**SUDAN UNIVERSITY OF SCIECNE AND TECHNOLOGY**

**COLLEGE OF PETROLEUM ENGINEERING AND TECHNOLOGY**

**DEPARTEMENT OF OIL TRANSPORTATION AND RIFINING**

# Fouling Effect on heat Exchanger of Sour Water Treatment unit - Khartoum Refinery Company

*By:*

**ALI MOHAMED ALI ABD ELGADIER**

**FAIZ ELSDIG BREIMA HAMEDAN**

**HUSSAM ELDEIN  MUSTAFA ALBASHEIR**

**OSMAN ADAM OSMAN MOHAMED**

**RAMAH AZHARI OSMAN ALI**

Supervisor:

**MR. MOHAMED IDRES OSMAN**

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# الآيــــة

قَالَ تَعَالَى:

﴿ لَقَدْ أَرْسَلْنَا رُسُلَنَا بِالْبَيِّنَٰتِ وَأَنزَلْنَا مَعَهُمُ الْكِتَٰبَ وَالْمِيزَانَ لِيَقُومَ النَّاسُ بِالْقِسْطِ ۖ وَأَنزَلْنَا الْحَدِيدَ فِيهِ بَأْسٌ شَدِيدٌ وَمَنَٰفِعُ لِلنَّاسِ وَلِيَعْلَمَ اللَّهُ مَن يَنصُرُهُۥ وَرُسُلَهُۥ بِالْغَيْبِ ۚ إِنَّ اللَّهَ قَوِيٌّ عَزِيزٌ ﴿٢٥﴾ ﴾

صدق الله العظيم

الحديد : ٢٥

# Dedication

*We would like to dedicate this research to our Dear*

*parents..*

*To the people who paved our way of science and knowledge*

*All our teachers Distinguished*

*To the taste of the most beautiful Moments with our friends..*

*Also we dedicate this research to Our brothers and sisters*

*Who spent Their life to provide sufficient, Happiness and*

*love..*

*Finally we dedicate this research to Our colleagues In*

*Transportation And Refining department, specially All batch*

*$23^{th}$ petroleum engineering Students..*

# شكر وعرفان

# Abstract

Fouling is the deposition of any kind of extraneous material that appears on the surface of process equipment, such as heat exchangers and reactors. It is a major economic penalty to oil refineries especially Khartoum Refinery (Sour Water Stripping Unit). Through deposited of this material inside heat exchangers witch effect onto the performance of finned tube heat exchangers systems. Due to most important of fouling it must be reduced to minimum. Our project about simulation of Khartoum Refinery Sour Water Stripping Unit. Then installed and designed these units by using HYSYS program. Compared the results which approved that the efficiency of unit is dependable for fouling limits of. Also this project provides a review on the fouling mechanism and its effect onto the performance of heat exchangers systems.

# التجـــــريد

ترسب أي نوع من المواد الدخيلة التي تظهر على سطح معدات المعالجة ، مثل المبادلات الحرارية والمفاعلات تعتبر واحده من اكبر المشاكل التي تسبب خساره اقتصادية كبيرة بالنسبة لمصافي تكرير النفط وبلاخص شركه مصفاة الخرطوم وزلك في وحده معالجة المياه الحمضيه من خلال ترسب المواد داخل المبادلات الحراريه مما يسبب تدهورفي أداء المبادلات الحرارية ونسبه للاهميه العاليه للترسيب فكان لابد من التركيز عليه وتقليله الي ادني حد و يتلخص مشروعنا حول محاكاة لوحده معاجه المياه الحمضيه لمصفاة الخرطوم ثم اضافة و تصميم وحدات لها ومحاكاتها ببرنامج ال هايسس ومن ثم مقارنه النتائج لتحديد كفاة الوحدات واثبات انها وحده يمكن الاعتماد عليها لتقليل نسبه الترسيب و ايضا يمد هزا المشروع مراجعه لآليه وتأثيرها علي اداء المبادلات الحراريه.

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# Symbol

| Symbol | Description |
| --- | --- |
| DCU | Delay cocking unit |
| CDU | Crude Distillation Unit |
| SWSU | Sour Water Stripping Unit |
| FCC | Fluidizing catalytic cracking |
| WGS | Waste gas sweating |
| GDHT | Gasoline diesel hydro treating |
| DCU | Delay cocking unit |
| CDU | Crude Distillation Unit |
| KRC | Khartoum Refinery Company |
| SWSU | Sour Water Stripping Unit |
| NAP | naphtha assess  propensity |
| QTB | quench tower bottoms |
| RPG | raw pyrolysis gasoline |

# Chapter One

## Introduction

# 1. Introduction

## 1.1 Introduction

Fouling is the accumulation of unwanted material on solid surfaces to the detriment of function. The fouling materials can consist of either living organisms (bio fouling) or a non-living substance (inorganic and/or organic). Fouling is usually distinguished from other surface-growth phenomena, in that it occurs on a surface of a component, system or plant performing a defined and useful function, and that the fouling process impedes or interferes with this function.

Other terms used in the literature to describe fouling include: deposit formation, encrustation, crud ding, deposition, scaling, scale formation, slugging, and sludge formation. Fouling phenomena are common and diverse, ranging from fouling of ship hulls, natural surfaces in the marine environment (marine fouling), fouling of heat-transfer components through ingredients contained in the cooling water or gases, and even the development of plaque or calculus on teeth, or deposits on solar panels on Mars, among other examples. This article is primarily devoted to the fouling of industrial heat exchangers, although the same theory is generally applicable to other varieties of fouling. In the cooling technology and other technical fields, a distinction is made between macro fouling and micro fouling. Of the three, micro fouling is the one which is usually more difficult to prevent and therefore less important.

Fouling can occur on any fluid-solid surface and have other adverse effects besides reduction of heat transfer. It has been recognized as a nearly universal problem in design and operation, and it affects the operation of equipment in two ways: Firstly, the fouling layer has a low thermal

conductivity. This increases the resistance to heat transfer and reduces the effectiveness of heat exchangers.

Secondly, as deposition occurs, the cross sectional area is reduced, which causes an increase in pressure drop across the apparatus.

In the industry the fouling of heat transfer surfaces has always been a recognized phenomenon, although poorly understood. Fouling of heat transfer surfaces occurs in most chemical and process industries, including oil refineries, pulp and paper manufacturing, polymer and fiber production, desalination, food processing, dairy industries, power generation and energy recovery.

Fouling is considered the single most unknown factor in the design of heat exchangers. In general, the ability to transfer heat efficiently remains a central feature of many industrial processes. As a consequence much attention has been paid to improving the understanding of heat transfer mechanisms and the development of suitable correlations and techniques that may be applied to the design of heat exchangers. On the other hand relatively little consideration has been given to the problem of surface fouling in heat exchangers.

Fouling can occur as a result of the fluids being handled and their constituents in Combination with the operating conditions such as temperature and velocity. Almost any solid or semi-solid material can become a heat exchanger foulant, but some materials that are commonly encountered in industrial operations as foulants include:

## 1.2 Inorganic materials:
- Airborne dusts and grit.

- Waterborne mud and silts.

- Calcium and magnesium salts.

- Iron oxide

## 1.3 Organic materials:
- Biological substances, e.g. bacteria, fungi and algae.

- Oils, waxes and greases.

- Heavy organic deposits, e.g. polymers, tar Carbon.

## 1.4 Problem statement:
- How heat transfer efficiency reduced?.

- How the cross sectional area reduced?.

- The effect of the resistivity of the flowing fluid inside the tube.

## 1.5 Objective of study:
- To decrease the cock accumulation inside the heat exchanger tube & to improve the Sour Water Stripping Unit efficiency.

## 1.6 Methodology:
Used the aspen HYSYS program for conceptual design, optimization and performance, monitoring in oil & gas production, gas processing and petroleum refinery.

# Chapter Two

## Literature Review

# 2. Literature Review

## 2.1 Introduction

There are many of people made studies to avoid fouling in heat exchanger from the solution they obtained many of them physical solution, chemical and by adding agent and here we will show real experiment happened and the solutions suggested for antifouling:-

Sonja Richter et al., (2018) Black tar-like fouling material was driving frequent shutdowns and increasing corrosion in the inlet area of a gas plant that processes lean gas with high acid gas content (68%CH4, 20%CO2and 12%H2S). Analytical work indicated that the nitrogen containing corrosion inhibitor (CI) polymerized with sulfur compounds (polysulfide's, elemental sulfur and/or H2S) in a type of a vulcanization process resulting in a hard-to-clean insoluble fouling product. Corrosion testing confirmed the role of the CI in creating this fouling. A customized autoclave testing was designed to include powdered elemental sulfur circulating in the bulk fluid this allowed for a recreation of the condition in the plant where solid elemental sulfur comes out of solution and fouling occurs. The tests reproduced the tar-like fouling substance in the presence of the incumbent corrosion inhibitor. The data showed that a surfactant (wetting agent) used to keep elemental sulfur from depositing would also protect the steel from elemental sulfur corrosion. Other CIs were tested, but none provided protection at an acceptable dosage level without forming this fouling material.

The problem solved by the fouling conditions was successfully replicated in the lab by using water sampled from the field and powdered elemental sulfur. Based on the testing result, the incumbent corrosion inhibitor injection

was stopped maintaining the wetting agent injection only. No other corrosion inhibitor was found to provide protection at economical dosing and the system Continues to be run without injection of corrosion inhibitor.

(Paul E. Eaton and Jeff Williams 2008) The problem of fouling is treated from three points of view; laboratory, plant, and economic. A laboratory apparatus, which simulates a furnace operating in a fouling mode, is discussed and test results are given for real situations. Two fouling problems, which occur in operating refinery furnaces, are evaluated with and without the presence of a chemical antifouling. The economic aspects of fouling are presented in terms of antifouling effectiveness in reducing cleaning costs and lost profits caused by charge cutback, required for furnace cleanout.

By laboratory experiment the furnace tube fouling severity was determined and shown to be reduced with antifouling in laboratory simulations and two plant tests. The laboratory equipment was capable of reproducing the primary variable which affects fouling: namely surface temperature. The laboratory predictions were confirmed accurate by plant tests conducted in operating refineries. The economic benefits include increased operating efficiency, increased run length and reduced maintenance costs as a result of decreased furnace fouling rates.

Seth et al (2017) here we describe recent efforts to develop and deploy thin, sol-gel-derived coatings to mitigate fouling and promote continuous operation of process-critical exchangers without compromising heat transfer efficiency. Hybrid organic/inorganic sol-gel coatings can be formulated to exhibit repellency towards a broad range of organic and inorganic fouling species encountered in crude oil and hydrocarbon processing. Primary attributes of the spray-applied coatings include low surface energy, chemical-

and wear-resistance, flexibility, and very low thickness, ensuring minimum impact on heat transfer efficiency as well as mechanical and chemical durability. This paper describes application of different sol-gel coatings onto carbon steel and stainless steel materials – the dominant metallurgies for shell-And-tube (S&T) exchangers in petroleum handling and refining. We report on the fouling performance of these coatings in crude oil and produced water environments and describe efforts to scale-up the technology for deployment to the field on commercial S&T exchangers. Use of hybrid sol-gel coatings for fouling mitigation in S&T exchangers has been investigated. Variations in metal surface pre-treatment, application Process and coating composition were evaluated for use on carbon and stainless steel tubing. We demonstrate sol-gel coating stability at temperatures exceeding 600°F (316 °C) in crude oil, and in saturated steam at 365°F (185 °C). Reduction in mineral-scale fouling due to hard water immersion is also observed for sol-gel coated samples. Quantitative lab studies show that crude oil fouling rates for sol-gel coated tubes are significantly lower than for uncoated tubes and, as importantly, accumulated deposits are removed at shear stress values corresponding to typical operating conditions in commercial heat exchangers. Finally, we have developed a manufacturing process for applying the coating to a commercial U-tube exchanger and are actively assessing field performance of thin sol-gel coatings.

(B.G. Santos2009) Although petrochemical process streams are primarily composed of hydrocarbons, corrosion and fouling is observed in various locations and environments in operating plants. An electrochemical high potential measurements are used to study the effect of metallurgy and surface temperature and high pressure facility is used to study the corrosion behavior of carbon, low alloy and stainless steels in several petrochemical environments.

The electrochemical techniques such as cyclic voltammeter and open circuit roughness on the initiation of corrosion/fouling on carbon and stainless steels in several solutions (i.e. naphtha, raw pyrolysis gasoline and quench tower bottoms). The experiments are conducted using aquasi eference Ag metal electrode. Initial results suggest that corrosion /fouling rates vary with surface roughness and conductivity, which are controlled, by varying the Concentration of water. Scanning electron microscopy and energy dispersive X-ray analysis (SEM/EDX) is Used to look at the nature of the deposit formed after applying the aforementioned electrochemical techniques. Electrochemical impedance spectroscopy (EIS) is used to determine the solution resistance of naphtha and quench tower bottoms. A number of fouling characteristics including the time for initial surface coverage, the rate of film formation and the Properties of the surface film have been studied using cyclic voltammeter and open circuit potential.

The propensity for different steels to corrode and become covered with insulating carbon based deposits in several petrochemical environments was studied as a function of surface roughness and electrode metallurgy. Electrochemical techniques were shown to be a valuable tool to identify the onset and propagation of fouling on these surfaces under normal petrochemical process conditions. Cyclic voltammeter was used to qualitatively assess the propensity of naphtha (NAP), quench tower bottoms (QTB) and raw pyrolysis gasoline (RPG) to foul on carbon steel surfaces. Open circuit potential measurements with SEM/EDX surface Analysis were used to establish the extent of surface fouling on 304 and 316 in QTB and NAP environments. There is an observed difference in the morphology of the deposits formed in NAP and QTB mixtures which can be attributed to the availability of water in

the mixture. A decrease in surface roughness is shown to reduce the extent of surface fouling on stainless steel in the mixtures studied. This is most consistently observed with 304. This is attributed to an increase in chromium content in 304 as compared to 316. More experimental investigation is required to understand the relationship between corrosion and fouling.

## 2.2 Theoretical background:

### 2.2.1 Fouling

As we mentioned before the deposition of any undesired material on heat Transfer surfaces is called fouling. Fouling may significantly impact the thermal and mechanical performance of heat exchangers. Fouling is a dynamic phenomenon which changes with time.

Fouling increases the overall thermal resistance and lowers the overall heat transfer coefficient of heat exchangers. Fouling also impedes fluid flow, accelerates corrosion and increases pressure drop across heat exchangers. Different types of fouling mechanisms have been identified. They can occur individually but often occur simultaneously. Descriptions of the most common fouling mechanisms are provided below:

### 2.2.2 Types of fouling:

Many types of fouling can occur on the heat transfer surfaces. The generally favored scheme for the classification of the heat transfer fouling is based on the different physical and chemical processes involved. Nevertheless, it is convenient to classify the fouling main types as:

1. Particulate fouling: It is the deposition of suspended particles in the process streams onto the heat transfer surfaces. If the settling occurs

due to gravity as well as other deposition mechanisms, the resulting particulate fouling is called "sedimentation" fouling. Hence, particulate fouling may be defined as the accumulation of particles from heat exchanger working fluids (liquids and/or gaseous suspensions) on the heat transfer surface.

2. Crystallization or precipitation fouling: It is the crystallization of dissolved salts from saturated solutions, due to solubility changes with temperature, and subsequent precipitation onto the heat transfer surface. It generally occurs with aqueous solutions and other liquids of soluble salts which are either being heated or cooled.

3. The deposition of inverse solubility salts on heated surfaces, usual. Chemical reaction fouling: The deposition in this case is the result of one or more chemical reactions between reactants contained in the flowing fluid in which the surface material itself is not a reactant or participant. However, the heat transfer surface may act as a catalyst as in cracking, coking, polymerization, and oxidization.

4. Corrosion fouling: It involves a chemical or electrochemical reaction between the heat transfer surface itself and the fluid stream to produce corrosion products which, in turn, change the surface thermal characteristics and foul it.

5. Biological fouling: It is the attachment and growth of macro-organisms and /or Micro-organisms and their products on the heat transfer surface. It is usually called "Bio-fouling".

6. Solidification or freezing fouling: It is the freezing of a pure liquid or higher melting point components of a multi component solution onto sub-cooled surfaces.

**2.2.3 Fouling processes**:

The overall fouling process is usually considered to be the net result of two simultaneous sub-processes; a deposition process and a removal (re-entrainment) process. All sub-processes can be summarized as:

1. Formation of foulant materials in the bulk of the fluid.
2. Transport of foulant materials to the deposit-fluid interface.
3. Attachment/ formation reaction at the deposit-fluid interface.
4. Removal of the fouling deposit (spelling or sloughing of the deposit Layer).
5. Transport from the deposit-fluid interface to the bulk of the fluid.

$$Rf = \emptyset d - \emptyset r$$

Where $\emptyset d$ and $\emptyset r$ are the rates of deposition and removal respectively. The fouling factor, $Rf$ as well as the deposition rate, $\emptyset d$, and the removal rate, $\emptyset r$, can be expressed in the units of thermal resistance as m2·K/W or in the units of the rate of thickness change as m/s or units of mass change as kg/ m2· s.

**2.2.4 Influential Aspects of Fouling:**

The classification of various aspects of fouling can be broken down according to the physical and chemical processes involved in the process of fouling growth and propagation. Epstein (1983) suggested a novel approach to this by stating that there were five primary fouling categories, known as mechanisms, and for each there are five successive events, processes. The five mechanisms include crystallization fouling, particulate fouling, corrosion fouling, chemical reaction fouling and bio fouling. The solidification fouling was considered as a specific type of crystallization fouling. The five processes

include initiation, transport, attachment, removal and ageing. Epstein referred to the combination of the five mechanisms and five processes as the 5×5 matrix. The aim of formulating this matrix was initially to break the overall fouling problem down into simpler elements that could be progressively solved. However fouling is distinctly transient. In nature and the processes involved in fouling can occur simultaneously within a unit experiencing fouling. These points emphasize the complexity involved in the analysis of fouling phenomenon.

**2.2.5 A Review of Wilson Plot Method in Heat Exchangers:**

The Wilson plot developed by Wilson (1915) constitutes a suitable Technique to estimate the heat transfer coefficients and thermal resistances in a shell and tube heat exchanger. It is based on the separation of the overall thermal resistance into the inside convective thermal resistance and the remaining thermal resistances participating in the heat transfer process. the overall thermal resistance of the condensation process in shell and tube condensers ($R_{ov}$) can be expressed as the sum of the thermal resistances corresponding to external convection ($R_o$), the external fouling film ($R_{f,o}$), the tube wall ($R_t$), the internal fouling film ($R_{f,i}$) and the internal convection ($R_i$).

$$R_{ov} = R_o + R_{f,o} + R_t + R_{f,i} + R_i$$

Taking into account the specific conditions of a shell and tube condenser and the equations correlating the overall thermal resistance, Wilson theorized that if the mass flow of the cooling liquid was modified, then the change in the overall thermal resistance would be mainly due to the variation of the in-tube convection coefficient, while the remaining thermal resistances remained nearly constant. For the case of fully developed turbulent liquid flow inside a circular tube, the convection coefficient was found to be proportional to a

power of the reduced velocity ($v_r$) which accounts for the property variations of the fluid and the tube diameter. Further the overall thermal resistance was represented in the original Wilson plot as a linear function of the experimental values of $1/v_r^n$ as shown in figure.
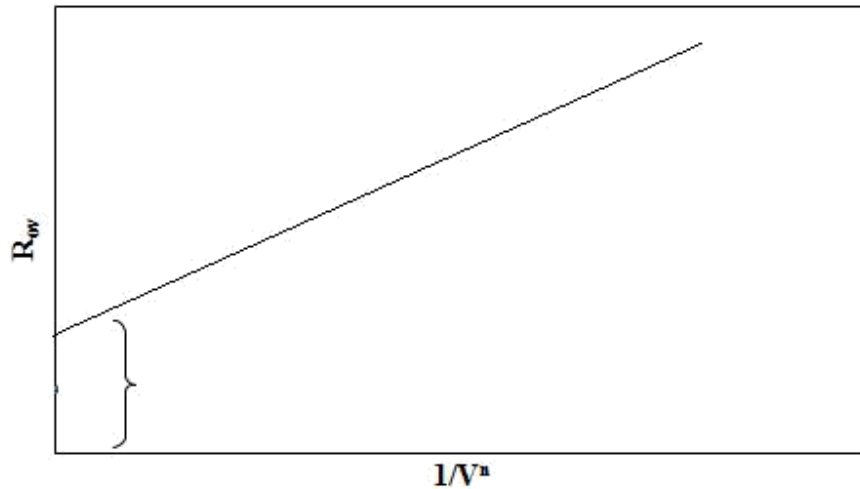


**Figure 2.1 sum of thermal resistance vs. 1/velocity**

## 2.2.5 A Basic Description of Fouling:

Fouling induces an increase in the thermal resistance and the subsequent decrease in thermal efficiency. For a clean surface that has not experienced fouling, the heat is transferred from the bulk of the liquid of the hot side by convection to the heat transfer surface and then is transmitted through the surface by conduction. The overall resistance is quantified in the form of the overall heat transfer Coefficient ($U_c$).

$$\frac{1}{Us} = \frac{1}{Hs} + \frac{1}{ht} + \frac{1}{kt}$$

The variables $U_c$, $h_s$, $h_t$ and $k_t$ represent the clean overall heat transfer coefficient, heat transfer coefficient of the shell side, tube side and the thermal

conductivity of the heat transfer surface, respectively. The occurrence of fouling adds an extra obstacle to the transfer of heat and the mode of transfer is conduction since the foulant deposit is solid. The deposit has a considerable impact on the overall heat transfer coefficient because the thermal conductivity of a foulant deposited on a heat exchanger surface is invariably smaller than that of the metal on which it resides. This impact causes the thermal resistance to increase and the thermal efficiency to significantly fall by adding another resistance to heat transfer. This can be described by calculating the new fouled value of the overall heat transfer coefficient ($U_f$) where $R_f$ represents the foulant resistance on the tube side of the heat transfer surface (Bott, 1995).

$$RF = \frac{1}{Uf} + \frac{1}{Uc}$$

Taborek et. al., (1972) published an article entitled "Heat Transfer Fouling: The Major Unresolved Problem in Heat Transfer". The article

Outlines ideas on the fouling problem through analyzing its stages and suggesting various predictive models. Afterwards many researchers such as Some scales (1981), Watkinson (1988), Hewitt et al.,(1994) and Zubair et al., (1999) categorized thermal fouling into six categories based on the dominant mechanism of fouling evolution. These are crystallization, solidification, particulate, corrosion, chemical reaction and biofouling. The classification of various aspects of fouling can be broken down according to the physical and chemical processes that occur.

The results from calculating the overall heat transfer coefficient in the above equations for both clean and fouled surfaces can be used to obtain the

total heat transferred and the fouling resistance. The total heat transferred is calculated using the total heat transfer surface area and the logarithmic mean temperature difference.

$$Q = UA\Delta T_{lim}$$

The fouling resistance is difference between the inverse value of the overall heat transfer coefficient for the clean and fouled surface.

### 2.2.6 Heat Exchanger:

The process of heat exchange between two fluids at different temperatures and separated by a solid wall is found in many engineering applications. The equipment used to implement such heat exchange process is termed as a heat exchanger. A heat exchanger is a device in which two fluid streams, one hot and one cold, are brought into thermal contact with each other in order to transfer heat from the hot fluid stream to the cold one. It provides a relatively large surface area of heat transfer for given volume of the equipment. The specific applications of heat exchangers are most frequently found in chemical process industries as well as power production, waste heat recovery, Cryogenic, air conditioning, petrochemical industries, etc. Heat exchangers may be classified on the basis of contacting techniques, construction, flow arrangement or surface compactness. A shell and tube heat exchanger is most widely used in process plants. Shell and tube heat exchangers contribute more than 65% of the exchangers in chemical process industries (Shah and Sekulic, 2003). This is due to the fact that they provide area density greater than 700 $m^2/m^3$ for gases and greater than 300 $m^2/m^3$ for liquids (Kakac and Liu, 2002). Besides higher efficiency, reduced volume, weight and cost for specific heat duty justify shell and tube heat exchangers to be the best among all other kinds

of heat exchange equipment's. This exchanger is generally built of a bundle of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. The major components of this exchanger are tubes, shell, front end head, rear end head, baffles and tube sheet. Figure 1.1 (Incropera and Dewitt, 2010) shows the schematic diagram of a typical single pass heat exchanger. The fluid flowing through the inner tubes is referred to as 'tube-side fluid' while the fluid flowing through the annulus is referred to as shell-side fluid. The scope of application of this exchanger includes a pressure range of 300 bar on shell side and 1400 bar on the tube side. The temperature that can be handled ranges within -100$^o$ C and 600$^o$ C.
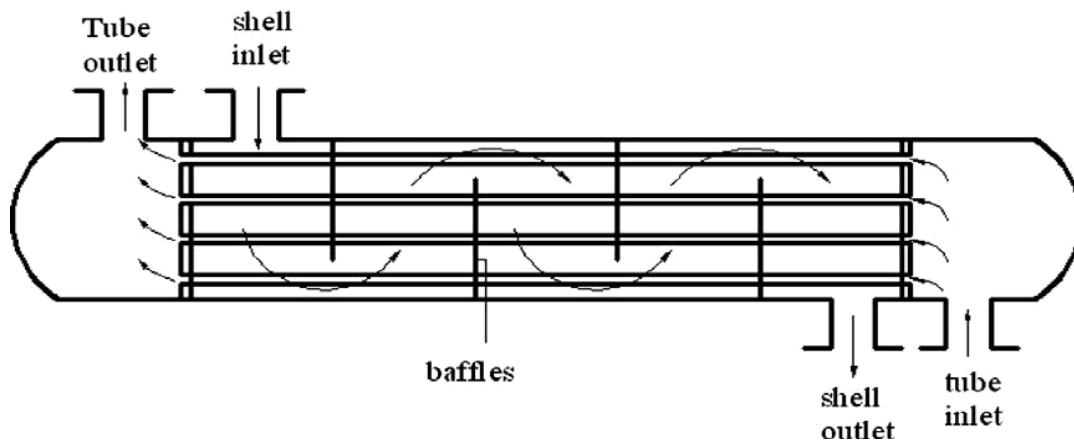


**Figure 2.2: Shell and Tube Heat Exchanger with one shell pass and one tube pass**

**2.2.7 Heat Exchanger Fouling:**

The accumulation of unwanted deposits on the heat transfer surfaces of a heat exchanger is usually referred to as fouling. Undesirable materials may be crystals, sediments, polymers, coking products, inorganic salts, biological growth, corrosion products, and so on. The presence of these deposits represents a resistance to the transfer of heat and consequently reduces the efficiency of the particular heat exchanger. Fouling is a synergistic

consequence of transient mass, momentum and heat transfer phenomena involved with exchanger fluids and surfaces which significantly affects the heat exchanger operating performances.

Thermal fouling in the presence of temperature gradient means accumulation of undesirable deposits of a thermally insulating material which provides added thermal resistance to heat flow on heat transfer surfaces over a period of time. This solid layer not only adds thermal resistance to heat flow, but also increases hydraulic resistance to fluid flow along the tubes. It is an extremely complex phenomenon characterized by combined heat, mass and momentum transfer under transient conditions. Fouling can occur as a result of the fluids being handled and their constituents in combination with operating conditions such as temperature and velocity.

Though any solid or semisolid can become a heat exchanger foulant, but commonly encountered foulants in industrial operations include inorganic material such as air borne dusts and grit, waterborne mud and slits, calcium and magnesium salts, iron oxide and organic materials such as biological substances, bacteria, fungi, algae, heavy organic deposits, polymers, tars and carbon.

The thermal fouling in the presence of a temperature gradient influences the heat transfer and flow conditions in a heat exchanger by providing an Additional resistance to heat flow process. The effect of the presence of fouling layer on temperature distribution is illustrated in Figure1.2 (Bott,1995). $T_1$ and $T_6$ represent the bulk temperatures of hot and cold fluids respectively. Under turbulent flow conditions, these temperatures extend almost to the boundary layer in respective fluids since there is a good mixing and the heat is carried physically.

In general, the thermal conductivity of foulants is extremely low as compared to that of the tube material. The thermal resistances offered by both the deposit layers require a large temperature gradient to drive the heat through the foulants. But in actual operating conditions, the temperature difference across the tube wall is comparatively low (Bott, 1995).
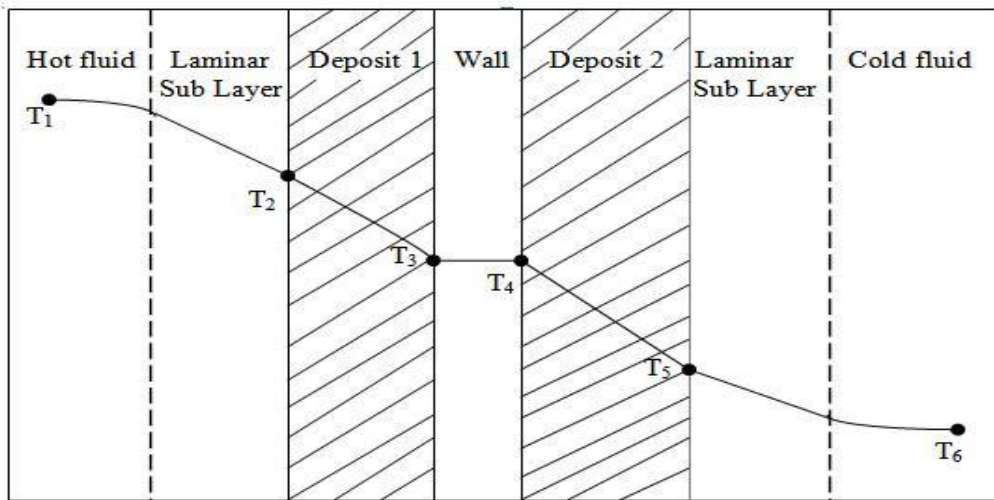


Distance

**Figure 2.3: Temperature distribution across fouled heat exchanger surfaces**

The problem of heat exchanger fouling therefore represents a challenge to designers, technologists and scientists in terms of heat transfer technology. In most commonly observed fouling phenomenon, three basic stages can be Visualized in relation to deposition on surfaces from a moving fluid (Steinhagen, 2000).
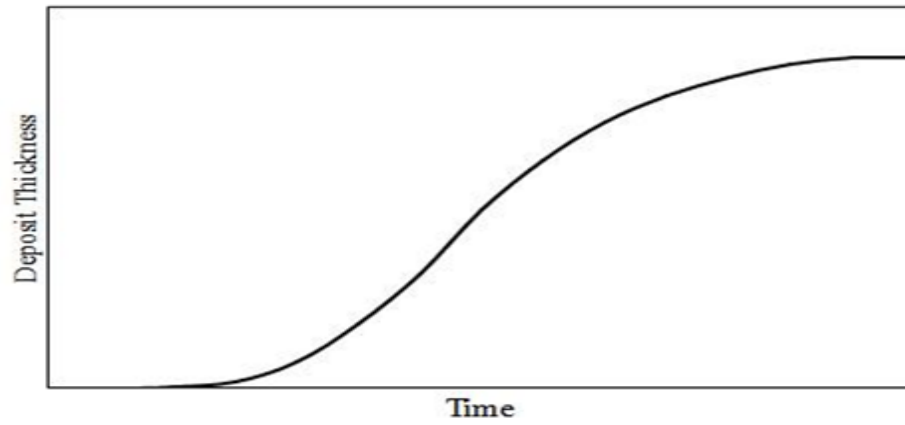
**Figure 2.4: Variation of deposit thickness with time**

# Chapter Three

**Methodology**

# 3. Methodology:

## 3.1 Feed Composition:

These operating data obtained from the Sour Water Unit of Khartoum Refinery Company.

Table3-1: feed composition

| Feed composition kg\h | |
|---|---|
| Water | 56740.49 |
| Carbon | 748.9 |
| Ammonia | 10635.82 |
| Hydrogen Sluphide | 16874.72 |

## 3.2 Case Study:

KRC Sour Water Stripping Unit (SWS) was designed with the capacity of 125t/h sour water comes from FCC, DCU (fractionator overhead knockout drum), GDHT and ADU. SWSU started up in July 2010, during the overhaul in March 2011, the shell sides of the sour water/purified water exchangers as seriously blocked by something like asphalt, similar problem existed in purified water air-cooler, and DCU sour water filter was also blocked in short time. The elbow in the suction of the purified water pump was found to be blocked by coke in September, 2011.

## 3.3 Process Description:

### 3.3.1 Main Process Description:

The sour water as the feed firstly goes through the degassing section to remove light hydrocarbons gases which are very small amount and neglected,

and part of H2S which at very high amount contained in water, combining with settlement de-oiling by gravity and high efficiency vortex de-oiling, to get oil Content in the feed to maintain less than 100ppm, thus to keep stripper under normal operation. Feed water tank is water-sealed tank sealed with water from the top, to avoid light hydrocarbons gas leakage, thus to protect the environment from polluting. After sour water which contains sulfur and ammonia is stripped and purified, it can both meet inlet water quality of waste water treatment plant, and can also return back to upstream units for reuse, thus to save water resources. Low pressure technology is a mature technology which is widely used. It has the advantages of reliable, low energy consumption, low investment and less and occupation. The stripper is equipped with high performance float valve trays which are characterized with low pressure drop, high efficiency and large operation flexibility and so on, it's suitable for long term operation. Stripping energy is supplied through bottom re-boiler by which recovery of condensate is available, then much part of the energy consumption for boiler feed water treatment is saved. Air cooler is used where ever is possible within the unit to reduce requirement of circulating cooling water. Waste gas sweeting package (WGS) is used to deal with malodorous gases from the sour water tank using water washing and high efficiency absorbent. Acid gas incinerator acid gas to convert H2S into SO2 and ammonia into nitrogen, the vent gas emits to atmosphere directly. Tank-in-tank regulating tank is reliable in operation, its processing capacity is 2-3 times higher than the similar tanks, and automatic control can be realized on this tank. It is suitable for long term operation with big adaptability to waste water, wide range for operating and adjusting and change of oil content in
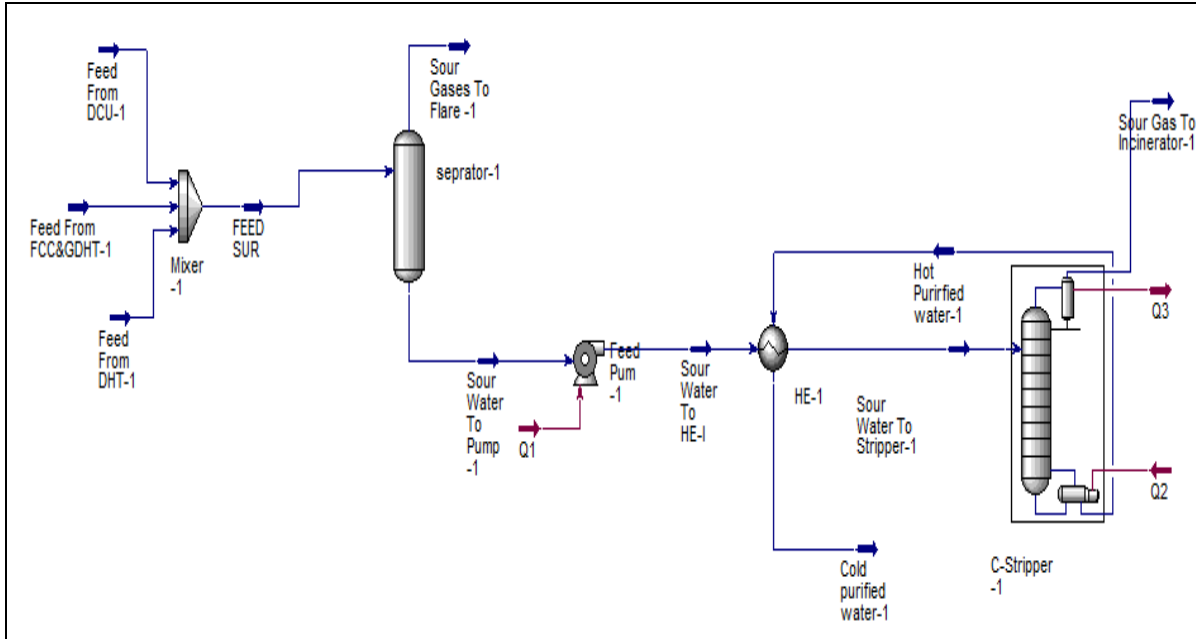
**Figure3-1: main process unit**

### 3.3.2 Proposed Process Description:

The Sour water which received from RFCC, DHT, DCU&GDHT are mixed in Mixture before they inter the new simple solid cyclone. So as to remove the coke particle and sour gas from received water. Then the water temperature will be raised by exchanged with high temperature purified water come from bottom of the stripper in the heat exchanger. Finally the sour gas stripped in stripper column and purified water produced are reuse again in process units.
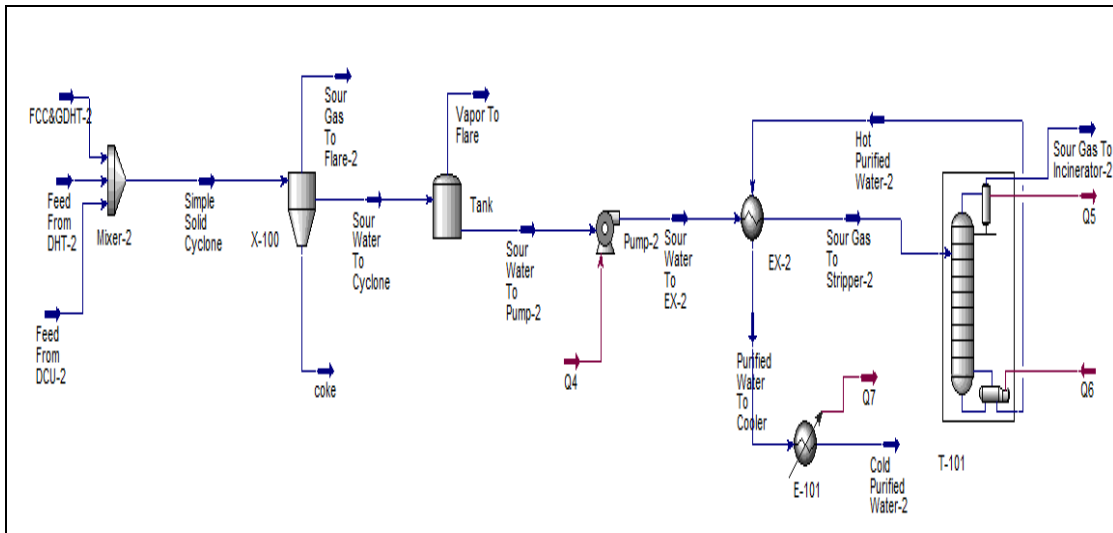
**Figur3-2: Proposed process unit**

## 3.4 Hysys Overview:

Aspen HYSYS (or simply HYSYS) is a chemical process simulator used to mathematically model chemical processes, from unit operations to full chemical plants and refineries. HYSYS is able to perform many of the core calculations of chemical engineering, including those concerned with mass balance, energy balance, vapor-liquid equilibrium, heat transfer, mass transfer, chemical kinetics, fractionation, and pressure drop. HYSYS is used extensively in industry and academia for steady-state and dynamic simulation, process design, performance modelling, and optimization.

## 3.5 Overall Material Balance:
### 3.5.1 Main process Material balance:

Table3-2: Inlet main process material balance

| INLET | |
|---|---|
| **Streams** | **TON\H** |
| Feed From DHT-1 | 10.00 |
| Feed From FCC&GDHT-1 | 55.00 |
| Feed From DCU-1 | 20.00 |
| **Total** | **85.00** |

Table3-3 out let main process material balance

| OUTLET | |
|---|---|
| **Streams** | **TON\H** |
| Sour Gases To Flare -1 | 19.41 |
| Cold purified water-1 | 44.66 |
| Sour Gas To Incinerator-1 | 20.92 |
| **Total** | **84.99** |

### 3.5.2 Proposed material balance:

| INLET | |
|---|---|
| **Streams** | **Ton\h** |
| Feed From DHT-2 | 10.00 |
| FCC&GDHT-2 | 55.00 |
| Feed From DCU-2 | 20.00 |
| **Total** | **85.00** |

Table3-4: inlet proposed material balance

Table3-5: out let proposed material balance

| OUTLET | |
|---|---|
| **Stream** | **Ton\h** |
| Sour Gas To Flare-2 | 19.41 |
| Sour Gas To Incinerator-2 | 13.97 |
| Vapor To Flare | 0.000 |
| Cold Purified Water-2 | 45.03 |
| **Total** | **78.41** |

| Inlet Material Streams | Counted | Mass Flow | Outlet Material Streams | Counted | Mass Flow | |
|---|---|---|---|---|---|---|
| Feed From DHT-1 | ☑ | 10.00 tonne/h | Sour Gases To Flare -1 | ☑ | 19.41 tonne/h | |
| Feed From FCC&GDHT-1 | ☑ | 55.00 tonne/h | Cold purified water-1 | ☑ | 44.66 tonne/h | |
| Feed From DCU-1 | ☑ | 20.00 tonne/h | Sour Gas To Incinerator-1 | ☑ | 20.93 tonne/h | |
| Feed From DHT-2 | ☑ | 10.00 tonne/h | coke | ☑ | 6.578 tonne/h | |
| FCC&GDHT-2 | ☑ | 55.00 tonne/h | Sour Gas To Flare-2 | ☑ | 19.41 tonne/h | |
| Feed From DCU-2 | ☑ | 20.00 tonne/h | Sour Gas To Incinerator-2 | ☑ | 13.98 tonne/h | |
| | | | Vapor To Flare | ☑ | 0.0000 tonne/h | |
| | | | Cold Purified Water-2 | ☑ | 45.03 tonne/h | |

Total Flow of Inlet Streams: 170.0 tonne/h

Total Flow of Outlet Streams: 170.0 tonne/h

Imbalance = (Total Flow of Outlet Streams) - (Total Flow of Inlet Streams): 0.0000 tonne/h

Unit Op Balance

Relative Imbalance (%) = Imbalance/(Total Flow of Inlet Streams) * 100%: 0.00 %

**Figur3-3: Over all HYSYS material balance**

### 3.6.1 Main Process Energy Balance:

Table 3-6: inlet main process energy balance

| INLET | |
|---|---|
| **Streams** | **KJ\H** |
| Q1 | 85676.49 |
| Feed From DHT-1 | -98630203.80 |
| Feed From FCC&GDHT-1 | -645873653.27 |
| Feed From DCU-1 | -206845448.25 |
| Q2 | 97225799.83 |
| **Total** | **-854037829** |

Table 3-7: out let main process energy balance

| OUTLET | |
|---|---|
| **Streams** | **KJ\H** |
| Sour Gases To Flare -1 | -20462189.03 |
| Cold purified water-1 | -695135903.31 |
| Q3 | 49160774.37 |
| Sour Gas To Incinerator-1 | -187599928.93 |
| **Total** | **-854037246.9** |

## 3.6.2 Proposed energy balance:

**Table3-8: inlet proposed energy balance**

| INLET | |
|---|---|
| **Streams** | **KJ\H** |
| Feed From DHT-2 | -98630203.80 |
| FCC&GDHT-2 | -645873653.27 |
| Feed From DCU-2 | -206845448.25 |
| Q4 | 77464.24 |
| Q6 | 71304441.76 |
| Total | -879967399.14 |

**Table3-9: out proposal energy balance**

| OUTLET | |
|---|---|
| **Streams** | **KJ\H** |
| Coke | -83774484.37 |
| Sour Gas To Flare-2 | -20462189.03 |
| Q5 | 33362009.12 |
| Sour Gas To Incinerator-2 | -103520127.80 |
| Vapor To Flare | 0.00 |
| Cold Purified Water-2 | -712849432.89 |
| Q7 | 7276359.04 |
| **Total** | **-909993865.93** |

| Inlet Streams | Counted | Energy Flow | Outlet Streams | Counted | Energy Flow | |
|---|---|---|---|---|---|---|
| Q1 | ☑ | 8.568e+004 kJ/h | Sour Gases To Flare -1 | ☑ | -2.046e+007 kJ/h | |
| Feed From DHT-1 | ☑ | -9.863e+007 kJ/h | Cold purified water-1 | ☑ | -6.951e+008 kJ/h | |
| Feed From FCC&GDHT-1 | ☑ | -6.459e+008 kJ/h | Q3 | ☑ | 4.916e+007 kJ/h | |
| Feed From DCU-1 | ☑ | -2.068e+008 kJ/h | Sour Gas To Incinerator-1 | ☑ | -1.876e+008 kJ/h | |
| Q2 | ☑ | 9.723e+007 kJ/h | coke | ☑ | -8.377e+007 kJ/h | |
| Feed From DHT-2 | ☑ | -9.863e+007 kJ/h | Sour Gas To Flare-2 | ☑ | -2.046e+007 kJ/h | |
| FCC&GDHT-2 | ☑ | -6.459e+008 kJ/h | Q5 | ☑ | 3.336e+007 kJ/h | |
| Feed From DCU-2 | ☑ | -2.068e+008 kJ/h | Sour Gas To Incinerator-2 | ☑ | -1.035e+008 kJ/h | |
| Q4 | ☑ | 7.746e+004 kJ/h | Vapor To Flare | ☑ | 0.0000 kJ/h | |
| Q6 | ☑ | 7.130e+007 kJ/h | Cold Purified Water-2 | ☑ | -7.128e+008 kJ/h | |
| | | | Q7 | ☑ | 7.276e+006 kJ/h | |

Total Flow of Inlet Streams: -1.734e+009 kJ/h
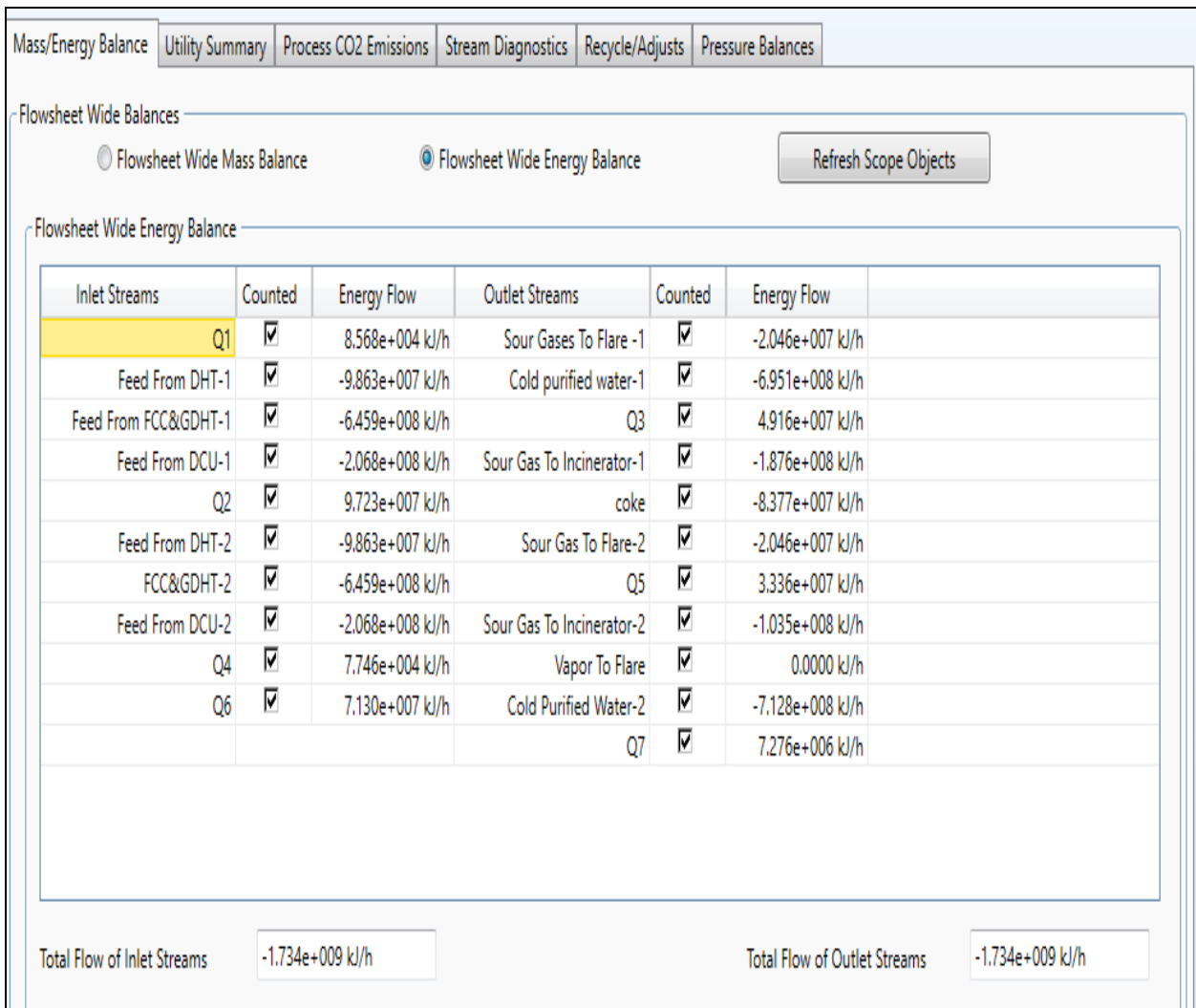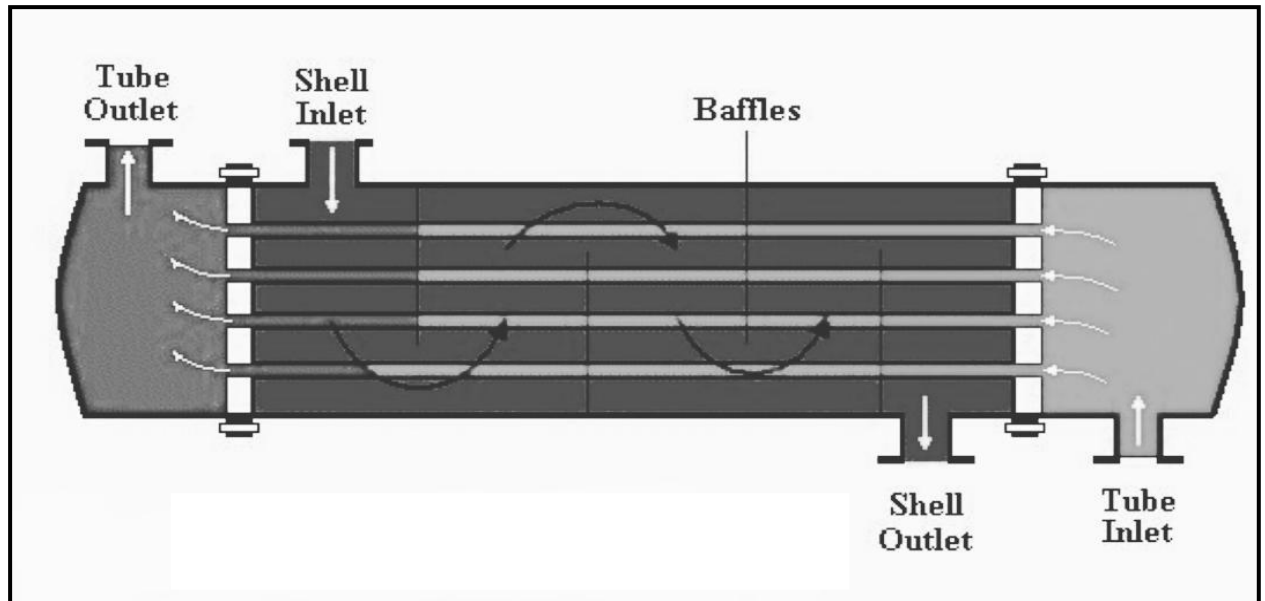
Total Flow of Outlet Streams: -1.734e+009 kJ/h

Figure 3-4: Overall HYSYS Energy Balance

## 3.7 Design of shell and tube heat exchanger:



**Figure 3.5 Heat exchanger design**

### 3.7.1 Data:

From energy balance

$M_w$ = 16.39 Kg/s

$Q_w$=8.5*10^8KJ/h

Table 3-10 inlet and outlet temperature °C

| Temperature | Hot fluid | Cold fluid | Difference |
|---|---|---|---|
| Higher temperature | 162 | 102 | 60 |
| Lower temperature | 75.33 | 35.62 | 21.71 |
| Deference | 86.67 | 66.38 | 20.29 |

Table 3.11 Physical properties of cold and hot water. [Appendix A, Appendix C]

| Fluid properties | Hot T = 82 °C | Cold T = 62 °C |
|---|---|---|
| $\mu \left(\frac{Kg}{m \times s}\right)$ [A] | $0.346 \times 10^{-3}$ | $0.442 \times 10^{-3}$ |
| $Cp \left(\frac{KJ}{Kg \times K}\right)$ [C] | 4.199 | 4.186 |
| $K \left(\frac{W}{m \times K}\right)$ [C] | $671 \times 10^{-3}$ | $656 \times 10^{-3}$ |
| $\rho \left(\frac{Kg}{m^3}\right)$ [A] | 970.6 | 982.7 |

——

### 3.7.2 Calculations:

$$\text{LMTD} = \frac{\Delta T_1 - \Delta T_2}{Ln(\frac{\Delta T_1}{\Delta T_2})} = \frac{(162-102) - (75.33-35.62)}{Ln\left(\frac{60}{39.71}\right)} = 49.15°C$$

$$R = \frac{T_{9\,in} - T_{9\,out}}{T_{w\,out} - T_{w\dot{n}}} = \frac{162-102}{75.33-35.62} = 1.5$$

$$S = \frac{T_{wou-\dot{n}}}{T_{9\,in} - T_{9\,out}} = \frac{39.71}{126.38} = 0.314$$

Temperature correction factor $F_t = 0.96$.[Appendix D1]

$$\Delta T_m = F_t \times \text{LMTD} = 0.96 \times 49.15 = 47.18°C$$

The heat transfer coefficient from HYSYS is

$U = 3.52*10^5$ KJ/ h

$Q = U \times A \times \Delta T$

$$A = \frac{Q}{U \times \Delta T} = \frac{8.47*10^8}{3.52*10^5*47.18} = 61$$

$A = 61\ m^2$

Table 3.12 Dimensions of Heat exchanger

| $d_\circ$ (mm) | $d_i$ (mm) | L (m) |
|:---:|:---:|:---:|
| 20 | 16 | 6 |

Area of tubes $= \pi \times d_\circ \times L = 3.142 \times 20 * 10^{-3} \times 6 = 0.37707\ m^2$

Number of tubes $= \frac{61.00}{0.37704} = 162\ tubes$

Bundle diameter

2-passes

$= 0.249$ [Appendix D3]

$= 2.207$ [Appendix D3]

$$D_b = D_\circ (\frac{N_t}{k})^{\frac{1}{n}} = 0.02(\frac{162}{0.249})^{\frac{1}{2.207}}$$

$D_b = 0.38\ m$

Use spilt ring floating head type

Shell diameter $D_s = 0.66 + 0.38 = 1.04$

Tube size coefficient

Mean water temperature $= \dfrac{75.33+35.62}{2} = 55.47\ ^\circ C$

Tube cross sectional area $= \dfrac{\pi}{4} \times D_i{}^2 = \dfrac{3.14\times16^2}{4} = 201\ mm^2$

Tube per pass $= \dfrac{162}{2} = 81$

Total flow area $= 81\times 201 * 10^{-6} = 0.016\ m^2$

Water cooling mass velocity

Water cooling flow / total flow area $\dfrac{m\times w}{A} = \dfrac{16.39}{0.016} = 1024\ \dfrac{Kg}{s\times m^2}$

Water cooling liner velocity $= \dfrac{1024}{982.7} = 1.04\ \dfrac{m}{s}$

$$h = \frac{5841 * 1.35 + 0.02 * t * U_t{}^{0.8}}{d_i{}^{0.2}} = \frac{5841 * 1.35 + 0.02 * 62 * 1.04^{0.8}}{16^{0.2}}$$

$h = 8965.8\ w/m^2 \times\ ^\circ C$

$$R_e = \frac{\rho \times U \times d_i}{\mu} = \frac{982.7 \times 1.04 \times 16 * 10^{-3}}{0.442 * 10^{-3}}$$

$R_e = 37647$

$$P_r = \frac{C_p \times \mu}{K} = \frac{988 \times 4.186 \times 0.442 * 10^{-3}}{656 * 10^{-3}}$$

$P_r = 2.8$

Neglect $\left(\dfrac{}{\mu\times w}\right)$

$$\frac{L}{d_i} = \frac{6 * 10^3}{16} = 375$$

$j^h = 4 * 10^{-3}$. [Appendix D5]

$$h_{id} = \frac{K}{d_i} \times j \times R_e \times P_r^{0.33} = \frac{0.656}{16 * 10^{-3}} \times 37647 \times 2.8^{0.33}$$

$$h_{id} = 8672.3 \ \frac{w}{m^2 \times °C}$$

Shell side coefficient

Chose baffle spacing $= \dfrac{Ds}{5} = \dfrac{1.04}{5} = 0.228\ m$

Tube pitch $= 1.25 \times d° = 1.25 \times 20 = 25\ mm$

Cross flow area $(A_s) = \dfrac{Pt - d°}{Pt} \times Ds \times IB = \dfrac{25 - 20}{25} \times 0.228 \times 1.04 = 0.0638\ m2$

Mass velocity (Gs) = Mass flow rate/As

$= \dfrac{16.39}{0.0638} = 256.7\ Kg/s \times m2$

Equivalent diameter $(d_e) = \dfrac{1.1}{d°} \times (P_t\,2 - 0.917 \times 202)$

$= \dfrac{1.1}{20} \times (252 - 0.917 \times 202$

de = 14.2 mm

mean shell side temperature $= \dfrac{162 + 75.33}{2} = 118°C$

$Re = \dfrac{G_s \times d_e}{\mu} = \dfrac{256.7 \times 14.2 * 10{-3}}{0.346 * 10{-3}} =$

$Re = 10535$

$P = Cp \times U = \dfrac{4.199 \times 0.346 * 10{-3} \times 988}{671 * 10{-3}}$

$K_r$

$Pr = 2.2$

Chose 25% baffle cut at Reynolds number = 10535

$jh = 5 * 10{-2}$. [Appendix D6]

Without viscosity correction term

$K\quad 1 \qquad\qquad\qquad\qquad 0.67\Gamma^2 \times 5 * 10^{1} \times 10535 \times 2.23$

$$h = de \times jh \times Re \times Pr = \cfrac{\overline{3}}{\cfrac{1}{14 * 10{-}3}}$$

$h = 69319.7 \; w/m2 \times °K$

$h° = hs = 693197 \; w/m2 \times °C$

Overall heat transfer coefficient

Thermal conductivity of stainless steel $(K_w) = 16 \; w/m^2 \times °C$

For cold water $h = 3000 \; w/m^2 \times °C.$ [Appendix D7]

For hot water $h_{d°} = 2000 \; w/m^2 \times °C.$ [Appendix D7]

$$\frac{1}{U°} = \frac{1}{h_°} + \frac{1}{h_{d°}} + \frac{d° \times L_n \frac{d°}{d_i}}{2 \times K \times w} + \frac{d°}{d_i} \times \frac{1}{h_i} \pm \frac{1}{h_{di}}$$

$$\frac{1}{U_\circ} = \frac{1}{69319.7} + \frac{1}{2000} + \frac{20 * 10^{-3} \times L_n \frac{20}{16}}{2 \times 16} + \frac{20}{16}$$
$$\times \frac{1}{\frac{1}{8672.3} + \frac{1}{3000}}$$

$$\frac{1}{U_\circ} = 2.543 * 10^{-5} + 0.0005 + 1.39 * 10^{-4} + 4.856 * 10^{-4}$$

$$\frac{1}{U_\circ} = 12.258*10^{\wedge}\text{-}4$$

$$U_\circ = \frac{1}{0.001258} = 815.7 \; w/m^2 \times °C$$

Pressure drop at tube side

tube side friction at Reynolds number 37674 $j_f = 2.2 * 10^{-3}$.[Appendix D8]

Neglecting the viscosity correction term

$$\Delta = N_s \times 8 \times j_p \times j_f \frac{L}{d} + 2.5 \times \frac{\rho \times U \times t^2}{2}$$

$$= 2 \times 8 \times 2.2 * 10^{-3} \frac{6 * 10^3}{16} + 2.5 \times \frac{982.7 \times 1.04^2}{2}$$

$$= 96722.8 \; N/m^2 = 97.7228 Kp_a$$

Pressure drop at shell side

Liner velocity $(U_s) = \frac{Gs}{\rho} = \frac{256.7}{970.6} = 0.264 \; m/s$

at Reynolds number 10535 shell side friction $j_f = 6.8 * 10^{-2}$.[Appendix D9]

$$\Delta P_s = 8 \times j_f \times \frac{D_s}{d_e} \times \frac{L}{I_B} \times \frac{\rho \times U_2^2}{2} \times \frac{m}{m \times w}$$

Neglecting the viscosity correction

$$\Delta P_s = 8 \times 6.8 * 10^{-2} \times \frac{1.04}{0.142} \times \frac{6}{0.28} \times \frac{970.6 \times 0.27^2}{2}$$

$$\Delta P_s = 247971 \ N/m^2 = 247.971 \ Kp_a$$

| Item | Symbol | Value | Unit |
|---|---|---|---|
| Tube outside diameter | $d_\circ$ | 20 | $mm$ |
| Tube inside diameter | $d_i$ | 16 | $mm$ |
| Tube length | $L$ | 6 | $m$ |
| Heat transfer area | $A$ | 61 | $m^2$ |
| Number of tubes | $N_t$ | 162 | Tubes |
| Shell diameter | $D_s$ | 1.04 | $m$ |
| Outside transfer coefficient | $h_\circ$ | 69319.7 | $w/m^2 \times °C$ |
| Inside transfer coefficient | $h_i$ | 8672.3 | $w/m^2 \times °C$ |
| Overall transfer coefficient | $U$ | 815.7 | $w/m^2 \times °C$ |
| Fouling factor | $h_{id}$ | 3000 | $w/m^2 \times °C$ |
| Fouling factor | $h_{\circ d}$ | 2000 | $w/m^2 \times °C$ |
| Pressure drop in tube side | $\Delta P_t$ | 96.72 | $KP_a$ |
| Pressure drop in shell side | $\Delta P_s$ | 247.9 | $KP_a$ |

Table 3.13 summary of Heat Exchanger design

# Chapter Four

**Result and Discussion**

# 4. Result and Discussion

## 4.1 Result:

When compared the parameters obtained from our case study with the available KRC Sour Water Stripping Unit parameters, we obtain   the results as blew show:

Table4-1: Results Comparison Table

| Compared  parameters | SWU Result | New Case Result |
|---|---|---|
| DUTY (KW) | 25667.8 | 8543.5 |
| Shell side  Inlet Temperature (o C) | 127.4 | 162 |
| Shell side  Outlet  Temperature (o C) | 38.5 | 75.33 |
| Tube  side  Inlet Temperature (o C) | 35.6 | 35.62 |
| Tube  side  Outlet  Temperature (o C) | 95 | 102 |
| Fouling Factor (m2K/W) | 0.000821 | 0.000213 |
| Pressure drop in tube side (Kpa) | 320 | 280 |
| Pressure drop in shell side (Kpa) | 221.5 | 100 |
| Mass flow rate ton\h | 85 | 85 |
| Overall Heat Transfer Coefficient (KJ\C-h) | 1.389*10^6 | 3.524*10^6 |

## 4.2 Discussion:

Mass flow rate and pressure drop have significant direct effect on each other. Increase in mass flow rate will increase the pressure drop, which should be in allowable condition. It is necessary to evaluate optimal value of mass flow rate and pressure drop in different fouling condition to satisfy desired heat transfer. At initial level there is a zero fouling or say clean condition. The graphs give the correlation between mass flow rate, pressure drop, fouling factor and other thermal parameters.

### 4.2.1 Analysis of Shell Side Flow Pressure Drop:

Pressure drop decrease from 278.5 Kpa  in old case  to 100 Kpa   when installed new  simple sold cyclone in new case  there is a relative decrease in shell side pressure drop.

### 4.2.2 Analysis of Tube Side Flow Pressure Drop:

Pressure drop decrease from 320 Kpa  in old case  to 280 Kpa   when installed new  simple sold cyclone in new case  there is a relative decrease in tube side pressure drop that mean there is lilt resistance inside the tube side.

### 4.2.3 Analysis of Overall Heat Transfer Coefficient and Tube Side Flow:

An overall heat transfer coefficient has significant role in heat transfer process  iterations based on mass flow rate at various fouling conditions. In this case, the change of mass flow rate pattern is same in all fouling condition. The gradual increase in fouling has decreased an overall heat transfer coefficient gradually. Gradual decrease in overall heat transfer coefficient will decrease the heat transfer rate of heat exchanger.

**4.2.4 Analysis of Fouled Heat Transfer Coefficient and Tube Side Flow:**

Illustrated the effects of iterations based on mass flow rate at fouling conditions for an analysis of fouled heat transfer coefficient and tube side flow. The fouled heat transfer coefficient has significant role in heat transfer process The change of mass flow rate pattern is same in all fouling condition. The gradual increase in fouling has decreased the fouled heat transfer coefficient gradually. Fouled heat transfer has much variation then overall heat transfer coefficient. Gradual decrease in fouled heat transfer coefficient will decrease the heat transfer rate of heat exchanger. At the initial level of fouling there is major drop in fouled heat transfer coefficient and at further as the fouling increase the fouled heat transfer coefficient drop decreases.

**4.2.5  Analysis of Duty (Heat Exchanged) and Uo & Uf:**

Represents based on mass flow rate iteration at constant fouling factor (f =0.000213 m2k/W). As the mass flow rate increase gradually there is a gradual increase in overall and fouled heat transfer coefficient as well as in heat exchanged. The graphical representation gives correlation between overall & fouled heat transfer coefficient and heat exchanged for mass flow rate iterations at constant fouling condition. At optimized mass flow rate condition the value of overall heat transfer coefficient is 987.7 W/m2K and value of fouled heat transfer coefficient is 815.7 W/m2K. This satisfies the desired heat transfer of heat exchanger.

# Chapter Five

**Conclusion and Recommendation**

# 5. Conclusion and Recommendation

## 5.1 Conclusion:

The case study is considered the best option depending on the installed new separator before the heat exchanger in order to suggest the best solution, and to avoid the off line methods of fouling reduce this methods have bigger maintenance costs during plant life while the in line methods increase the initial cost of the plant as our case study is.

**The old case:**

Although a part of coke is removed by sedimentation, the flow rate of mixed sour water (about 125t/h) is so high that the investment of filter will be high where the water produced by backwashing discharges is a big problem if discharge to the sour water Tank the coke will circulate in the unit and this has bad effect on long term operation.

**Case study:**

Treat sour water firstly by cyclone separator then by filtration, the load of the filter can be decreased, and the coke removal effect will be improved. If the existing equipment can be reutilized, we only need to add the new storage tank. Although the process is a little complex such measure is most effective for long period operating the main conclusions are summarized as follows:

1. As the mass flow rate and fouling increase there is relative increase in pressure drop at constant fouling factor for shell and tube both side.

2. While increasing mass flow rate in same manner for different fouling conditions there is not any significant effect on pressure drop due to fouling of sour water at shell side.

3. While increasing mass flow rate in same manner for different fouling conditions there is minor change in pressure drop due fouling of cooling water at tube side..

4. While increasing mass flow rate in same manner for different fouling conditions there is increase in overall heat transfer coefficient with increase in mass flow rate and decrease as the fouling increase.

5. While increasing mass flow rate in same manner for different fouling conditions there is increase in fouled heat transfer coefficient with increase in mass flow rate and significantly decrease as the fouling increase.

6. As the mass flow rate increase there is increase in heat transfer. Heat transfer is strongly influenced by shell side mass flow rate. Small change at shell side mass flow rate will give significant heat transfer.

## 5.2 Recommendations:

Other key areas include considering the coke removal and, thus, considering the net fouling rate rather than the coke deposition. The initial focus should be on ensuring that the model developed in this project operates for the intended processes over a range of operating conditions. By broadening the scope of the model components and ensuring its operation then work could commence on its extension.

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# Appendix

# Appendix

D$_1$ Temperature Correction Factor
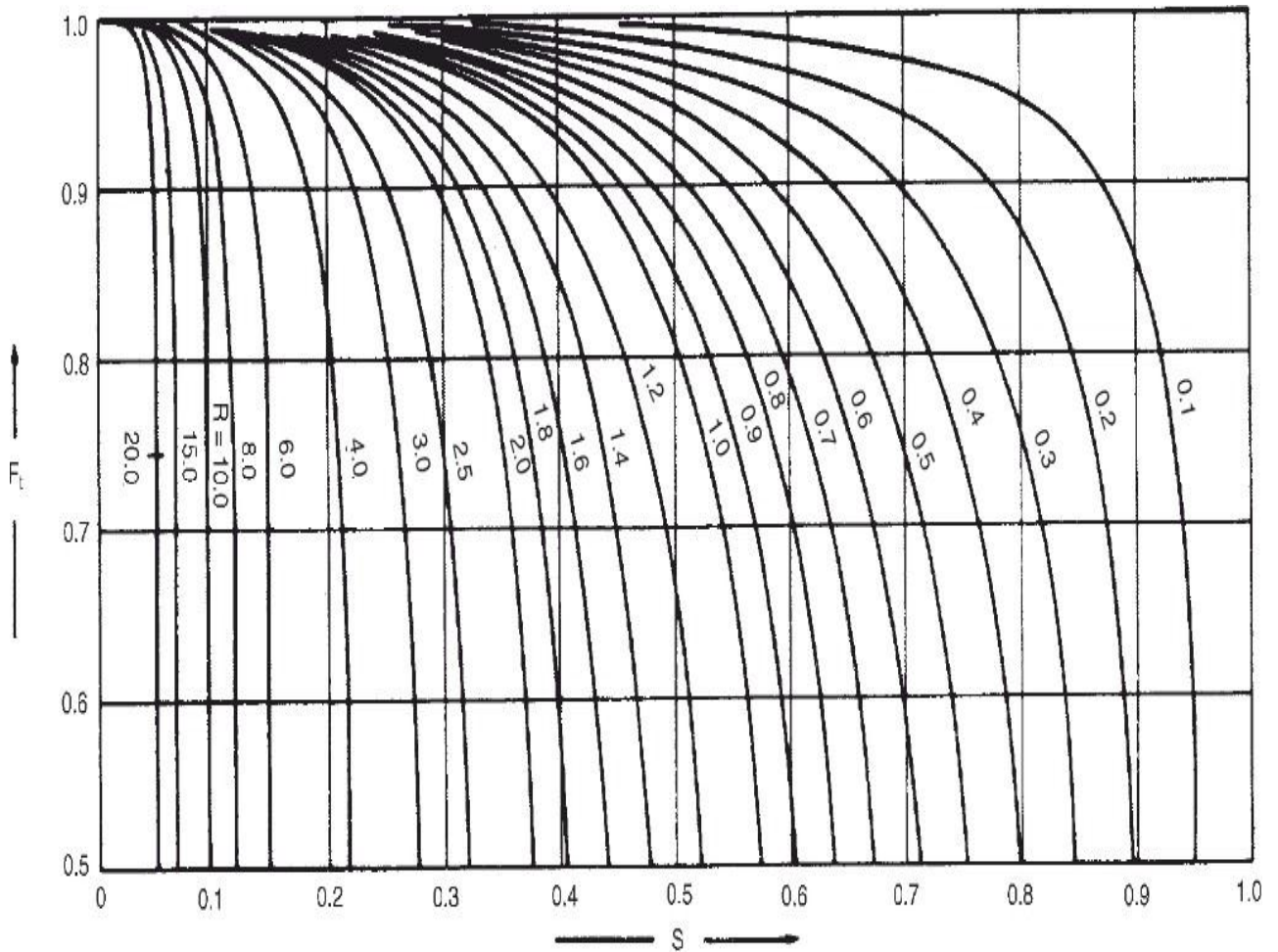


Figur5-1: Heat Exchanger and condenser Chart

Table 5-1:$D_2$ Heat transfer coefficient of water

| Shell and tube exchangers | | |
|---|---|---|
| Hot fluid | Cold fluid | $U$ (W/m$^2$ °C) |
| *Heat exchangers* | | |
| Water | Water | 800 – 1500 |
| Organic solvents | Organic solvents | 100 – 300 |
| Light oils | Light oils | 100 – 400 |
| Heavy oils | Heavy oils | 50 – 300 |
| Gases | Gases | 10 – 50 |
| *Coolers* | | |
| Organic solvents | Water | 250 – 750 |
| Light oils | Water | 350 – 900 |
| Heavy oils | Water | 60 – 300 |
| Gases | Water | 20 – 300 |
| Organic solvents | Brine | 150 – 500 |
| Water | Brine | 600 – 1200 |
| Gases | Brine | 15 – 250 |
| *Heaters* | | |
| Steam | Water | 1500 – 4000 |
| Steam | Organic solvents | 500 – 1000 |
| Steam | Light oils | 300 – 900 |
| Steam | Heavy oils | 60 – 450 |
| Steam | Gases | 30 – 300 |
| Dowtherm | Heavy oils | 50 – 300 |
| Dowtherm | Gases | 20 – 200 |
| Flue gases | Steam | 30 – 100 |
| Flue | Hydrocarbon vapours | 30 – 100 |
| *Condensers* | | |
| Aqueous vapours | Water | 1000 – 1500 |
| Organic vapours | Water | 700 – 1000 |
| Organics (some non-condensables) | Water | 500 – 700 |
| Vacuum condensers | Water | 200 – 500 |
| *Vaporisers* | | |
| Steam | Aqueous solutions | 1000 – 1500 |
| Steam | Light organics | 900 – 1200 |
| Steam | Heavy organics | 600 – 900 |

$D_4$ shell bundle clearance

Table 5-2:D5 tube side Heat transfer factor

Table 5-3: D6 shell side transfer factor

| Triangular pitch, $p_t = 1.25d_o$ | | | | | |
|---|---|---|---|---|---|
| No. passes | 1 | 2 | 4 | 6 | 8 |
| $K_1$ | 0.319 | 0.249 | 0.175 | 0.0743 | 0.0365 |
| $n_1$ | 2.142 | 2.207 | 2.285 | 2.499 | 2.675 |
| Square pitch, $p_t = 1.25d_o$ | | | | | |
| No. passes | 1 | 2 | 4 | 6 | 8 |
| $K_1$ | 0.215 | 0.156 | 0.158 | 0.0402 | 0.0331 |
| $n_1$ | 2.207 | 2.291 | 2.263 | 2.617 | 2.643 |
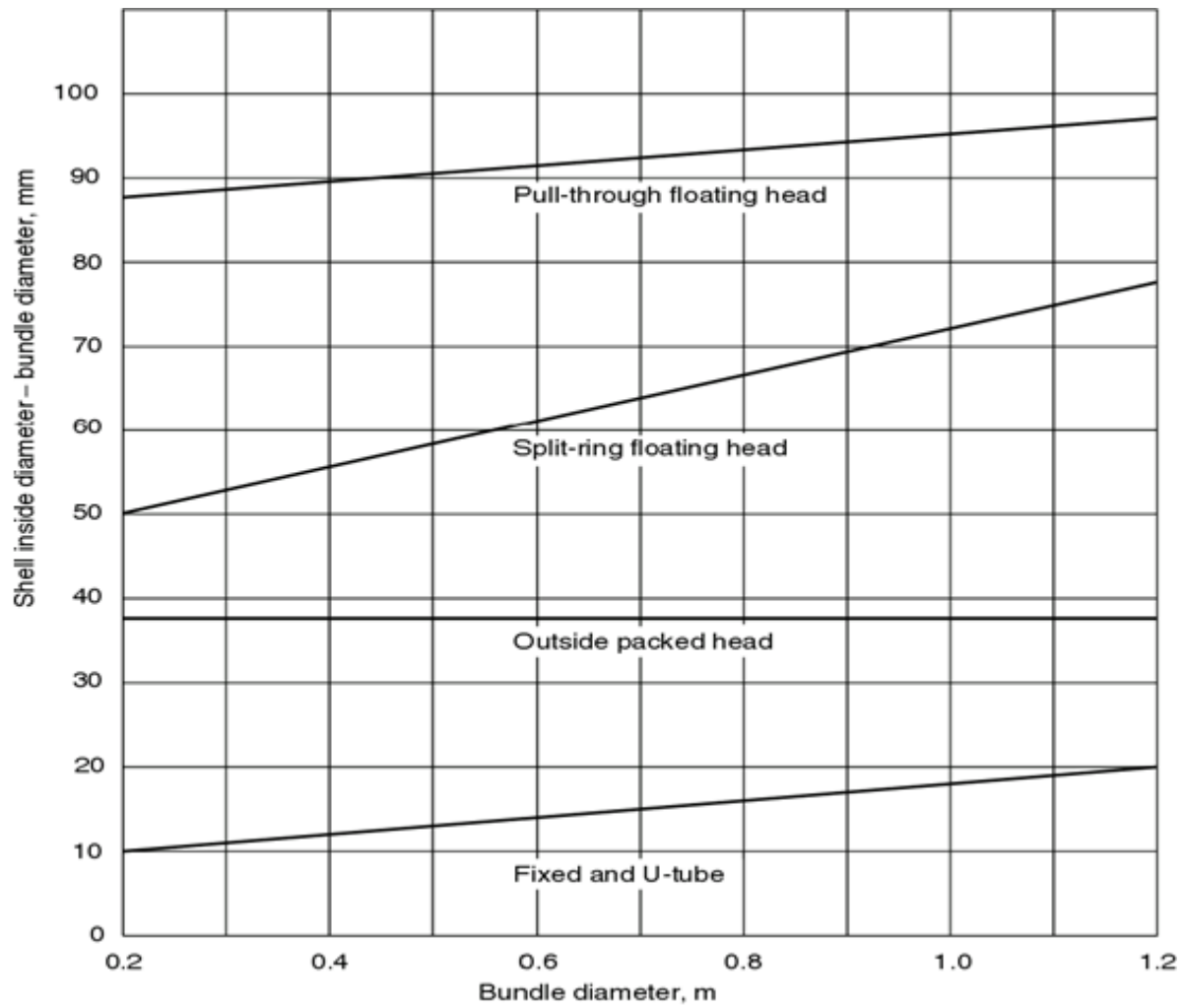
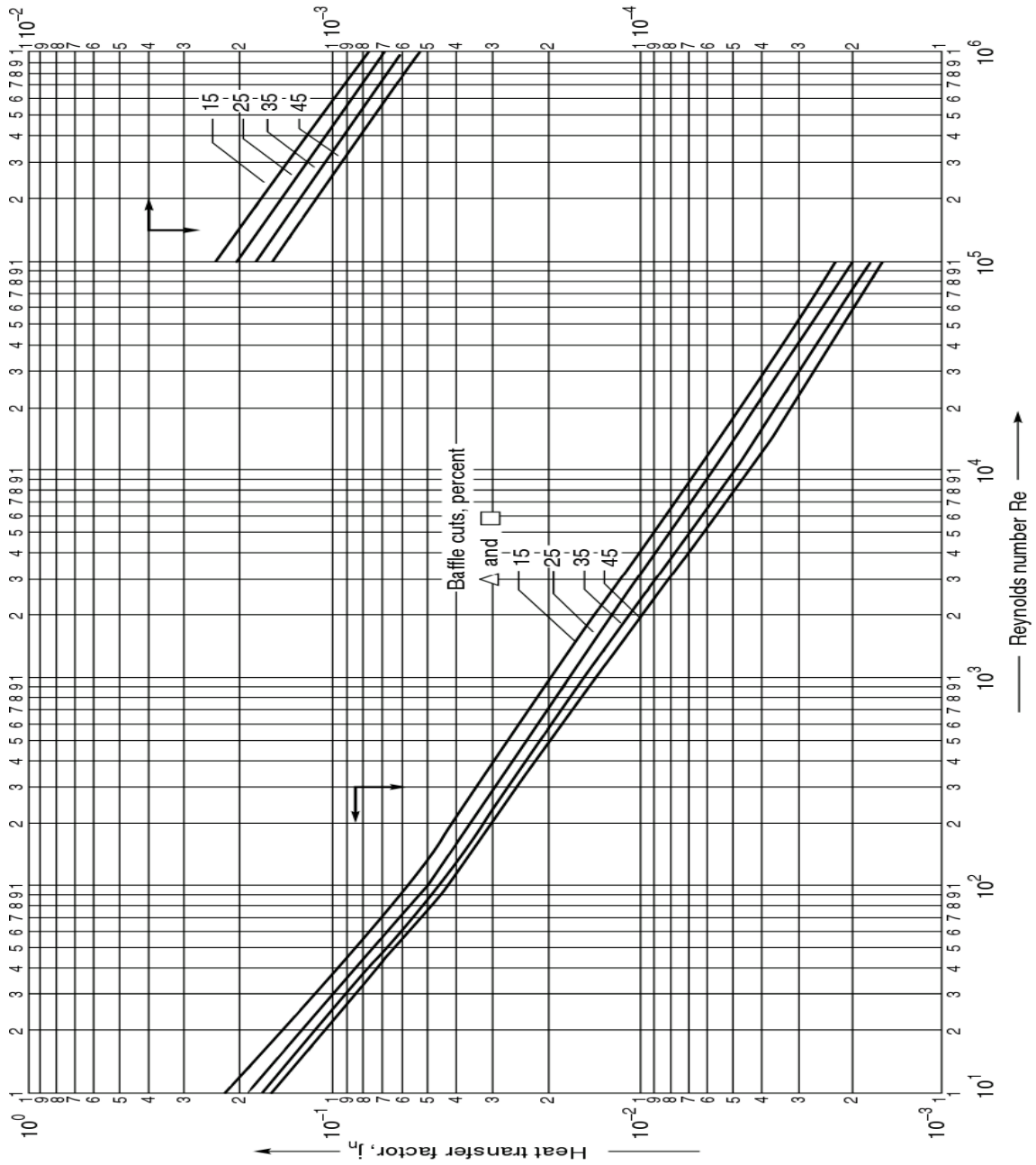Figur5-2: shell inside diameter vs. bundle diameter
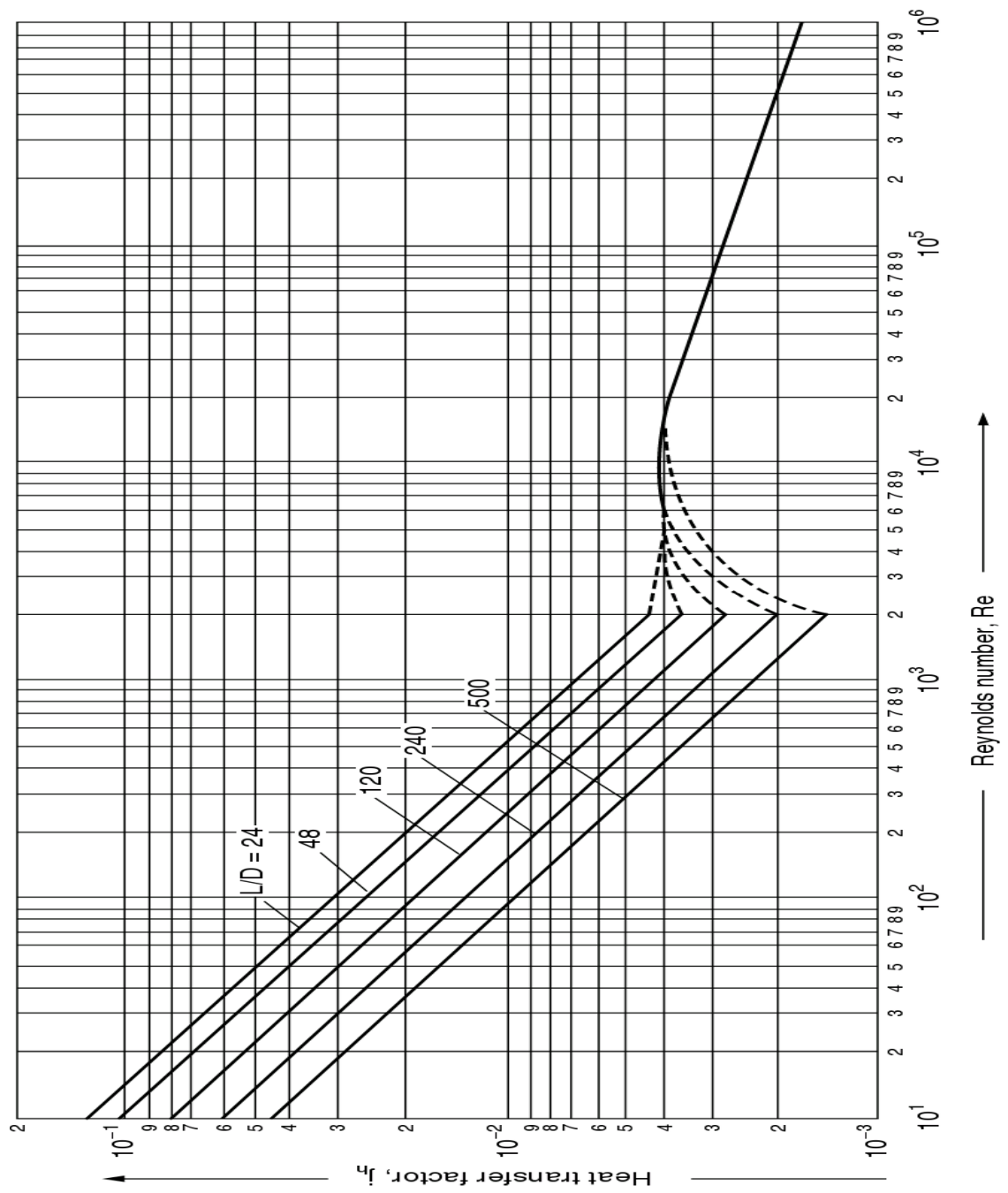
Figur5-3: heat transfer equipment vs. renold number

Figur5-4: heat transfer equipment vs. renold number

Table 5-4: $D_7$ Floating factors

| Fluid | Coefficient (W/m$^2$ °C) | Factor (resistance) (m$^2$°C/W) |
|---|---|---|
| River water | 3000 – 12,000 | 0.0003 – 0.0001 |
| Sea water | 1000 – 3000 | 0.001 – 0.0003 |
| Cooling water (towers) | 3000 – 6000 | 0.0003 – 0.00017 |
| Towns water (soft) | 3000 – 5000 | 0.0003 – 0.0002 |
| Towns water (hard) | 1000 – 2000 | 0.001 – 0.0005 |
| Steam condensate | 1500 – 5000 | 0.00067 – 0.0002 |
| Steam (oil free) | 4000 – 10,000 | 0.0025 – 0.0001 |
| Steam (oil traces) | 2000 – 5000 | 0.0005 – 0.0002 |
| Refrigerated brine | 3000 – 5000 | 0.0003 – 0.0002 |
| Air and industrial gases | 5000 – 10,000 | 0.0002 – 0.0001 |
| Flue gases | 2000 – 5000 | 0.0005 – 0.0002 |
| Organic vapours | 5000 | 0.0002 |
| Organic liquids | 5000 | 0.0002 |
| Light hydrocarbons | 5000 | 0.0002 |
| Heavy hydrocarbons | 2000 | 0.0005 |
| Boiling organics | 2500 | 0.0004 |
| Condensing organics | 5000 | 0.0002 |
| Heat transfer fluids | 5000 | 0.0002 |
| Aqueous salt solutions | 3000 – 5000 | 0.0003 – 0.0002 |
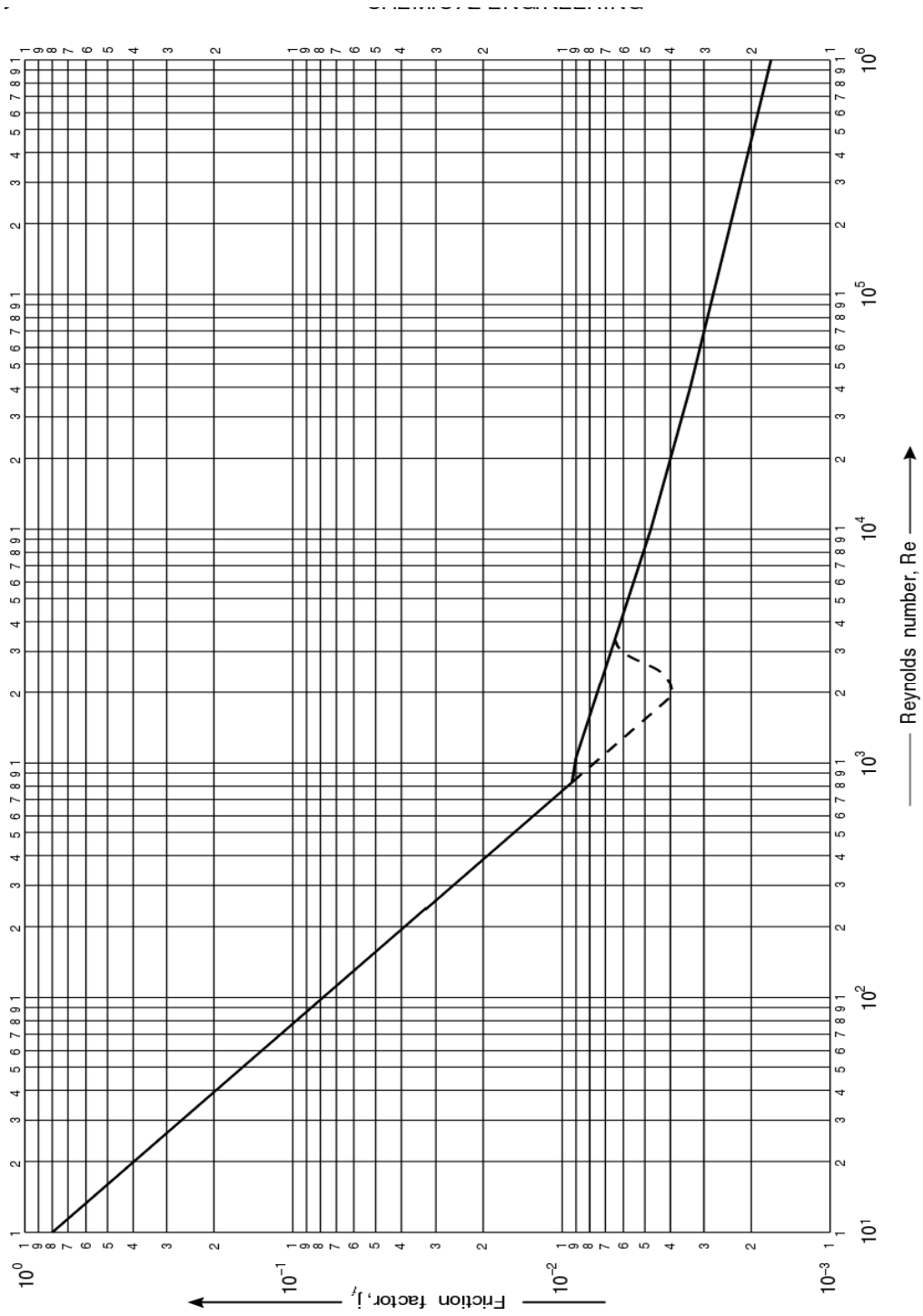
Figur5-5:D8 Tube side friction

Baffle cuts, percent

△ and □

15
25
35
45

— Reynolds number, Re ——→
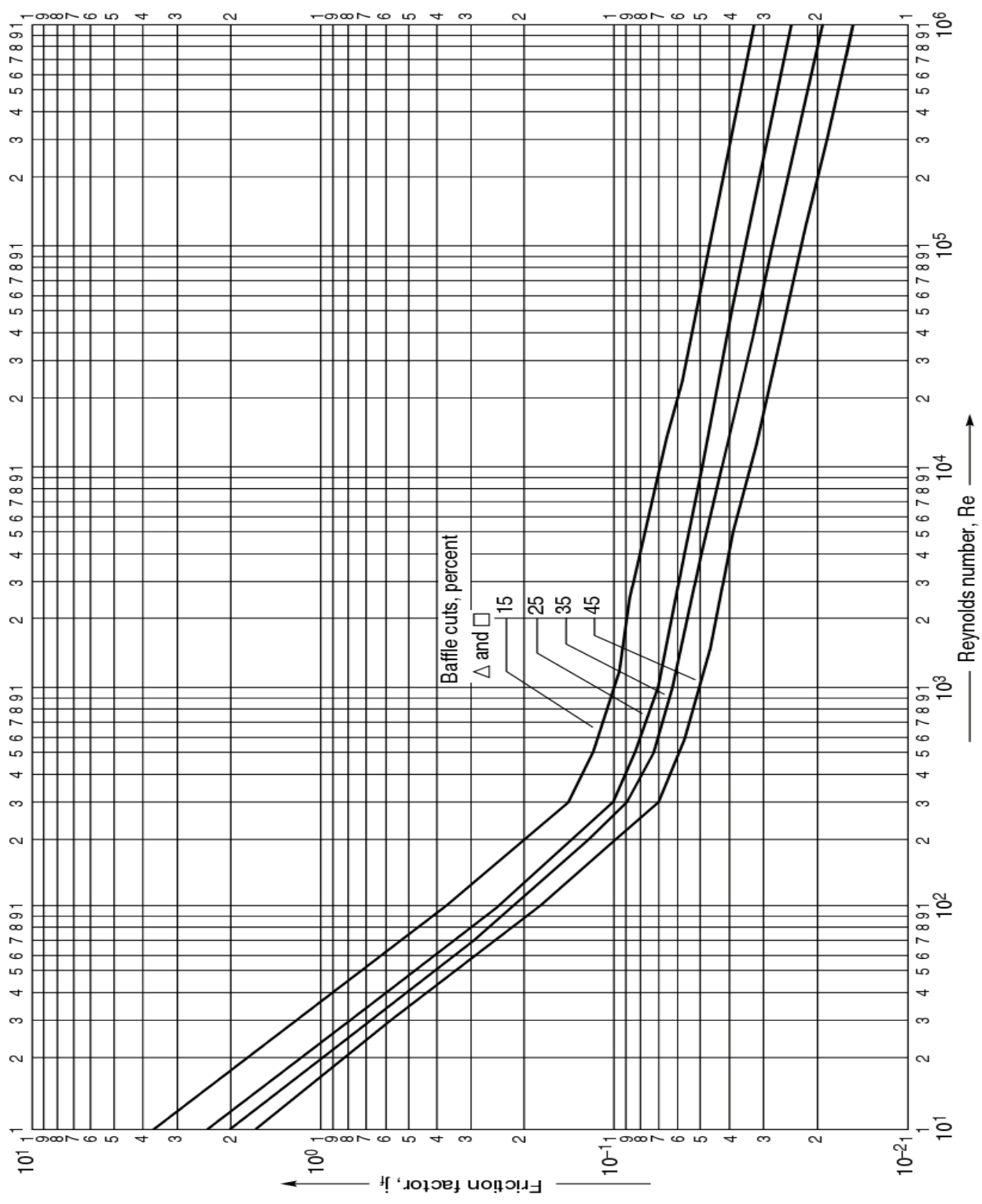
← —— Friction factor, j_f —— →

Figur5-6:D9 shell side friction factor

Table5-5:Properties of water at different temperatures.

| $T$ | $r$ | $C_p$ | m | $k$ | Pr |
|---|---|---|---|---|---|
| [K] | $[kg/m^3]$ | $[J/kg.K]$ | $[10^{-6}\ N.s/m^2]$ | $[10^{-3}\ W/m.K]$ | [ ] |
| 273.15 | 1000.0 | 4217 | 1750 | 569 | 12.99 |
| 275 | 1000.0 | 4211 | 1652 | 574 | 12.22 |
| 280 | 1000.0 | 4198 | 1422 | 582 | 10.26 |
| 285 | 1000.0 | 4189 | 1225 | 590 | 8.81 |
| 290 | 999.0 | 4184 | 1080 | 598 | 7.56 |
| 295 | 998.0 | 4181 | 959 | 606 | 6.62 |
| 300 | 997.0 | 4179 | 855 | 613 | 5.83 |
| 305 | 995.0 | 4178 | 769 | 620 | 5.2 |
| 310 | 993.0 | 4178 | 695 | 628 | 4.62 |
| 315 | 991.1 | 4179 | 631 | 634 | 4.16 |
| 320 | 989.1 | 4180 | 577 | 640 | 3.77 |
| 325 | 987.2 | 4182 | 528 | 645 | 3.42 |
| 330 | 984.3 | 4184 | 489 | 650 | 3.15 |
| 335 | 982.3 | 4186 | 453 | 656 | 2.88 |
| 340 | 979.4 | 4188 | 420 | 660 | 2.66 |
| 345 | 976.6 | 4191 | 389 | 668 | 2.45 |
| 350 | 973.7 | 4195 | 365 | 668 | 2.29 |
| 355 | 970.9 | 4199 | 343 | 671 | 2.14 |
| 360 | 967.1 | 4203 | 324 | 674 | 2.02 |
| 365 | 963.4 | 4209 | 306 | 677 | 1.91 |
| 370 | 960.6 | 4214 | 289 | 679 | 1.8 |
| 373.15 | 957.9 | 4217 | 279 | 680 | 1.76 |
| 375 | 956.9 | 4220 | 274 | 681 | 1.7 |
| 380 | 953.3 | 4226 | 260 | 683 | 1.61 |
| 385 | 949.7 | 4232 | 248 | 685 | 1.53 |
| 390 | 945.2 | 4239 | 237 | 686 | 1.47 |