GROWING CHALLENGES OF HEAT EXCHANGER’S OPERATION AND MAINTENANCE IN LNG PLANTS

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ABSTRACT

Malaysia LNG Group of Companies has three LNG Processing Plants located in Bintulu, Sarawak, Malaysia with a nameplate capacity of 23 million tones per annum. In LNG processing, natural gas are cooled down to liquid phase at -161°C to reduce its volume to about 600 times at near normal ambient pressure for safe and economical transportation to customers. This cooling requires huge amount of heat removal. The heat can be removed through sea cooling water exchangers, air cooled exchangers or a hybrid of both.

The three LNG processing plants in PETRONAS LNG Complex uses all the three methods and incorporated different design technology based on the year of construction. Each of these methods and design technologies had its operational challenges. This paper will describe the experiences and challenges in the operation and maintenance of these heat exchangers in the complex. There are total of 126 sea cooling water exchangers and 298 air cooled exchangers used in removing the heat to convert the incoming gas into cold liquid LNG in the complex. 90% of the sea cooling water exchangers had been in operations for 25 years while the air cooled heat exchangers had been in service for 15 years. The performance of these heat exchangers is critical for the continuous LNG production.

With the ever changing environment in the sea water and increasing demand to squeeze the assets, some heat exchangers had experienced performance issues and failures during operations. The presence of dissolved chemical such as ammonia, silt, living sea organism and suspended solid in the changing sea water environment had caused tube leaks and threatened the operations of the plant.

Since start up in 1982, corrosion of tubes in heat exchangers has resulted in numerous tube failures. The phenomenon of tube failures due to tube erosion-corrosion and also flow induced vibration has caused several plant production interruptions. It had been identified that high concentrations of suspended solids as the source of deposits on the heat transfer surfaces resulting in higher sea water velocities which had caused tube leaks. High concentration of acidic species, especially chlorides and ammonia, caused corrosion under the deposits and stress corrosion cracking of copper alloy tubes. Over the years with the ever changing sea water quality and higher production demand, the heat exchanger further deteriorated and underperform.

Changing tube materials from Aluminum Brass and Carbon Steel to copper nickel alloy with a specific percentage of iron content has shown excellent performance since the last 10 years in operations. The iron content of copper nickel alloy has provided a better corrosion resistance behavior in sea water application. Installation of screens at the inlet of individual heat exchangers, improvement in chlorination control to reduce fouling, replacement of zinc anodes with a better material to improve layering of protective oxides in the tubes and operating within design tube sheet velocity ranges to avoid deposits and erosion have also restored the performance of heat exchanger to its original design.

The newer LNG plant using air cooled heat exchanger or a hybrid instead of sea water heat exchangers is also spared from the changing environment. Fouling of the air cooled heat exchangers’ fins due to atmospheric contaminants had reduced its efficiency and poses cleaning challenges. Fan belts, motors and bearings failures are other typical problems faced in the
operation of air cooled heat exchangers. These require expanding resources, both parts and labor for proactive and reactive maintenance. Degradation of air quality has increased fouling rate of the air cooled heat exchangers. The tube fins are easily fouled within one year after cleaning. The air cooled heat exchanger fouled faster with a smaller tube pitch design. Online chemical foam cleaning, changing component materials and good maintenance practices have improved the performance of the air cooled heat exchangers.

Plant optimization to improve production capacity changes the operating conditions and cooling requirement. The changes in flow regime require resizing and material compatibility analysis for the affected heat exchangers. Mitigation and redesign of heat exchangers has been undertaken to ensure the exchangers meet the changing operating conditions.

The challenges faced over the years in operating and maintaining the heat exchangers has elevated engineering and design standard that is crucial for future design and construction consideration.
INTRODUCTION

Malaysia LNG Group of Companies has three LNG Processing Plants located in Bintulu, Sarawak, Malaysia with a nameplate capacity of 23 million tones per annum. In LNG processing, natural gas are cooled down to liquid phase at -161°C to reduce its volume to about 600 times at near normal ambient pressure for safe and economical transportation to customers. This cooling requires huge amount of heat removal. The heat can be removed through sea cooling water exchangers or air cooled exchangers or a hybrid of both.

The three LNG processing plants in PETRONAS LNG Complex; MLNG, MLNG Dua and MLNG Tiga uses all the three methods and incorporated different design technology based on the year of construction. Each of these methods and design technologies had its operational challenges. This paper will describe the experiences and challenges in the operation and maintenance of these heat exchangers in the complex. There are total of 126 sea cooling water exchangers and 298 air cooled heat exchangers used in removing the heat to cool down the incoming gas into cold liquid LNG. 90% of the sea cooling water exchangers had been in operations for 25 years while the air cooled heat exchangers had been in service for 15 years. The performance of these heat exchangers is critical for the continuous LNG production.

OVERVIEW OF SEA WATER COOLING SYSTEM IN PETRONAS LNG PLANTS

In the early 80's, when the first plant, MLNG was constructed, the sea cooling water system was designed to supply cooling water to the sea-water distiller, exchangers and surface condensers in parallel to the gas liquefaction trains and in common facilities. The cooling system generally uses sea water in a once through exchanger as the coolant. Each train has four cooling water pump (one standby) with a capacity approximately 18,000 m³/hr at the intake station, giving a capacity of 160,000 m³/hr. The water feed lines to the train size’s 112 inches diameter running 3.6 km long to the process plants are internal epoxy coated with internal cathodic protection using aluminum anodes.

Most of the heat exchangers are shell and tubes types constructed mostly of Al-brass (C68700) tubes. The tube sheet and header boxes are Cu-Al (C63000) or Cu-Ni (C70600) clad. Some exchangers are low finned tubes. Soft iron anodes are installed inside the header boxes as anodic protection. The sea water outlet temperature is controlled below 42 degree C and the tube wall tubes skin temperature on the water side are below 52 degree C. The water velocities in the tubes are at the low end of the range of 1.0 to 2.2 m/s. Wire screens were retrofitted in the inlet header boxes to prevent debris collecting on the tube sheets.

In the early 90’s, MLNG Dua was constructed with three additional new trains i.e. 4, 5 and 6. These trains use a hybrid of sea water cooled and air cooled heat exchangers. The sea water cooling system for the new trains were tapped from the existing sea water system of train MLNG through cross over piping. Provision had been made to ensure continuous supply of sea water to all the new trains in case of shutdown in the old trains. No additional pump was installed, but some modification was made to increase the supply rate on the nine (9) pumps from 170,000 to 180,000 m³/hr. Approximately about 70% of total sea cooling water is supplied to trains 1, 2 and 3 and 18% to trains 4, 5, 6 with the balance to the condenser of the utilities steam turbine and the common facilities. A minimum of 11 pumps are required depending on LNG production requirement.
The MLNG Dua trains have six sea cooling water heat exchanger the tubes are Al-Brass (C68700) while the tube sheet and header boxes are Al-brass D (C61400) cladded. The sea water outlet temperature is between 42 degree C and the tube wall skin temperature on the water side is below 52 degree C. The water velocities in the tubes are in the range of 1.0 to 2.2 m/s.

**THE HISTORY OF TUBE FAILURES AND HEAT EXCHANGER PERFORMANCE**

In early operation of heat exchangers in MLNG and MLNG Dua, there had been more than 150 documented cases of tubes failure occurrences due to pin hole perforations initiated from the inside tubes (seawater). Since 1985, Eddy Current Testing (ECT) were carried out on selected heat exchanger to detect deteriorated tubes prior to perforations. Many of the tubes were found experiencing wall random thinning with greater than 35% wall loss.
All failed tubes were detected on the aluminum brass tubes. As Figure 2 indicates several ‘horseshoe’ formation was observed on the extracted failed tubes which is an indication of metal removal due to the erosion. Subsequently several heat exchangers which used the aluminum brass tubes were upgraded to Cupro Nickel tubes (70/30) to provide a better corrosion resistance for the sea water application.

Tube material Al-Br (ASTM B111 C68700) and Cu Ni (ASTM B111 C71500) which is commonly used for heat exchangers in sea water application are prone to several failures modes. Investigations has revealed that the key source of problem leading to the tubes leaks of sea cooling water heat exchangers are dominantly caused by following failure modes.

- Stress corrosion cracking
- Galvanic corrosion
- Dealloying
- Sulfide attack
- Pitting/Crevice corrosion
- Erosion-corrosion.
- Corrosion under deposit

Investigation reveals that there are three major causes which resulted in the tube failures are follows:

- Leaks related to high water flow velocity with air ingress via SCW standpipe and varying internal tube diameter leading to erosion corrosion.
- Leaks related to severe fouling caused by barnacles, foreign material and anode material leading to under deposit corrosion
- Leaks related to inherent design that is, the top down design leading to erosion corrosion and under deposits corrosion.

Coupled with the ever changing environment both in the sea water and increasing demand to squeeze the assets, some heat exchangers had experienced performance issues and failures during operations. The presence of dissolved chemical such as ammonia, silt, living sea organism and suspended solid in the changing sea water environment had also caused tube leaks and threatened the operations of the plant.

In the past ten years of operation records, the sea cooling water heat exchangers had experienced several tube failures due to high sea water flow which resulted in tubes erosion-
corrosion. Upon the completion of rejuvenation and revamp project in 2003, the sea water velocity increased and exceeded the maximum range of tube material velocity. With increasing sea water flow rates, corrosion rates remain low due to the resilience of the protective layer of the tubes. However when the velocity for a given geometry of the tubes exceeds a critical value of the velocity, at which shear stresses are sufficiently high to strip off the protective corrosion film, damage in the form of impingement attack may occur.

With the increasing number of plugged tubes over the years, it was noted that the extreme turbulence of flow has caused faster tubes wall thinning which resulted in tube failures. Beside the higher flow velocity during operation, the formation of calcium deposits under low flow condition is the most common cause of pitting and crevice corrosion of the tubes.

Besides train's shutdown, low or non flow conditions exist during operation due to:

- Blockage of tubes to debris being lodged against the tubesheet
- Internal blockage by foreign material
- Insufficient water supply to heat exchanger which resulted to fouling

Figure 4 An Individual Small Pit Displays at Hemisphere Shape

Above figure reveals that small pits are hemispherical in shape and very likely start to merge with one another to form larger and deeper pits as the surface metal is further eroded.

Tube blockages by debris and other external particles and corrosion product of carbon steel sacrificial anodes have been found to varying degrees in all the heat exchangers. Prior to 1990, barnacle's growth in the channel boxes of various exchangers had also been found.

In 2007, mesh screen installed in the inlet of tube sheet (mesh screen was installed in 1982) were found blocked by out-of-specification saw dust injected to temporarily seal the leaking tubes. The blockage of the tubes caused low flow or no flow and initiated corrosion due to local concentrations of chlorides or the formation of calcium deposits.
In some exchangers, it was noted that the flow rate of the tubes had exceeded the max. tube velocity of aluminum brass and copper nickel tubes. Based on manual check on the tubes flow velocity, the flow rate across the tubes of the heat exchangers recorded was >3 m/s. Within five years after revamp project completion, tube failures increased to about >10% mainly due to flow accelerated failures and severe tubes erosion.

Selective tube failures investigation based on Energy Dispersive Spectrometer (EDAX) Analysis, indicated that sulfur and chlorine were present at the pit surfaces which are not part of element that forms copper tube’s protective layer. These elements, which are commonly found as sulphide and chloride ions in such environments, are known to cause severe corrosion in copper alloys. Furthermore, sulphide can also form a weak film which is easily removed through erosion.

Based on Figure 5, EDAX confirms that the presence of sulfur on the tube surface. This presence of sulfur leads to the formation of weak, porous, sulphine containing film as observed in Figure 6 instead of a stable oxide layer. The weak oxide layer can be easily damaged and become...
preferred pit surface for pits initiation. As damage become more severe, the effect of local turbulence and erosion become more significant.

The minimum flow requirement for copper nickel alloy and aluminum brass tubes is 1 m/s. The sea water supply to an exchanger could be insufficient when operating under these conditions:–

- When a train is not producing LNG but on standby, the water supply is considerably reduced as it will be taken from 24” crossover line from the main supply header of an operating module, and

- During the early start up or shutdown of the trains, only one cooling water pump is operated.

The design of tube velocities is 1.5m/s – 2.2m/s and the average 1.8m/s with three pumps in operation. This average tube velocity is reduced to about 1.2m/s when only two pumps is operating when the LNG production is below 95%.

With the practice of injecting the saw dust to minimize the impact of tube leaking during operation, the out-of-specification saw dust injected to the heat exchanger had caused blockage to the mesh screen and accelerated the tubes flow rate throughout the heat exchangers. During train shutdown in year 2008, it was found that about 40% of the tubesheet blocked by out-of-specification saw dust which resulted tube failures. This blockages has also resulted in deposition of solids generally occurs below a tube velocity of 1 m/s.

Exposing to polluted water with certain degree of ammonia and chloride content or any sulfides present can interfere with the surface film protection of then tubes, producing a black film containing cuprous oxides and sulfide. Based on analysis and investigation carried out in 2000 and 2003, it was highlighted that some tubes of sea water application failed due to corrosion under the protective layer caused by ammonia attacks. The source of ammonia was found in steam condensers originating from the hydrazine dosed to the Boiler Feed Water. The hydrazine reacts with oxygen to form nitrogen and water with potential to cause the partial breakdown to ammonia. The major suspected source of the ammonia is from the sea water intake. It is known that ammonia levels of the sea water fluctuate over the years and no monitoring was done to measure the level of ammonia of sea water. There is an ammonia plant nearby to the sea water intake station.

**CHLORINATION UNIT PERFORMANCE**

In order to minimize the growth of marine and other organic material, a low level of Free Residual Chloride (FRC) is maintained throughout the cooling water system. The Cooling Water Intake Station (CWIS) has the facility to inject a solution of Sodium Hypochlorite (NaOCl) into the incoming sea water. Sodium Hypochlorite solution is produced in the electro-chlorination unit, using electrolysis of sea water by passage of a D.C current. The Sodium Hypochlorite solution produced in the electro-chlorination unit flow by gravity via a GRE transfer line to the dosing points at the CWIS. The purpose of the unit is to maintain a level of 0.2 – 0.5 ppm FRC at the cooling water out fall of each trains end so as to ensure that no marine or organic growth inside the cooling water system.

The CWIS has four inlet bays and during normal operation, only three bays are in service and the Hypochlorite storage tanks are bypassed and spaded. Although the purpose of the unit is to have a FRC level of 0.2- 0.5ppm in the cooling water out fall of each trains, from the loads record of four chlorinator units over the period of 2000 – 2009, it was found that three out of four chlorinators don’t meet the design capacity and even demonstrated a constant decline in chlorination load (kA). As a consequence it was found that the FRC in the cooling water out fall of
each trains was only in operation 30% - 40% of the time to maintain the specification of a FRC of 0.2-0.5ppm.

CORRECTIVE MEASURE TAKEN TO PREVENT TUBE FAILURES

Air Ingress

To prevent air ingress a good discharge pressure at the SCW pumps was maintained to avoid possibility of air ingress via the 112” SCM standpipe along the 3.6km lines. One 36” common crossover header was installed at the discharge of the SCW pump to balance SCW between the three 112” SCM lines.

Fouling by Water Based Deposits

Since 1983, barnacle growth on the channel boxes of the exchangers had occasionally reported. In 1987, chlorination of the seawater was reviewed and comparison was made on past Free Residual Chlorine (FRC) levels at all heat exchangers’ outlet and the inspection record during turnaround. It was concluded that a continuous chlorine level of 0.2 – 0.5ppm FRC is required to keep the heat exchangers free from marine fouling. Shock dosing (3ppm FRC at pump intake station) is required if chlorine level at outfall is less than 0.1ppm for 3 consecutive days.

With the above chlorination guideline, it was proven that barnacle growth can be eliminated as observed in all heat exchangers in all trains.

Chlorination of sea water however has adverse effects on the exchanger tubes. Aluminum brass and 70/30 Copper Nickel tubes are susceptible to attack at all level of chlorination. In the presence of chlorine, the protective oxide layer will not form on the tube surfaces. Thus, to ensure formation of this protective layer and the reformation of the film damaged during maintenance, it was decided that there should be no chlorination during major turnaround start ups for the first 24 hours, sea water is kept flowing with at least one cooling water pump running. Due to aging and under performance of the existing old chlorination unit, the unit was revamped to a new bipolar cell type. Close monitoring and tight control of chlorine injection at the intake station as well as the free residual chlorine of the outfall of the SCW were carried out to reduce marine fouling.

Fouling by Foreign Material

Responding to the high degree of tube blockages found in the early days, stainless steel screens were fitted in front of a number of inlet tube sheet commencing in 1985. This was to prevent debris from entering and blocking the tubes during operation.

The screens were fitted at the distance of 25mm from the tubesheet as the tapered screen anchor plugs are not fully driven in. With the 25mm distance debris caught on the screen will not block individual tube end to cause a low flow.
These screens had the potential risk of causing galvanic corrosion in this part of the heat exchangers. However, since the installation in 1985, no galvanic corrosion was noted and this could be the result of the sacrificial anodes which continue to cathodically protect the tube plates and tube ends.

**Fouling by Anode Material**

Pitting/crevice corrosion found were related to the breakdown of protective films. A ready supply of fresh rust or ferrous ions in solutions to reform the protective layer will slowdown this corrosion process.

Zinc anodes originally installed by Original Equipment Manufacturer (OEM) were experiencing rapid consumption in sea water and a replacement was done to change all zinc anodes to soft iron anodes which provide a better performance. Normal steel anode shows the typical exfoliation type of rust that is often seen on iron anodes. This corrosion product will cause fouling of tubes and also prevents the ferrous ion to dissolve in the water. Soft iron (Armco ion) anodes can obtain better dissolution without rust lumps built up which can lead to under deposit corrosion.
Tube Cleaning

Tube cleaning were carried out periodically to remove hard scales and deposits in the inner tube surface. This is being carried out during train’s turnaround either using mechanical or chemical cleaning method. It was found that poor tube cleaning quality will result in the presence of scale and fouling debris which if not removed properly will later results in tube erosion – corrosion.

Chemical cleaning maybe carried out at minimum controlled flow rates to ensure that blockages cannot occur. The selection of chemical product for cleaning should be evaluated and analyzed to ensure no adverse impacts on the performance of tube material after cleaning.

Tube Material Selection

While all leakage failures confined to aluminum brass, both aluminum brass and 70-30 copper nickel alloys experienced were have reported corrosion base on Eddy current inspection.

In general, the choices of aluminum brass and copper nickel (70-30) tubes for sea water exchanger are appropriate. On affected exchangers, an upgrade to a more resistance type has been evaluated. Titanium, super duplex stainless steel and copper nickel with additional iron content are alternatives for replacement.

Extensive analysis and study on the material selection has resulted in the selection of copper nickel alloy with a specific content of iron to provide a better corrosion resistance in sea water application. Copper Nickel alloy (ASTM B111 C71640 with 1.83% iron) has proven excellent with sea water application. The first heat exchanger using this new material was put on trial in year 1998 and after more than ten years in operation, no tubes failures was found. Copper nickel alloy with 1.83% iron content provided a higher mechanical strength and corrosion resistance as compared to standard copper nickel alloy. The new tubes material is also noted capable to withstand higher tube flow velocities exceeding 3.5m/s at certain condition on the short term period. The retubing of selected heat exchangers was initiated in the year 2008 with the replacement of all aluminum brass and copper nickel tubes with copper nickel alloy with 1.83% iron content tubes. About 4,000 tubes have been replaced with this tubes material and another 50,000 tubes of aluminum brass tubes will be replaced in year 2009.

Improved Water Tube Velocity

All heat exchangers should be operated with seawater velocities between tube material velocity’s range to avoid deposits and erosion-corrosion. The seawater flow velocities were closely monitored to ensure the operating velocities are in the range of tube material velocities. Tube velocities can be varied by throttling the common outlet valve (MOV) of three condensers to avoid erosion corrosion. The flow distribution can be measured by using portable ultrasonic flow meter to ensure that the flow through the heat exchangers are within the acceptable tube velocity limits.

Mitigate Inherent Design Problem

On the propane heat exchanger in train 4,5,6 of MLNG Dua, a series of Computational Fluid Dynamic (CFD) calculations was conducted to improve the system by having a better understanding on the impact of the hydraulic leading to maldistribution inside the heat exchanger’s channel boxes. The CFD studies of the flow through the inlet piping and water box into heat exchanger showed that there were fluid flow turbulence problem based on the current design at some heat exchangers. The results showed that the problem with the current piping design is that fluid must flow through closely coupled elbows; through a reducer, through a sudden expansion, and then having to make a 90 degree turn in order to find its way to the tube sheets. Example of design issues are illustrated in the figures below.
Based on these findings, it was decided to mitigate the problem by installing the bottom section of the tubes in the first pass with a better tube material instead of Al-Br which are more resistance to high velocity and erosion effects.

Other factors to consider in reducing SCW heat exchangers failures are as below:

1) Water Quality Improvement
   a) **Cleanliness** - It is crucial to ensure cleanliness of water supply for heat exchangers. Debris, sediments and any other external particles that are passed through heat exchanger is to be screened and filtered.
   b) **Dissolved oxygen and sulfides** to be properly controlled or eliminated to ensure no failures of copper nickel alloy. Copper alloy tubes do not stand up well in severely polluted water that dissolved oxygen has been consumed in decay process and sulfides are present.
   c) **Residual chlorine** from sea water to be within the limit of operation and it shall be kept within the range of 0.3 – 0.4ppm at the inlet tube sheet.
   d) **Acidity** - In aerated water of PH less than 5, a protective film does not easily form on copper nickel tubes, so they corrode and thin rapidly. For Al br tubes, which tend to corrode under highly alkaline conditions.
   e) **Temperature** of sea water to be controlled and monitored to ensure a protective film readily forms on copper nickel alloy in warm water but forms very slow in cold water.

These factors need to be considered for the selection of tube metallurgy for sea water application.

2) Operation and Maintenance
   a) **Passivation** – Online Ferrous Sulphate injection has become of the standard requirement to minimize tube erosion during operation. When adding iron – sulphate solution to oxygen-containing water (sea water), the formation of the protective layer on copper alloys is enhanced. The solution is added at upstream of the heat exchanger to avoid the formation of trivalent iron because Fe+++ is ineffective and may even react adversely. It has been a practice for ferrous sulphate injection for all sea cooling water heat exchangers.
b) **Preventive Maintenance** - Preventive maintenance is also carried out at every regulatory shutdown. All heat exchangers are cleaned to remove all deposits and to ensure cleanliness of heat exchangers. Eddy Current Testing (ECT) are carried out on selected heat exchangers. Tubes which show > 30% loss in wall thickness are preventively plugged. It has been a general rules in industry where retubing work is to be executed if the number of plugged tubes has exceeded 10% of total tubes population.

3) **Heat Exchanger Design**

The principal of heat exchanger design that influence tube performance to be evaluated and analyzed properly to reduce tube failures during operation.

a) **Velocity** - At velocities of less than 1m/s, sediment deposits, debris buildup and biological fouling in and on tubes can be excessive, which can cause copper nickel alloy and stainless steel tubes to fail permanently due to under deposit corrosion

b) **Tube diameter** - Tube of large diameter are preferred for heat exchanger because any solids that pass through the screens will also flow through tubes

c) **Shape** - The selection of tube shape either once through of U tubes to properly selected based on type of service or application. U tubes bundle must be avoided if the bundle prone to such corrosion if sediment and debris are not removed from their bends.

d) **Orientation** of heat exchangers must follow TEMA standards recommendation for corrosive services and applications.

e) **Venting** - Exchanger are normally fitted with vent cocks so they can be purged to clear gas or air pockets. Condensers, particularly when chlorine used as a biocide, tend to suffer corrosion when gases are not vented.

f) **Tubesheet material** - selection of tube sheet material which is matching with tube material is necessary to avoid possibility of galvanic corrosion

g) **Channel Boxes Material** – Corrosion product from waterbox due to wrong choice of material matching between waterbox and the tubes and tubesheet can cause adverse galvanic corrosion.

**CHALLENGES IN PLANT DEBOTTLENECKING AND OPTIMIZATION PROGRAM**

Plant debottlenecking to increase production capacity changes the operating conditions and cooling requirement. The increase in cooling regime require resizing and material compatibility analysis for the affected heat exchangers. Mitigation and redesign of heat exchangers has been undertaken to ensure the exchangers meet the changing operating conditions.

The challenges faced over the years in operating and maintaining the heat exchangers has elevated engineering and design standard that is crucial for future design and construction consideration.

The alternative using air cooled heat exchanger is one of the options to mitigate the issues of sea water exchangers for cooling system. However, air cooled heat exchangers in train 4,5,6 and 7,8 of MLNG Dua and MLNG Tiga have different failures characteristic and issues. Top of the list is
fouling of the air cooled heat exchanger’s fins due to atmospheric contaminant. This reduces efficiency and poses cleaning challenges. Fan belts, motors and bearings failures are other typical problems faced in the operations of air cooled heat exchangers. These require expanding resources, both parts and labor for proactive and reactive maintenance.

The increased number of open burning nearby the plants, and change of air quality has accelerated the fouling rate of air cooled heat exchangers. The fin fans were found rapidly fouled after one year in service. The reduction of air flow across the tube bundles has resulted to the underperforming of air cooled heat exchanger and its efficiency of heat exchanger.

**CONCLUSION**

Changing tube materials from aluminum brass to copper nickel alloy with a specific percentage of iron content has shown an excellent performance since last ten years in operation. The specific iron content of copper nickel alloy has provided a better corrosion resistance behavior in seawater application. Installation of screens at the inlet of individual heat exchangers, improvement in chlorination control to reduce fouling, replacement of zinc anodes with a better material to improve layering of protective oxides in the tubes and operating within design tube sheet velocity ranges to avoid deposits and erosion have also restored the performance of heat exchanger to its original design.

Fouling of the air cooled heat exchanger’s fins due to atmospheric contaminants had reduced its efficiency and poses cleaning challenges. Fan belts, motors and bearings failures are other typical problems faced in the operation of air cooled heat exchangers. These require expanding resources, both parts and labour for proactive and reactive maintenance. Degradation of air quality has increased fouling rate of the air cooled heat exchangers. The tube fins are easily fouled within one year after cleaning. The air cooled heat exchanger fouled faster with a smaller tube pitch design. Online chemical foam cleaning, changing component materials and good maintenance practices have improved the performance of the air cooled heat exchangers.

Plant optimization to improve production capacity changes the operating conditions and cooling requirement. The changes of flow regime require resizing and material compatibility analysis for the affected heat exchangers. Mitigation and redesign of heat exchangers has been undertaken to ensure the exchangers meet the changing operating conditions.

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