



Development and Performance Testing Evaluation of Parts Affected With Fouling And Pitting Corrosion

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Abstract: Fouling is the formation of an unwanted layer on the surfaces of processing equipment, such as evaporators, which can deteriorate the capacity of the surface to transfer heat under the conditions for which it was designed (Awad, 2011; Chen et al., 2004). Fouling has been recognize as a universal problem in design and operations (Bott, 2001; Kuppan, 2000). First, because the fouling layer has a lower thermal conductivity, resistance to heat transfer is increased. Second, deposits reduce the cross sectional area triggering a greater pressure drop across the apparatus (McDonald and Magande, 2012). More than 90% of industrial heat exchangers suffer from fouling problems, and costs of heat exchanger fouling have estimated to be 0.25% of the gross domestic product (GDP) of industrialized countries (Garrett-Price et al., 1985; Pritchard, 1988; Rausch et al., 2005; Steinhagen et al., 1993). In addition, the disposal of cleaning chemicals have contributed to the environmental footprint of heat transfer fouling (Changani et al., 1997). Therefore, it is important to understand which factor caused fouling and develop new technology or methods to reduce the fouling in corn processing

Keywords: fouling, heat exchanger. Corrosion, radiator, pitting -corrosion.

INTRODUCTION

Heat exchangers are mechanisms used for the continuous exchange of heat between Heating, Ventilation, and Air-Conditioning (HVAC) equipment or its associated components, as well as the recycling of working fluid in HVAC

equipment. Heat exchangers are a common piece of equipment in the thermal, power, and process industries. (Ayodeji, O 2018)

Heat exchangers are classified into seven categories based on seven-meter bars:(1) construction, (2) transfer processes,(3) degree of surface compactness, (4) flow arrangements,(5) number of passes,(6) phase of the process fluids, and(7) heat transfer mechanism.

i Construction is the art and science of forming objects; the construction of heat exchangers is critical because it determines what the heat exchanger will be used for.

ii Heat transfer processes vary depending on their application.

iii The degree of surface compactness, which determines the shape of a heat exchanger.

iv Flow arrangement; there are three main types of flows; spirometry, spirometry, and spirometry.

TYPES OF HEAT EXCHANGERS

1.0 Plate Heat Exchangers (PHE)

Plate heat exchangers (PHE), also known as plate-and-frame heat exchangers, are widely used in dairy and food processing plants, chemical industries, power plants, and central cooling systems. They have excellent heat transfer characteristics, allowing for a very compact design and are easily dismantled for maintenance, cleaning, or modifying the heat transfer area by adding or removing plates. Each plate contains a bordering gasket, which seals the channels formed when the plate pack is compressed and mounted on a frame. Cold and hot fluids flow in opposite channels, and heat transfer occurs between adjacent channels. The plate corrugation promotes turbulence inside the channels, which improves heat transfer efficiency and the mechanical strength of the plate pack (Su Guoping, *et al*, 2017 and Elmaaty, *et al*, 2017).

Because of its good corrosion resistant properties in cooling water, 316L stainless steel (SS) is one of the materials used to manufacture PHE plates. However, the parameters of normal cooling water determine the overall corrosion stability of a plate heat exchanger, such as temperature, pH, conductivity, hardness, alkalinity, and, most importantly, chloride ions concentration (Addepalli,et al, 2015).

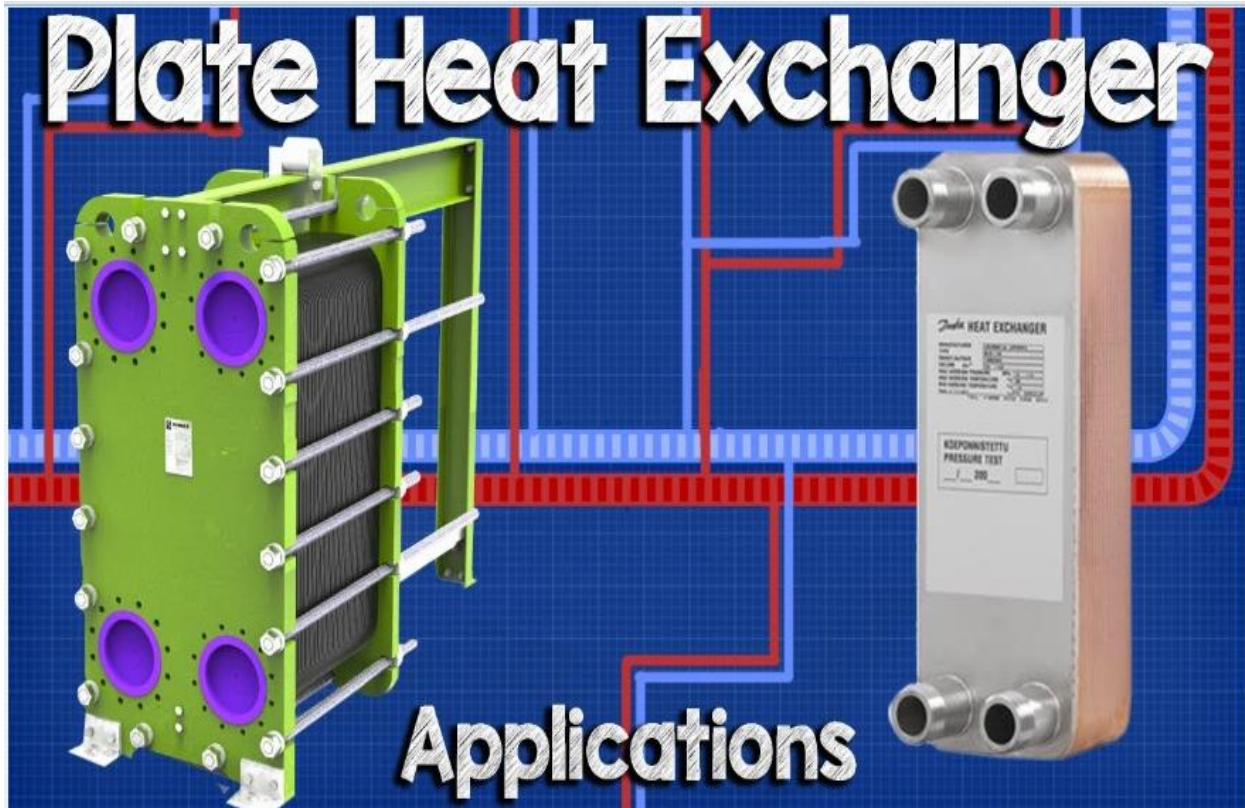


Figure.1: Typical plate heat exchanger application.

In China, many PHEs used in heating power plants have recently experienced internal leakage, threatening the plant's safety and efficacy. According to existing research, local plate corrosion, including local cracking and perforation, accounts for a greater proportion of the reasons for PHE internal leakage (Khodamorad, et al, 2011).

Over 90% of the heat energy used in energy generation and management is transported through various types of heat exchangers (Wilfried et al., 2020). Heat exchangers have a wide range of applications as general process equipment in power plants, the chemical industry, the petroleum industry, the food industry, the aero and space industry, the nuclear industry, and many other industries. The shell-tube heat exchangers are the most commonly used of these (Mukherje, 2004).

2. Shell- tube heat exchanger (STHE)

The shell-tube heat exchanger (STHE) is the oldest type of heat exchanger (Mukherje,2004); STHE design entails two distinct activities, according to Mukherje(2004): thermal design and mechanical design. While the thermal

design part entails sizing, which entails determining all of the major construction parameters (namely, the number, outer diameter, thickness, and length of tubes, tube pitch, number of tube passes, shell diameter, baffle spacing and cult, nozzle sizes, shell type selection, and some other constructional details), the mechanical design entails determining the thicknesses. And exact dimensions of the system's various components (tube sheets, flanges, shell,) including the bill of materials and engineering sketches such as bundle assembly and setting plan drawings. This research focuses on the use of some related thermal equations, along with relevant correlations, for the optimum thermal design of shell tube heat exchangers.

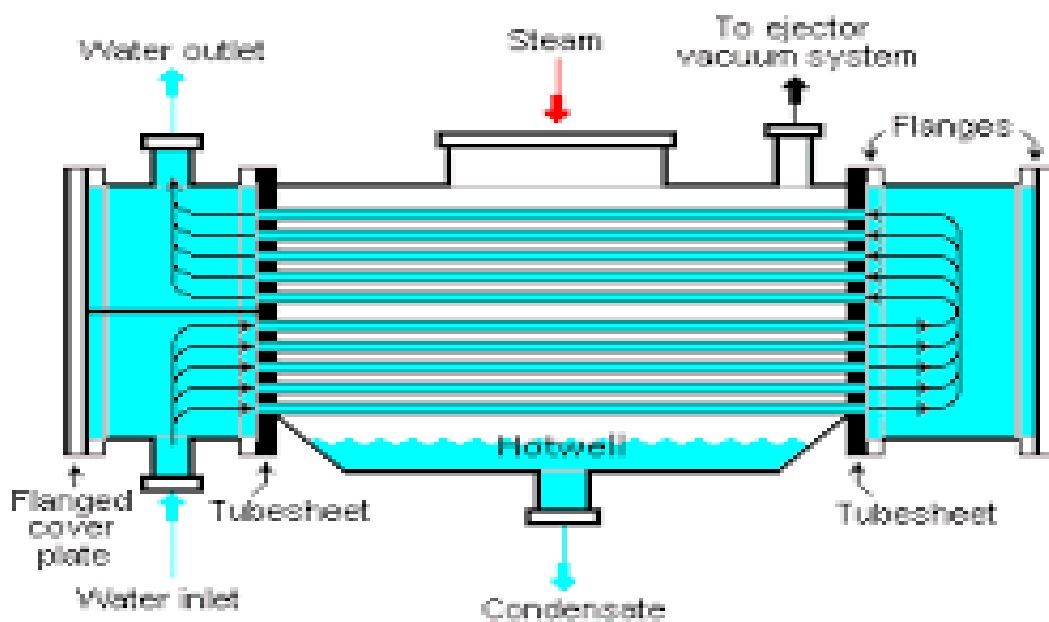


Figure .1.: Shell- tube heat exchanger (STHE)

A MECHANICAL COMPONENT THAT COULD BE AFFECTED WITH FOULING

Car- Radiator

Radiators are heat exchangers used for cooling internal combustion engines. This is achieved by circulating a liquid called engine coolant through the engine block where it is heated then through a radiator where it loses heat to the atmosphere and then return to the engine;

When fluid[water] that contain impurities is poured in the radiator, fouling begins to set in

Also, traveling in dusty roads regularly without radiator maintenance , fouling begins to set in.



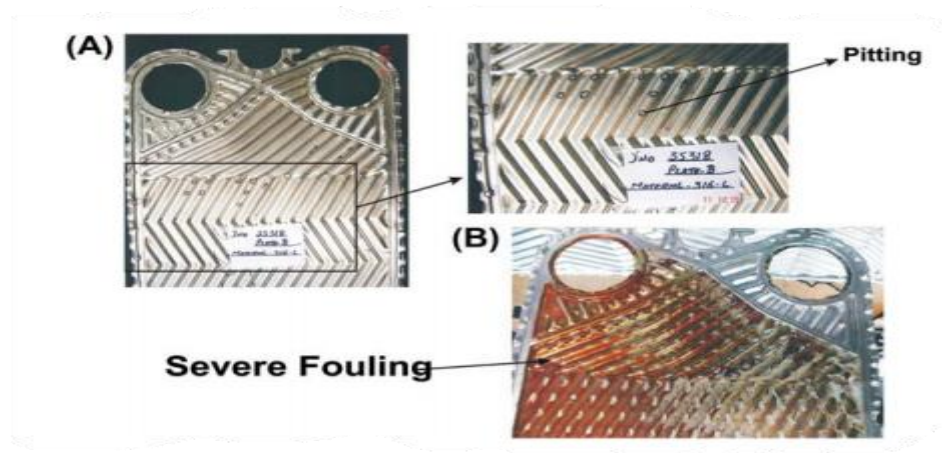
A car-radiator

Methods For Testing Fouling And Pitting Corrosion

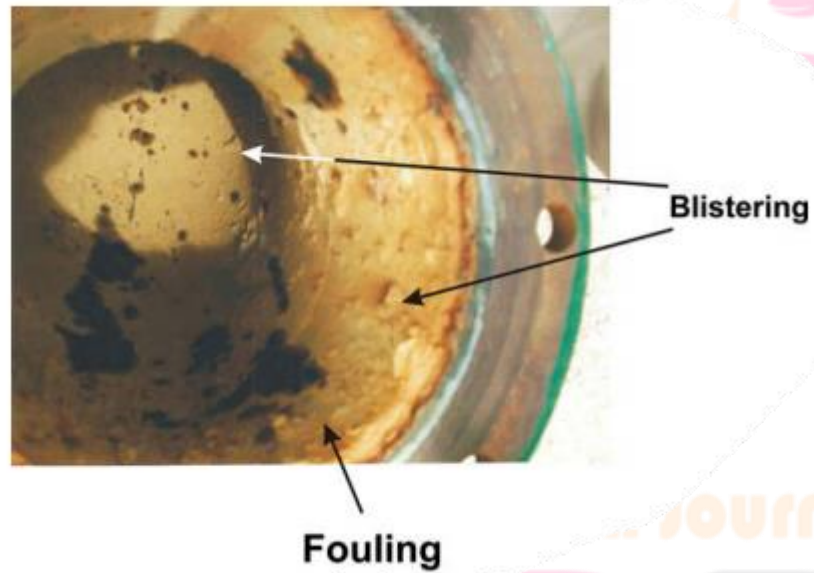
1. Macroscopic morphology analysis of failed heat exchanger plates
2. Chemical analysis of raw water, reverse osmosis (R/O) water, CT feed and CT bleed water;
3. Evaluation of plate heat exchanger efficiency; and
4. Maintenance procedures for fouling and pitting corrosion prevention and protection of heat exchangers.

Macroscopic morphology analysis

The Olorunshogo generating facility provided useful information on the operational parameters system. A metallographic structure of the cross section of the corroded metal surface will be carried out in order to estimate the approximate number, size, and distribution of the pits, as well as to measure the depth of the pits, which will indicate the attack intensity shown below

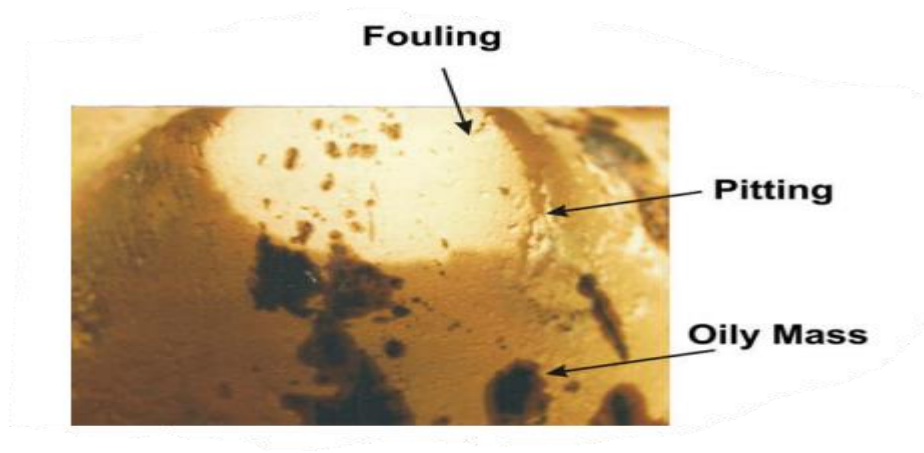


: Failed plates (A) severely pitted plate (B) fouling at the plate.

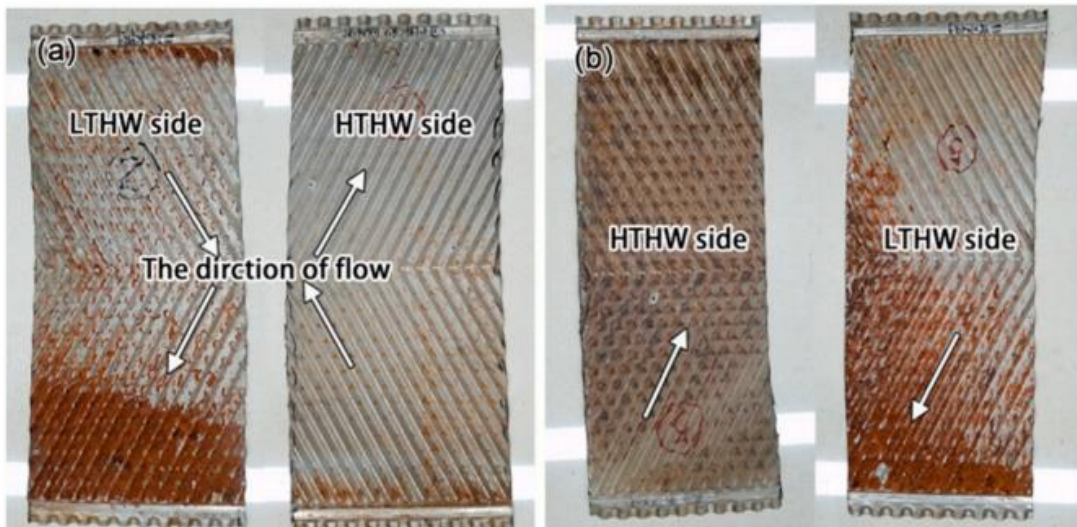


Cooling tower line pipe inside showing fouling and blistering.

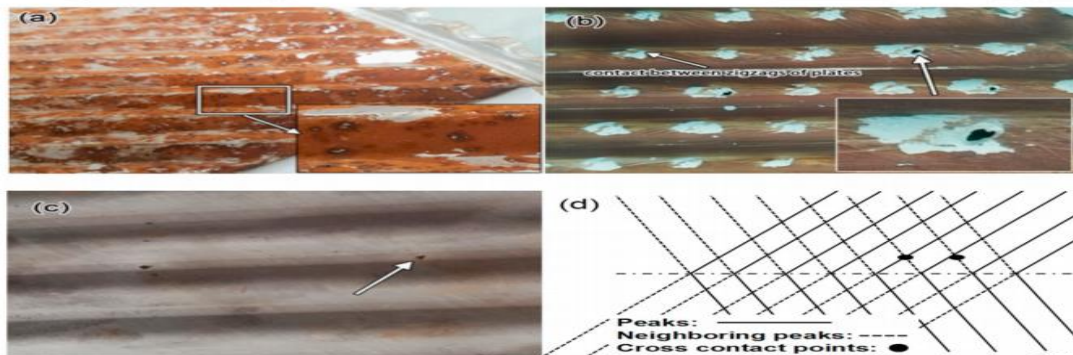
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: Cooling tower line pipe inside showing fouling and pitting



: Macroscopic morphology of failed plates from PHE: (a) plate 1 and (b) plate 2



: Macro examination of both sides of the failed plates: (a) pit in LTHW side, (b) perforations in LTHW side, (c) pit in HTHW side, and (d) illustration of CC

Chemical Analysis

To minimize excessive scaling, corrosion, and algae formation in the system, the right amount of chemicals were introduced to the CT water. The pH of the cooling tower water was controlled with sulfuric acid (H₂SO₄) (CT water). The dose levels were determined by Local Supplier 'A' (LS-A) and are indicated in the outcome (Table 4.1). Water quality and operating parameters were monitored on a monthly basis. CT water should be devoid of hypochlorides, chlorides, iron, and excessive dissolved solids, according to the purposed specification of Local Supplier 'B' (LS-B) (TDS). CT water should be devoid of hypochlorides, chlorides, iron, and excessive dissolved solids, according to the purposed specification of Local Supplier 'B' (LS-B) (TDS). Table 3 shows the CT requirements provided by LS-B.

In a closed circuit cooling system, the Engineer used NALCOOL 2000 (Industrial and Engine Cooling Water Treatment System). Out of 32 damage plates, two highly pitted (perforated) and fouled PHE's 316L plates were evaluated for failure analysis, as shown in figure 3.1.

Performance evaluation of plate heat exchanger efficiency

A power engine was shut down for maintenance after around 2000 hours of service, and the PHEs were also opened for cleaning. On the closed circuit side of PHE's plates, there were no deposits or fouling, but the CT waterside (open circuit system) displayed severe pitting and sludge (fouling), as illustrated in Fig. 3.8. In addition, CT pipelines and bends with severe pitting were evaluated.

. Procedures for preventing and protecting heat exchangers from fouling and pitting corrosion through routine maintenance.

1.0 Cleaning techniques are followed to completely eliminate pits and corroded components. It is not recommended to use solutions that are too harsh on the base metal. The use of a coating that prevents pitting on metal surfaces will be used to manage pitting corrosion.

Pitting corrosion will be controlled by the use of a coating that will prevent pitting on metal surface. This includes using corrosion-resistant materials, ensuring that fluids in contact with the material are washed away on a regular

basis, using cathodic protection, avoiding stagnant zones, using inhibitors or controlling fluid chemistry, and maintaining the substance's protective coating.

2.0 Fouling Mitigation

The methods developed to control fouling were classified as:

- (1) Chemical methods,
- (2) Mechanical methods and
- (3) Changing the phase of the solution.

By adding foreign chemicals in a solution, reduction of fouling was achieved by chemical methods of fouling mitigation. Chemical additives developed by many companies have been extensively used to mitigate fouling in the industrial sector. Various additives can be used to prevent act in different ways, such as (a) sequestering agents, (b) threshold agents, (c) crystal modifiers and (d) dispersants. Some of the common water additives are EDTA (sequestering agent), polyphosphates, polyphosphates (threshold agents), polycarboxylic acid, and its derivatives (sequestering and threshold treatment). Sequestering agents such as EDTA complex strongly with the scaling cations such as Ca^{++} , Mg^{++} , and Cu^{++} in exchange with Na^{+} , thus preventing scaling as well as removing any scale formed previously.

They are used effectively as anticipants in boiler feed water treatment. (Troup and Richardson, 1978) Claimed that their use is uneconomical when hardness levels are high. Polyphosphates and polyphosphates as threshold agents are also used to reduce scaling in boilers and cooling water systems. Very small quantities of these agents are effective in reducing scaling from super saturated salt solutions.

To mitigate particulate fouling by chemical means, dispersants were used to reduce the surface tension of deposits. It helps in disintegrating the suspended particles into smaller fragments that do not settle so readily. Addition of certain chemicals slowed down, and terminate chemical reactions. Dispersants were very helpful in keeping the foulants away from the surface. Particles such as corrosion products were used as catalysts.

Cleaning of heat exchangers

A decrease in the performance of a heat exchanger beyond acceptable level requires cleaning. In these applications, the cleaning was carried out on line to maintain acceptable performance without interruption of operation. At other times, off-line cleaning was used.

Specified on-line cleaning generally utilizes a mechanical method designed for only tube side and requires no disassembly. An on-line chemical feed cleaning technique (flow reversal) was adopted, and care taken not to upset the rest of the liquid service loop.

On-line mechanical cleaning technique was also employed. On line tube side, cleaning technique involve use of sponge-ball and brush systems. The advantage of on-line cleaning is the continuity of service of the exchanger with no cleaning-mandated downtime.

Off-line chemical cleaning is a technique that is used very frequently to clean exchangers. Some refineries and chemical plants have their own cleaning facilities for dipping bundles or re-circulating cleaning solutions. In general, this type of cleaning is designed to dissolve the deposit by means of a chemical reaction with the cleaning fluid. The advantages of chemical cleaning approach include the cleaning of difficult-to-reach areas. Often in mechanical cleaning, there is incomplete cleaning due to regions that are difficult to reach with the cleaning tools. There is no mechanical damage to the bundle from chemical cleaning, although there is a possibility of corrosion damage due to a reaction of the tube material with the cleaning fluid. This potential problem may be overcome through proper flushing of the unit. Disadvantages of off-line chemical cleaning include corrosion damage potential, handling of hazardous chemicals, use of a complex procedure.

Off-line mechanical cleaning is a frequently used procedure. The approach is to abrade or scrap away the deposit by some mechanical means. The method includes high-pressure water, steam, lances and water guns. In off-line mechanical cleaning there are some advantages such as excellent cleaning of each tube is possible, good removal potential of very tenacious deposits. Disadvantages include the inability to clean U-tube bundles successfully, usual disassembly problem and the great labor needed.

Guidelines for selecting between chemical and mechanical cleaning, and among the various types of chemical cleaning processes were carefully followed. Water-based fluids can transport and deposit a wide variety of

minerals, and corrosion products form due to the reaction of the aqueous fluids with the metals of construction. Hydrocarbon and petrochemical fluids transport and deposit a variety of organic scales. Common inorganic scale forming compound includes various iron oxides, hardness deposits (carbonates and silicates). Cleaning situation are be considered when choosing between mechanical and chemical cleaning, as well as the specific technique within the general category. The general categories of mechanical cleaning are abrasive, abrasive hydraulic, hydraulic and thermal.

Builder molecules such as ethylenediaminetetraacetic acid (EDTA) suppress the effects of hard water, and coupling agents such as glycol ethers, improve the dissolution of some organic deposits.

Detergent formulations are effective only for removing the lighter deposits. Refinery fluids, aromatics and terpenes are used to dissolve the organic deposits. N-methyl-2- pyrrolidinone also is a very effective polar solvent with low toxicity characteristics. They reiterated that the effectiveness of the application depends greatly on proper application conditions, such as flow rate and temperature. Combination of surfactants, organic solvents and water emulsions are good cleaning agents. Emulsions with an organic outer phase are particularly useful for cleaning large vessels. Oily rust deposits having both organic and inorganic compositions can be removed by acidic emulsions, combining an acid and an organic solvent.

Test for pitting corrosion

1. Visual Examination

A **visual examination** of the corroded metal surface is the first and basic method used. Count the number of pits through a microscope eyepiece over a defined surface area such as 20cm^2 to determine the approximate size and distribution of the pits. The number of pits is not necessarily the most important factor to consider. Pit depth is by far the biggest danger. One narrow deep pit can be more dangerous the many shallow pits. A metallographic cross section to measure the depth of the pits will reveal the intensity of the attack.

2. Sonics testing

Sonics testing is where ultrasonic pulses of sound energy are transmitted through an oil or water based coolant onto the metal surface. Waves are generated and reflect echoes that are converted in to electrical signals. These signals

can be interpreted to show the location of pits, crevices and flaws in the metal. This test has good sensitivity and provides instantaneous information about the depth, width and location of the pits and flaws.

3. Electromagnetic testing

Electromagnetic testing is used to detect defects or irregularities in the structure of electrically conducting materials such as steel and iron. Materials with defects will produce a magnetic field that is different from that of a reference material without defects.

4. Electrochemical testing

Electrochemical testing to measure pitting in any metal such as cyclic polarisation and potentiostatic tests are also an option. These short-term electrochemical tests provide instant results.

5. Immersion test

An immersion test or weight loss method is another option. These tests take more time to run. They involve removing a metal sample and immersing in a solution. After a few days, it can be removed so the corrosion rate can be calculated. You can observe the pits, pit depth under a

1.0 Results and Discussion

1.1 Results

Tables (4.1–4.10) contain the findings of the inquiry into the causes and consequences of fouling on plate heat exchangers, as well as the tests for pitting corrosion treatment, prevention, and protection.

Table 4.1: Cooling tower water additions

Additives	Quantity
A.C 220	0.450 kg/CT/24 h
A.C 204	0.200 kg/CT/24 h
A.C 460	2.0 kg/CT/168 h

Sodium hypo-chlorite	0.5 kg/CT/48 h
Sulfuric acid	10–15 kg/24 h

Table 4.2:Chemical analysis of CT water samples made by LS-A.

Parameters	Limit	Results 1 (3 months)	Results 2 (6 months)
pH	7.8–8.6	8.94	8.40
TDS (ppm)	2500–3200	2280	3100
Ca hardness (ppm)	<350 320	320	310
Mg hardness (ppm)	----	-	-
Total alkalinity (ppm)	<500	490	460
Chloride (ppm)	----	-	-
Phosphate (ppm)	3.0–6.0	5.0	5.0
Iron (ppm)	<0.5	Traces	0.1
Ryzen index	4.8–6.0	4.46	–

Table 4.3:CT specifications suggested by LS-B.

CT parameters	Values
System volume	05 ^{m3}
Recirculation rate	120 ^{m3} /h
Temperature drop	06 C
Water quality	Reverse osmosis (R/O)
Evaporation	0.457 ^{m3} /h/0.015 m3/h
Bleed off	0.015 ^{m3} /h
Bleed off	0.472 ^{m3} /h

Table 4.4: Operating conditions of PHE in heating power plant.

Contents	Design
Material	316L
Temperature of LTHW	55 °C (outlet side) / 45 °C (inlet side)
Temperature of HTHW	120 °C (inlet side) / 70 °C (outlet side)
Pressure of LTHW	1.6 MPa
Pressure of HTHW	2.5 MPa
Water quality of LTHW	Tap-water
Water quality of HTHW	Permeate water from reverse osmosis
Flow velocity	0.1-1m/s

Table 4.5: Plate Heat Exchanger (PHE) Record in term of Temperature and Pressure for 2016

2016 PHE Readings	Temperature B/F [°C]	Temperature A/F [°C]	Pressure B/F [MPa]	Pressure A/F [MPa]
1.	57.1	48.0	0.57	0.43
2.	58.4	47.6	0.58	0.44
3.	60.0	48.8	0.60	0.41
4.	63.2	48.8	0.61	0.40
5.	64.3	48.9	0.48	0.39

Table 4.6: Plate Heat Exchanger Record in term of Temperature and Pressure for 2017

2017 PHE Readings	Temperature B/F [°C]	Temperature A/F [°C]	Pressure B/F [MPa]	Pressure A/F [MPa]
1.	60.1	48.3	0.49	0.40
2.	59.4	47.7	0.49	0.39
3.	60.4	47,6	0.50	0.38
4.	51.8	47.2	0.51	0.41
5.	59.1	46.1	0.52	0.42

Table 4.7: Plate Heat Exchanger Record in term of Temperature and Pressure for 2018

2018 PHE Readings	Temperature B/F [°C]	Temperature A/F [°C]	Pressure B/F [MPa]	Pressure A/F [MPa]
1.	63.0	48.1	0.51	0.44
2.	61.1	47.0	0.49	0.43
3.	63.0	46.5	0.52	0.44
4.	60.0	44.1	0.51	0.44
5.	60.1	46.1	0.50	0.43

Table 4.8: Plate Heat Exchanger Record in term of Temperature and Pressure for 2019

2019 PTE Readings	Temperature B/F [°C]	Temperature A/F [°C]	Pressure B/F [MPa]	Pressure A/F [MPa]
1.	59.8	59.2	0.48	0.41
2.	60.2	47.0	0.47	0.41
3.	59.2	48.7	0.45	0.41
4	60.1	47.7	0.48	0.41
5.	62.4	48.8	0.49	0.40

Table4.9: Plate Heat Exchanger Record in term of Temperature and Pressure for 2020

2020 PTE Readings	Temperature B/F [°C]	Temperature A/F [°C]	Pressure B/F [MPa]	Pressure A/F [MPa]
1.	63.5	46.2	0.53	0.40
2.	60.1	44.5	0.54	0.41
3.	58.9	43.4	0.49	0.44
4	50.8	48.6	0.54	0.43
5	50.1	44.1	0.53	0.42

Table 4.10: Chemical analysis of raw, reverse osmosis (R/O), CT feed and CT bleed water

Parameters	Raw water	R/O water	CT feed water	CT bleed water
pH	7.40	6.23	6.97	7.05
TDS (ppm)	2020	54.9	503	3060
Ca hardness (ppm)	105.7	3.48	29.05	168.5
Mg hardness (ppm)	62.94	0.61	9.11	80.91
Total hardness (ppm)	522.5	11.0	110.0	753.5
Chloride (ppm)	496.0	14.2	142.0	709.0
Ferrous (ppm)	0.60	0.365	0.04	0.248
Lead	Traces	Traces	Traces	Traces

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