer:

Ca ions present = AMP required

800ppm = 30 ppm

which means:

Water present = AMP required

1000000 ppm = 30ppm

1L water = 0.000030 kg AMP

188300 kg/hr water = 5.649 kg/hr of AMP required.

2) Material Balance for Polymer 1/ Polymer 2:

Polymer 1 is Poly-acrylate

Polymer 2 is Poly-alkylsulfonate

Water present = Polymer required

1000000ppm = 30ppm

188300 kg/hr water = 5.649 kg/hr polymer required.

Table 11 Flowrates of the components

	Water	**Ca ions**	**AMP**	**Polymer1/Polymer2**
Flowrate	188300 kg/hr	15.064 kg/hr	5.649kg/hr	5.649 kg/hr

As AMP is solid we need it in solution with 50% concentration in de-ionized water along with polymer 1 or 2

So we need 16.947 L/hr solution having composition:

Table 12 Composition of components in solution

Component	Composition
De-ionized Water	0.33%
AMP	0.33%
Polymer	0.33%

When water is saturated with 800/800 Ca/HCO ions concentration, the AMP/polymer 1 test run gives a inhibition of 64% while for blend with polymer 2 it gives a value of 74%. Results from test above are very significant:

Table 13 Effect of Inhibition on Fouling Factor for 800ppm caco³ concentration

	Ca ions(ppm)	Polymer Composition(ppm)	Initial fouling factor value(m^2K/W)	Final fouling factor value(m^2K/W)	Inhibition
AMP/ Polymer 1	800ppm	30ppm	0.00053	0.0001908	64%
AMP/Polymer 2	800ppm	30ppm	0.00053	0.0001378	74%

5.3 Scale Inhibitor effect on the Overall heat transferred and heat exchanger performance:

5.3.1 LMTD method:

I) Without Inhibitor:

Table 14 Parameters of heat exchanger

Property/Parameter	Value
Effective heat transfer area	142.6 m^2
Heat transfer coefficient for hot side	5851.8 W/m^2K
Heat transfer coefficient for cold side	4677.3 W/m^2K

Fouling resistance:

Water (R_{fw}) = 0.00053 m^2K/W

Weak Liquor (R_{fl}) = 0.00018 m^2K/W

Heat transfer coefficient for hot side = h_l = 5851.8 $W/m^2.K$

Heat transfer coefficient for cold side = h_w = 4677.3 W/m^2K

H values are calculated as per the geometry of exchanger and data given.

Overall Heat Transfer Coefficient = $1/h_l + 1/h_w + x/k_{titanium} + R_{fw} + R_{fl}$ (38)

U = $(1/5851.8) + (1/4677.3) + (0.5*10^{-3}/21) + 0.00053 + 0.00018$

U = 894.05 W/m2.K

So now we calculate total heat transferred using:

Q = $UA\Delta T$ (39)

ΔT is Log mean temperature difference.

Which is 21.2

A is total effective heat transfer area = 142.6

So Q = 894.05*142.6*20.2

Q = 2702.82 KW

II) With scale Inhibitor (AMP/Polymer1 (Polyacrylate)):

With Scale Inhibitor(AMP/ Polymer 1(Polyacrylate)) fouling resistance are reduced:

Water (R_{fw}) = 0.0001908 m2.K/W

Weak Liquor (R_{fl}) = 0.00018 m2.K/W

Heat transfer coefficient for hot side = h_l = 5851.8 W/m2.K

Heat transfer coefficient for cold side = h_w = 4677.3 W/m2.K

H values are calculated as per the geometry of exchanger and data given. Eq. (38) gives,

Overall Heat Transfer Coefficient = $1/h_l + 1/h_w + x/k_{titanium} + R_{fw} + R_{fl}$

U1 = $(1/5851.8) + (1/4677.3) + (0.5*10^{-3}/21) + 0.0001908 + 0.00018$

U1 = 1283.21 W/m2.K

So now we calculate total heat transferred using eq. (39)

Q = $UA\Delta T$

ΔT is Effective Log mean temperature difference.

Which is 17.28K

A is total effective heat transfer area = 142.6

So Q1 = 1283.21*142.6*17.5

Q1 = 3202.25 KW

So Thermal Effectiveness of AMP with polymer 1 blend is calculated as:

E1 = ((3202.25 - 2702.82)/2702.82)*100

E1 = 18.48% increase in heat transfer.

III) With Scale Inhibitor (AMP/Polymer2 (Polyalkylsulfonate)):

Water (R_{fw}) = 0.0001378 m2.K/W

Weak Liquor (R_{fl}) = 0.00018 m2.K/W

Heat transfer coefficient for hot side = h_l = 5851.8 W/m2.K

Heat transfer coefficient for cold side = h_w = 4677.3 W/m2.K

H values are calculated as per the geometry of exchanger and data given. Eq. (38) gives,

Overall Heat Transfer Coefficient = $1/h_l + 1/h_w + x/k_{titanium} + R_{fw} + R_{fl}$

U2 = (1/5851.8) + (1/ 4677.3) + (0.5*10^{-3}/21) + 0.0001378 + 0.00018

U2 = 1376.85 W/m2.K

So now we calculate total heat transferred using eq. (39)

Q = UAΔT

ΔT is Effective Log mean temperature difference.

Which is 15.89K

A is total effective heat transfer area = 142.6m^2

So Q2 = 1376.85*142.6*17

Q2 = 3337.76 KW

So Thermal Effectiveness of AMP with polymer 2 blend is calculated as:

E2 = ((3337.76 – 2702.82)/2702.82)*100 (E2 is thermal effectiveness of AMP/Polymer 2 blend)

E2 = 23.5% increase in heat transfer

5.3.2 Results of LMTD method

1) With AMP/Polymer 1 Blend:

18.48% increase in heat exchanged.

The polymer used is Polyacrylate.

2) With AMP/Polymer 2:

23.5% increase in heat exchanged.

So these results show that AMP/ Poly-alkylsulfonate blend is more effective in scale inhibition and increasing the heat transfer of Gasket plate heat exchanger. But the sulphate emission ability of polymer 2 causes environment hazard while polymer 1 is environment friendly.

Either of these two polymer blends can be used for the inhibition of calcium carbonate scale deposit. These blends will be used in solution form with de-ionized water.

5.3.3 Aspen Performance table for Plate Heat Exchanger:

1) With zero fouling factors:

Table 15 Performance file without fouling factor(for clean fluids)

	A	B	C	D	E	F	G	H	I	J	K
2	Total mass flow rate		28.5556		kg/s		52.3056		kg/s		
3			In		Out		In		Out		
4	Vapour mass flow rate	0	kg/s	0	kg/s	0	kg/s	0	kg/s		
5	Liquid mass flow rate	28.5556	kg/s	28.5556	kg/s	52.3056	kg/s	52.3056	kg/s		
6	Vapour mass quality	0		0		0		0			
7	Temperature	75	C	35.92	C	32.5	C	49.63	C		
8	Pressure	10	bar	9.96279	bar	10	bar	9.87037	bar		
9											
10	Heat transfer coeff (mean)	5851.8	W/(m2*K)			4677.3	W/(m2*K)				
11	Fouling resistance	0	m2*K/W			0	m2*K/W				
12	Velocity (Port/Plate)	1.85	m/s	0.1	m/s	3.63	m/s	0.19	m/s		
13	Wall shear stress (mean)	2.11	N/m2			6.8	N/m2				
14	Pressure drop (allow/calc)	0.08	bar	0.03721	bar	0.3	bar	0.12963	bar		
15											
16	Total heat exchanged	3752.1	kW								
17	Overall coef. (dirty/clean)	2432.5	W/(m2*K)	2432.5	W/(m2*K)						
18	Effective surface area	141.2	m2								
19	Effective MTD	10.93	C								
20	Actual/Reqd. area (dirty/clean)	1		1							
21	Risk of maldistribution	Yes									
22											
23	No of Exchangers	1									
24	No of Plates	232									
25	Passes (hot/cold)	1		1							
26	Channels (hot/cold)	115		116							
27	Plate length	1606	mm								
28	Plate width	610	mm								
29	Plate pitch	4.47	mm								
30	Plate thickness	0.5	mm								
31	Port diameter	136	mm								
32	Chevron angle	45	Degrees								
33											

Performance / Drawing

This figure shows that with zero fouling resistance, the total heat exchanged by the exchanger under given process and exchanger data is = 3752.1 KW

Overall Heat transfer coefficient = 2432.5 W/m2*K

2) Without Scale Inhibitor:

Table 16 Performance Table with fouling factors (without inhibitor)

		A	B	C	D	E	F	G	H	I	J
				Hot Side				Cold Side			
1											
2	Total mass flow rate		28.5556		kg/s		52.3056		kg/s		
3			In		Out		In		Out		
4	Vapour mass flow rate	0	kg/s	0	kg/s	0	kg/s	0	kg/s		
5	Liquid mass flow rate	28.5556	kg/s	28.5556	kg/s	52.3056	kg/s	52.3056	kg/s		
6	Vapour mass quality	0		0		0		0			
7	Temperature	75	C	47.06	C	32.5	C	44.75	C		
8	Pressure	10	bar	9.96287	bar	10	bar	9.87026	bar		
9											
10	Heat transfer coeff (mean)	6111.5	W/(m2*K)			4634.3	W/(m2*K)			
11	Fouling resistance	0.00018	m2*K/W			0.00053	m2*K/W			
12	Velocity (Port/Plate)	1.85	m/s	0.1	m/s	3.63	m/s	0.19	m/s	
13	Wall shear stress (mean)	2.12	N/m2			6.89	N/m2			
14	Pressure drop (allow/calc)	0.08	bar	0.03713	bar	0.3	bar	0.12974	bar	
15											
16	Total heat exchanged	2683.2	kW							
17	Overall coef. (dirty/clean)	896.2	W/(m2*K)	2464.1	W/(m2*K)					
18	Effective surface area	141.2	m2							
19	Effective MTD	21.2	C							
20	Actual/Reqd. area (dirty/clean)	1		2.75						
21	Risk of maldistribution	Yes								

This figure shows the result of performance of heat exchanger without scale inhibitor with fouling resistance:

Weak Liquor: 0.00018m^{2}K/W

Cooling Water: 0.00053 m^{2}K/W

The total heat exchanged is 2683.2KW which is close to theoretical value.

3) With Scale Inhibitor (AMP/ Polyacrylate blend):

Fouling resistance for both fluids are:

Weak Liquor: 0.00018m^{2}K/W

Cooling Water: 0.0001908 m^{2}K/W

Table 17 Performance table with Scale Inhibitor(AMP/Polymer1(Polyacrylate))

	A	B	C	D	E	F	G
1			**Hot Side**				**Cold Side**
2	Total mass flow rate		28.5556		kg/s		52.3056
3			In		Out		In
4	Vapour mass flow rate	0	kg/s	0	kg/s	0	kg/s
5	Liquid mass flow rate	28.5556	kg/s	28.5556	kg/s	52.3056	kg/s
6	Vapour mass quality	0		0		0	
7	Temperature	75	C	42.39	C	32.5	C
8	Pressure	10	bar	9.96284	bar	10	bar
9							
10	Heat transfer coeff (mean)	6015.9	W/(m2*K)			4660	W/(m2*K)
11	Fouling resistance	0.00018	m2*K/W			0.00019	m2*K/W
12	Velocity (Port/Plate)	1.85	m/s	0.1	m/s	3.63	m/s
13	Wall shear stress (mean)	2.11	N/m2			6.85	N/m2
14	Pressure drop (allow/calc)	0.08	bar	0.03716	bar	0.3	bar
15							
16	Total heat exchanged	3131.9	kW				
17	Overall coef. (dirty/clean)	1285.3	W/(m2*K)	2455.6	W/(m2*K)		
18	Effective surface area	141.2	m2				
19	Effective MTD	17.28	C				
20	Actual/Reqd. area (dirty/clean)	1		1.91			
21	Risk of maldistribution	Yes					

The Aspen EDR performance table show a total heat exchange of 3131.9KW.

So increase in heat transfer is 17%.

4) With Scale Inhibitor (AMP/Polyalkylsulfonate):

Fouling resistance for both fluids are:

Weak Liquor: 0.00018 m^2K/W

Cooling Water: 0.0001378 m^2K/W

**Table 18 Performance table for Gasket plate heat exchanger with scale inhibitor
(AMP/Polyalkylsulfonate(Polymer 2))**

		Hot Side				Cold Side			
1		**Hot Side**				**Cold Side**			
2	Total mass flow rate	28.5556		kg/s		52.3056		kg/s	
3		In		Out		In		Out	
4	Vapour mass flow rate	0	kg/s	0	kg/s	0	kg/s	0	kg/s
5	Liquid mass flow rate	28.5556	kg/s	28.5556	kg/s	52.3056	kg/s	52.3056	kg/s
6	Vapour mass quality	0		0		0		0	
7	Temperature	75	C	41.53	C	32.5	C	47.17	C
8	Pressure	10	bar	9.96284	bar	10	bar	9.87032	bar
9									
10	Heat transfer coeff (mean)	5996.6	W/(m2*K)			4663.3	W/(m2*K)		
11	Fouling resistance	0.00018	m2*K/W			0.00014	m2*K/W		
12	Velocity (Port/Plate)	1.85	m/s	0.1	m/s	3.63	m/s	0.19	m/s
13	Wall shear stress (mean)	2.11	N/m2			6.84	N/m2		
14	Pressure drop (allow/calc)	0.08	bar	0.03716	bar	0.3	bar	0.12968	bar
15									
16	Total heat exchanged	3213.7	kW						
17	Overall coef. (dirty/clean)	1378.5	W/(m2*K)	2453.3	W/(m2*K)				
18	Effective surface area	141.2	m2						
19	Effective MTD	16.54	C						
20	Actual/Reqd. area (dirty/clean)	1		1.78					
21	Risk of maldistribution	Yes							

The Aspen performance result show a heat exchange of 3213.7KW for given process data.

So increase in heat transfer is 20%

Chapter 6:

Process Description, Design, Material Balance and costing on New Equipment's

6.1 - Process Description

6.1.1 - Objective

The objective of this process is to reduce fouling in cooling water cause by calcium carbonate. Calcium carbonate has abnormal solubility behavior as its temperature rise its solubility decreases. This unlikely behavior cause precipitation inside plate type heat exchanger. We have proposed a mixing of blend of two components with makeup stream of cooling tower. As cooling water originates from cooling tower. Blend we are using are AMP solution/Acrylate with desire concentration of 30ppm/30ppm in stream. This concentration against 800 ppm of Calcium carbonate will avoid precipitation. And it will reduce fouling up to 74%

.

6.1.2 – Equipment's

1). Solution Tanks:

We are using two tanks for AMP solution & Acrylate:

For AMP Solution: We need relatively small tank as its loss is minimum.

For Polymer: For acrylate we will use relatively large tank, 3 times bigger than AMP solution Tank because acrylate is more volatile and we will face much loss of it.

2). Mixer:

A mixer tank will receive AMP solution and polymer in required amount as signaled by controller. Agitator will help us to mix both components uniformly. Mixer agitator type is pitched blade.

3). Metering Pump:

Metering pump will be of Positive displacement type. It will be uses as dosing pump and will consume power in mill horsepower.

4). Check Valve:

It will be used after and before pump in order to avoid any damage.

5). Control Valves:

Two diaphragm Valves after solution and polymer tanks which will receive signal from sensor and will release required amount of material.

6). Sensor:

Sensor we are going to use is electrochemical type sensor. It have ability to measure concentration of materials up to 0.5 ppm.

Before going to process description we need mass balance and design of all these components.

Process Flow Diagram:
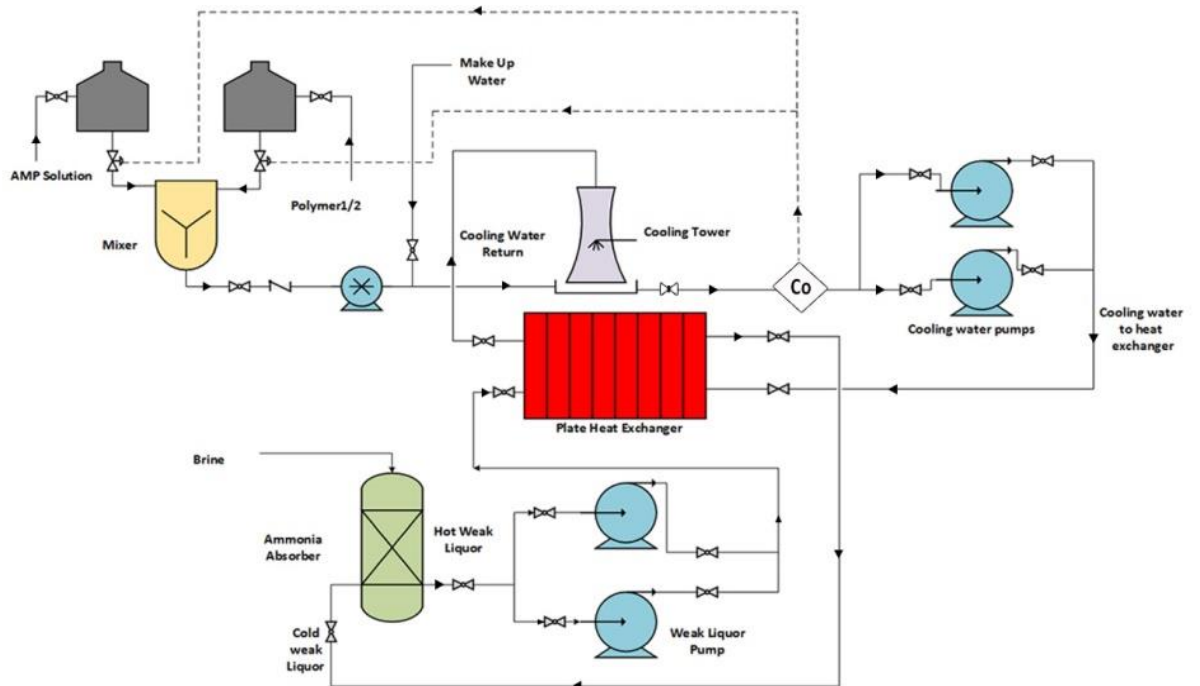
Figure 26 Process Flow Diagram including new equipment.

6.2 - Mass Balance

6.2.1 - Mass Balance for dosing blend across cooling tower

Data:

Flow rate of Plate type heat exchanger = 10800 L/hr

Flow rate of Plate type heat exchanger = 3 L/s

Outlet temperature = 50 C = 122 F

Inlet Temperature = 32.5 C = 90.5 F

Temperature gradient in centigrade = 17.5

Temperature gradient in Fahrenheit = 31.5

Desired Concentration of AMP in Water = 30 ppm

Desired Concentration of polymer in Water = 30 ppm

Density of AMP = 1.33kg/L

Assumptions:

Single cooling tower deals with 3 PHEs.

Cooling tower Base Volume = 8 cubic meter = 8000 L

Evaporation loss will be 1% for 12 F temperature difference.

Drift loss will be = 0.2 %

Blow down loss will be = 0.1 %

AMP loss with in cooling tower = 1 ppm

Polymer loss with in cooling tower = 5 ppm because it is more volatile

Calculations Based on Assumptions:

Flow rate of water in cooling tower from hot stream= 10800 L/hr x 3 = 32400 L/hr

Makeup water = Blow down + Drift loss + evaporation loss

Blow down = 0.1%

Drift loss = 0.2 %

Evaporation loss = 2.4 %

Over all loss = 2.7 %

Makeup water = 2.7/100 x 32400 L/hr

Makeup water = 874.8 L/hr

Initial Blend Require

Initial AMP required @ 30 ppm (one time)

30mg/L x 8000 L = 240 g AMP

Initial Polymer required @ 30 ppm (one time)

30mg/L x 8000 L = 240 g polymer

Continuous Blend Requires

AMP loss = 1 ppm

Mass Balance on AMP

AMP in via doser = AMP out via evaporation

= AMP loss x Flow Rate

= 1 mg/ L x 32400 L/hr

= 32.4 g / hr

As concentration of AMP solution will be 50% Mass/mass so mass flow rate of solution will be **64.8 g/ hr**

Polymer loss = 5 ppm

Mass Balance on Polymer

Polymer in via doser = Polymer out via evaporation

= Polymer loss x Flow Rate

= 5 mg/ L x 32400 L/hr

= 162 g / hr

Total Blend = 162 + 64.8 =226.8 g/hr

These result are based on assumption, They can vary in different conditions. e.g It will be different for Summers and winter.

6.2.2 - Mass balance for different Streams

Overall balance

Material In = Material Out

Dosing Blend + Make up water = Water evaporated + (AMP + Polymer) loss via evaporation

Stream Balance

Make up Stream + Hot Stream = Evaporated Stream + Cooled water stream.

874,8 L/hr + 32400 L/hr = 874.8 L/hr + 32400 L/hr

Balance on Blend

Concentration of AMP in ppm in makeup stream = 32.4g/874.8 L

=32400mg/874.8 L

=**37 ppm aprox**

Concentration of polymer in ppm in makeup stream = 162g/874.8 L

=162000mg/874.8 L

=**185 ppm aprox**

Table 19 Property Table for Additives

Property	AMP	Tank 1 (AMP Solution)	Tank 2 (Poly Acrylate)	Mixer
Dosing requires (g/hr)	32.4	64.8	162	226.8
Daily Dosing requires (kg)	0.777	1.555	3.888	5.4438
Relative ratio (AMP:water:Polymer)	1:0:0	1:1:0	0:0:1	1:1:5
Dosing concentration in Make up stream	37 ppm	-	185 ppm	37/185 ppm

6.3 – Design of New Equipment

6.3.1 - Tank design

Blend Daily Requirement

AMP require per day = 32.4 x 24 = 777.6 g = 0.7776 Kg

AMP Solution require per day = 64.8 x 24 = 1555.2 g = 1.5552 kg/day

Polymer require per day = 162 x 24 = 3888 g = 3.888kg

Estimated Tank Volume Required:

As these solutions will be prepared in batch so tanks should have capacity of at least one week storage.

Weekly AMP required = 0.7776 x 7 = 5.4432

Volume occupied by Weekly AMP = 5.4432/1.33   (1.33 kg/L is density of AMP)

= 4.0926 L

Volume occupied by Water in AMP solution = 5.4432 /1

=5.4432

Weekly volume occupied by AMP solution = 4.0926 + 5.4432 =**9.5458 L**

Weekly Polymer required = 3.888kg x 7 = 27.216 kg

Weekly Volume occupied by polymer = 27.216/0.94   (0.94 kg/L is density of acrylate)

=**28.95 L**

Average density of blend = (27.216+10.88)/(9.5458+28.95) = 0.9897 kg/L = 0.9897 g/ml

Tanks Volume should be at least 10 L for AMP and 30 L for Polymer.

And Mixer volume should be 2 L

6.3.2 Mixer Design

Mixer Used is a blender with agitator of pitched blade

Mixer Batch Volume = 2L

Liquid Density (ρ) = 1204 Kg/m^3

Agitator speed (N) = 1947.82 rpm

Agitator speed (N) = 32.46 revolutions per second

Power Number (Np) = 1.37

Tank Length = 0.1115 m

Diameter = 0.0446 m

Power of mixer is calculated by,

$P = Np.\rho.N^3.D^5$

P = 10W = 0.01 kW

6.3.3 - Make Pipe Design:

Flow rate = 874.4 kg/hr

Pipe dia = 32.114 mm

Cross section Area = 810 mm sq

Velocity = 0.3 m/s

6.3.4 - Metering Pump

A reciprocating pump used for very low flow rate. Its flow rate can be adjustable. It is of diaphragm style. Which is driven by solenoid with check valves. It has ability to dose small flow rates with very high accuracy. It can handle flow rate upto 100 g/hr. It consumes very less power such that just 0.125 horse power.

Mass flow rate of blend = 226g/hr

Average density of blend = 0.9897 g/ml

Volumetric Flow rate of blend = Q = 228.3520 ml/hr

Head = H = 0.4 meter = 1.3123

Power = Q* H* Liquid Density * g/ 3.6*10^6

Power required will be = 2.46*10^{-7} Watt

6.4 - Process

6.4.1 - Initial Dosing

After installation of these equipment. When plant starts operating, initially we have zero reading from sensor of concentration of AMP/Polymer. It will send signal to control valves to open. AMP solution and polymer will start moving toward mixer where they will mixed uniformly via agitator. Then it will mixed with makeup water and concentration of AMP and polymer in overall stream will start increasing. These valves will remain open until concentration reaches 30 ppm for both AMP and polymer.

As it is estimated above that about 240 gram for each AMP and polymer are required for initial dosing. After 30 ppm these component starts acting against 800 ppm of calcium carbonate. And we will observe significant decrease in fouling.

6.4.2 - Continuous Dosing

Now problem is we are losing some amount of AMP and polymer in cooling tower due to evaporation and drift losses. So we need continuous dosing of this material in order to maintain 30 ppm. Cooling water leaving Plate type heat exchanger will exhibit almost temperature of 50 degree Celsius.

When it will enter in cooling tower from top. 2.7% of water will lose due to evaporation and drift loss. So now in order to balance mass environment we need some makeup water and dosing material. Cooled water leaving cooling water will pass through concentration sensor. If it will sense decrease in concentration. It will send signal to controller and Tank valves will be open until it reaches desired concentration.

6.5 Costing

6.5.1 Total Direct Cost

Equipment cost:

1. Tank cost:
a. Cost of AMP solution Tank with capacity of 10 L = $80
b. Cost of Acrylate Tank with capacity of 30 L = $200
2. Cost of Mixer with agitator = $250
3. Cost of Sensor = $70
4. Cost of Control valves = 2 x $50 = $100
5. Cost of Metering Pump = $300
6. Check Valve cost = $60

Total Equipment Cost: $1060

Instrumentation Cost = $200

Piping Cost = $ 180

Electrical cost = $140

Total direct Cost = $1600

6.5.2 Indirect Cost

Engineering design and supervision cost: $400

Contractor fee = $200

Construction expenses = $200

Total indirect cost = $800

Total Capital Cost = Direct + Indirect

= 1900+800 = $2400

6.5.3 Operating Cost

Chemical Cost

AMP requirement annually = 1.555 kg x 350 =   544.25 kg

AMP annual cost = 544.25 x $0.74 = 402.745 = $402

Polymer requirements annually = 3.88 kg x 350 = 1358

Polymer annual cost = 1358 x $ 2.25 = $3055

Total Chemical Cost = $3500

Total Cost after one year will be = **$5900**

Table 20 Total Cost

Cost Type	Amount (USD)
Total Direct Cost	1600
Total Indirect Cost	800
Total Capital Cost	2400
Total Operating Cost	3500
Total Cost after 1 year	5900

Suppose before installation of this process each cleaning for single PHE cost us $200 and if single Heat exchanger will face 14 cleanings per years normally. After installation of this process they will reduce to 2 cleanings only.

If each cooling tower operates 3 PHEs then we are avoiding 36 cleanings per year.

Annual money saved = 36 x $200 = $7200

Break even = 5900/7200 = 0.81 years = Almost in 10 months

Chapter 7:

Results and Conclusions

7.1 Results

The result of the effect of the scale inhibitor on the performance of Plate Heat exchanger calculated theoretically and by the Aspen EDR software are as follows:

7.1.1 LMTD Method

Table 21 Comparison table

Process type	Heat Exchanged By Plate Heat Exchanger
Without scale inhibitor	2702.82 KW
With scale inhibitor (AMP/Polymer 1)	3202.25 KW
With scale Inhibitor (AMP/Polymer 2)	3337.76 KW

AMP/Polyacrylate cause 18.48% increase in heat transfer by inhibiting scaling of calcium carbonate.

While AMP/Polyalkylsulfonate causes 23.5% increase in heat exchange and is more effective inhibition polymer blend.

7.1.2 Aspen Exchanger Design and Rating

Table 22 Comparison of Aspen Results

Process type	Heat Exchanged By Plate Heat Exchanger
Without fouling factors(Clean fluids)	3752.1 KW
Without scale inhibitor	2683.2 KW
With scale inhibitor (AMP/Polymer 1)	3131.9 KW
With scale Inhibitor (AMP/Polymer 2)	3213.7 KW

With AMP/Polyacrylate (Polymer 1) scale inhibitor 18.48% increase in heat transfer takes place.

While with AMP/Polyalkylsulfonate (Polymer 2) 23.5% increase in heat exchange takes place and so is more effective.

7.2 Conclusions

Water from cooling tower is hard and has calcium carbonate and other salts present in it. Calcium carbonate concentration is 800ppm for water used in heat exchangers at ICI soda ash plant for ammoniated brine cooling. This calcium carbonate precipitates when temperature increases and deposits as crystal on the plate of exchanger.

Scale Inhibition is used as a technique to lower the precipitation of calcium ions. AMP/Polyacrylate and AMP/Polyalkylsulfonate blends are used in the prevention. Calculation shows a decrease in scaling and increase in heat exchange by 17% for AMP/polymer 1 blend while 20% increase with AMP/Polymer 2 but polymer 2 causes sulphur emissions and hazardous for atmosphere. These blends are used in solution form. The results conclude that AMP/Polymer 1 is effective and

environmental friendly while either of these blends can be used to mitigate the scaling and lower the cleaning need.

This technique will be effective to the industry in terms of cost and time of cleaning and performance of heat exchanger. As this technique will reduce the regular need to clean the heat exchanger and increase the working time of Gasket Plate heat exchangers.

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