Improving Self-cleaning System for De-fouling Thermal Power Plant Heat Exchangers: Case Study

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Abstract

Fouling of heat transfer tubes was major threat on the heat transfer efficiency of the condenser at the case study thermal power plant. Such that the mechanical methods used to clean the tubes were inefficient in dealing with the increasing precipitation of insoluble metal salts on the tube walls, which in turn impeded the heat transfer process. A the system of injecting spherical rubber balls into the cooling water along its flow along the tube to scrub dirty on the tube surfaces as well as to create turbulence which disturbs the settling of the dirty on the tube walls was investigated using Finite Element Analysis. Ball sizes of diameter less than tube size were considered favorable so as to carter for possible thermal linear expansion of the rubber material on exposure to temperature. A magnetic water treatment unit was also added to enable the formation of weak precipitates of the metal salts, which has reduced tendency to stick onto the tube walls. This system was found to achieve substantial savings in terms of reducing downtime on condenser cleaning at the thermal power plant.

1.Introduction

The case study thermal power plant was using the shell and tube heat exchangers for condensing exhaust steam from the turbine. The cooling water passing at the tube side tended to cause gathering of deposits on flowing through the tubes. These deposits increased with time as minerals like calcium and magnesium formed insoluble salt precipitates in the pipe interior wall – this formation of scale build up inside the condenser surfaces cause fouling whic3333h effectively reduces heat transfer surface. This is normally exacerbated by use of raw cooling water, in case of ducts which are not being cleaned they are also chances of the deposition of mud inside the condenser tubes. Prolonged fouling consequently rises frictional resistance to waters flow due to the dirty layers hence fluid mal-distribution as well as reduced velocity on flow. Also fouling layers are of low thermal conductivity such that they are overall losses in heat transfer causing the decrease in efficiency (Fayard & Verona, 2011). Common offline mechanical cleaning methods such as molded plastics cleaners (pigs) or wire brushes are used to remove off deposits in the tubes when the condenser is not functioning. In some cases, chemical cleaning is also used to dissolve the deposits (Xu, et al., 2016). Both these methods require prior plant shutdown to use them and they fail to return the original tube cleanliness. For that reason, heat exchangers which carry out the cleaning process whilst in operation would be preferred as a way to reduce unplanned shutdowns which adversely affect production cost of energy. Thus fouling will be eliminated at an early stage to prevent cases of build-up of these tenacious deposits.

2. Fouling in heat exchangers

2.1 Forms of fouling

Fouling can be considered to be the build-up of undesirable deposits on the sides of the heat exchanger tubes is dependent on the nature of the fluid in flow. It falls into two distinct categories namely macro and micro fouling.

Macro fouling formed as a result of course matter which can be in the form of biological or inorganic source matter which is taken into the cooling water circuit via the cold water pump's suction effect during operation. As the cooling towers age, their inner surface detaches some fragments which also fall into the cooling water. The matter invades the heat transfer faces, offer resistance to heat transfer, flow blockage and amplifies pressure drops. Whereas *micro fouling* is due to chemical reactions of mineral salts in water, and this is the most worrying form of fouling in industries. It is difficult to avoid and hard to correct as this nature of fouling presents itself in different categories namely scaling or precipitation, crystallization, particulate, corrosion, chemical reaction and bio fouling(Putman, 2001).

Precipitating and scaling: It is depended on the elements of the working liquid through the heat transfer surfaces. In case of cold water, it is observed that as temperature changes on passing through the heat exchanger, salts of metal calcium and magnesium precipitate off the cooling water as calcite hence forming solid layers on surfaces - lime scales (Ishiyama 2009). These salts are termed inverse soluble salts because their solubility decreases as temperature increases. Growth of such scales diminishes the tube diameters leading to reduced fluid flow. The overall thermal efficiency of the heat exchanger is also diminished.

Particulate fouling: The fouling is due to colloidal particles, thus particles less than one micrometer in at least one dimension (Xu, et al., 1998.). Particles will be suspended in the fluid flow, frequently ambient impurities such as mud or iron minerals. Along the flow they adhere onto the heat transfer sides by flocculation and coagulation mechanisms. As time goes by the deposits hardens via deposits consolidation.

Corrosion fouling: Corrosion of the constituent metal which forms the heat transfer surface. It is depended on thermal resistance, roughness of the surface and substrate composition and stream of the fluid. Impurities within the fluid flow also facilitate this type of fouling. Tubes made up of iron and carbon steel are prone to forming iron oxide. It is a common scenario in power generating firms where temperature intensify to as high as 600 degree Celsius(Sakaguchi, 2003.) as given in Figure 1.

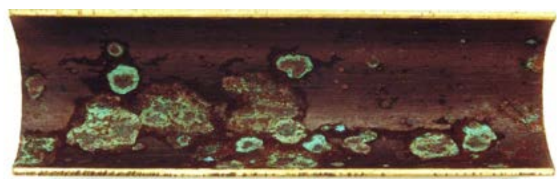


Figure 1. Iron oxide establishment on tube internal surface

Chemical reaction fouling: Chemical within fluid might reaction contacting the heat transfer faces. Even though not reactant to the fluid chemicals, the tube material can act as catalytic agent for the reaction. Elevated temperatures on the tube wall can enable carbonizing of organic matter (Xu et al 2016).

2.2 Online cleaning systems

2.2.1 Mechanical rubber balls

Online procedures of heat exchanger cleaning need no shut down of the service unit. The online techniques can be classified into two forms which are: mechanical and chemical. In the mechanical method projectiles are inserted inside the fluid flowing and the projectiles will wipe against the tube internal surfaces such that the fouling films are detached before they mount up to hard layers. The projectiles are designed such that they acquire the necessary abrasive nature to scrub of the dirty without damaging the tubes. The vulcanized natural rubber balls have proved to be effective when it comes to cleaning process. Grinding, coating or polishing agents can be used to differ on the abrasive nature of these balls. Ball choice for any heat exchanger system depends on the exchanger design, tube material and degree of fouling, as well as the cooling water flow velocity (Czolkoss, 2002). Specific types of cleaning balls have been designed for particular tube materials and nature of cooling water, this has been made possible by blend of rubber mixtures so as to yield hard and abrasive rubbers and basing on this classification of these balls as below was made possible (Bohmer 1998).While the **balls** have a peripheral skin layer formed around their surfaces as a result of the production process ground off, an additional fine polishing agent is put on the ball surface. As the rubber ball wear with time, the induced polishing agent enters more into the ball surface thus intensifies its cleaning effectiveness. Polishing balls offer negligible tube wear and they are impactful as they can master bio fouling related to titanium and stainless steel tubes. The polishing balls are mostly used because of the intensified cleaning effect they have, and they only wear with time such that replacement is required once they wear down by 0.5mm residual oversize with respect to the inner tube diameter. The further modification is spongy rubber ball with plastic granulate coating. The covering has a grade of

hardness made to be less that of the tube material to avoid damaging the tube. As compared to the sponge and polishing balls, the granulate ball handles even tough deposits without affecting the tube material. The balls are well applicable on copper tube surfaces hence scrubbing off dirty without harming the covering film on the tube surface.
In this system a **strainer** is used to isolate solid balls from water in pipe flow designs. It comprises of edge wise screen bars or perforated metal sheets resistant to corrosion whilst causing low pressure loss. The perforation designs are normally of the standard 60° triangular pattern extending from 0.020″ to ¾. They yield the strongest pattern. The standard 60° staggered array is the most accepted hole arrangement because of its integral strength and the wide series of open areas it provides. The burst pressure is depended upon material of manufacture, material thickness, size and geometry of straining building block and percentage openness of the perforated metal.Ball circulating pump is used to transport of the balls from the strainer side to their injection site at the cold water inlet flow side of the condenser. It is made to have a passage way to allow smooth balls through. The pump is sized basing on the head required as well as capacity. The pump has broad flow channel, low velocity, small size and suitable for non-stop operation. However the pump can be systematically put such that the rubber balls do not pass through the pump impeller.Then there is a short-term ball holder, which is a built in screen which acts a collector, where the balls are rinsed. Ball replacement and feeding is done at this site thus the inlet and outlet passages will be isolated. Check valves are used to avoid rolling back of the balls when pump is switched off. The collector size is dependent on the number of balls available. The cleaning mechanism uses a closed circulating loop containing spherical sponge rubber balls that are injected into the cooling water circuit heading to the heat exchanger inlet head. Difference in pressure between the inlet and outlet of the condenser tubes facilitates for the ball to move from inlet side through the tubes towards the outlet head hence scrubbing clean the tube inner surface on their motion(Suzuki, 2005.). Soon after the outlet the balls are trapped by a strainer such that they do not get exposed to the environment. A pump then draws the rubber balls (plus water) through itself thus the balls are collected again. The rubber balls will be a millimeter larger than the tube diameter to accomplish a firm surface contact with the tube inner surface, the number of balls is maintained at 10% the number total tubes per pass (Czolkoss, 2002).

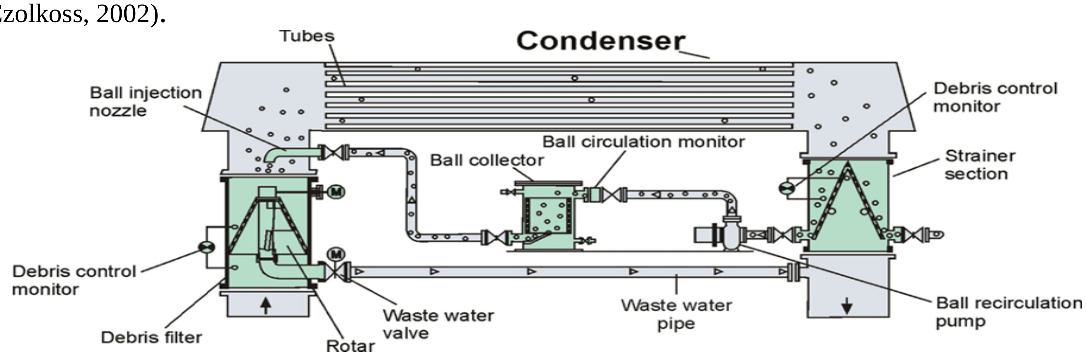


Figure 2. Representation of the ball cleaning system

2.2.2 Online Chemical Cleaning

Chemical inhibitors are used to deal with foulant that are originated mostly in heat exchangers of geometrical complexity such that no other cleaning technique is possible. Commercial anti-foulant are incorporated into the cooling water since they are poly-functional in their application thus effective and more versatile that they can manage any type of fouling(Ferreira, et al., 2009).The technique is useful in cases of already formed fouling deposits and the degree of the technique's effectiveness is depended on the deposits hardness and fouling mechanism. However the technique is unfriendly to the surroundings due to chemical agents used for instance chlorine and polyphosphates. Adding to the above, some chemical agent will even support corrosion and cracking in pipe material.

2.2.3 Thermal shock

The idea is based on the over and under heating of the tube wall surface causing brittle layers of deposits to crack as an outcome of thermal expansion. Thermal shock causes the foulant to fall off the heat transfer surface once the expansion results. Below shows a calcium deposit layer that was observed to be once integral on a surface and once rapid temperature changes resulted, the deposit layers disintegrated hence detaching off the surfaces (Muller-Steinhagen & Wattinson, 2011).

2.2.4 Hybridization of cleaning techniques

Combination of cleaning techniques is practical and has been observed to be more useful so as to completely eliminate offline manual cleaning methods hence increasing plant availability. Combinations can be chosen such that an optimal blend is set so as to achieve a perfect result. A blend of sponge ball cleaning method and anti-scaling agents at a great cycle frequency has been proved effective (Witternberg 2001). In the unit heat exchanger, the unit allows for the change of vapor to liquid, and the process is isothermal and happens at saturation temperature whilst the pressure will be constant. The design is similarly made like the usual shell and tube heat exchanger. Much focus will be put on the tube side of the condenser heat exchanger. The tube wall temperatures is the temperature on the wall of the tube containing the cooling fluid as it flow during process. As steam shields the tube, the material of the tube collects heat hence a temperature change. The condenser rubber ball as well as the brush cleaning systems is the most used in Industries. Hybridization of cleaning techniques has proved to be effective in industrial set ups.

3. Case study organization

3.1 Background

The case study organization has the mandate to develop as well as own, run and maintain thermal power generation stations for the supply of electricity. The organization has four coal fired thermal power stations in the country which produce for the home market. The plant where the study was carried was commissioned in 1958, and has a total capacity of 120 MW .The station comprised of 10 boilers feeding into a collective steam receivers from there the turbines are run. Since its approval, the station was interconnected to a local network. The organization seeks to meet the expectations of its stakeholders through use of ecologically pleasant technologies, as well reducing operational costs of energy production. Coal is locally acquired from the mines in the Western part of the country. While the major sources of water are the City Council reservoirs, as well as the boreholes at the station. Chemical energy derived from coal is transformed into heat energy through heating the boiler water into superheated dry steam. The turbine is joined to a rotor which holds a robust magnetic field, whose magnetic flux cuts across stationary three phase armature windings located on the alternator thus producing electrical power.

3.2 Power plant condenser system

The station uses a surface condenser for steam condensation cooling. Exhaust steam from the turbine is made to flow through the shell thus flowing over the outer surface of the tube bundles. Multiple tubes allow for increased heat transfer rate due to increased surface area. A Condenser unit is critical component for a power plant cooling system. The condenser receives exhaust steam at 37°C from the low pressure stage of the turbine, the steam is condensed to a liquid condensate of 35°C. The condenser unit decreases the turbine backpressure by establishment of a vacuum of pressure lesser than the atmospheric pressure, this rises the turbine output efficiency. The turbine surface condenser arrangement has a closed vessel with a number of tubes - 16mm in diameter.

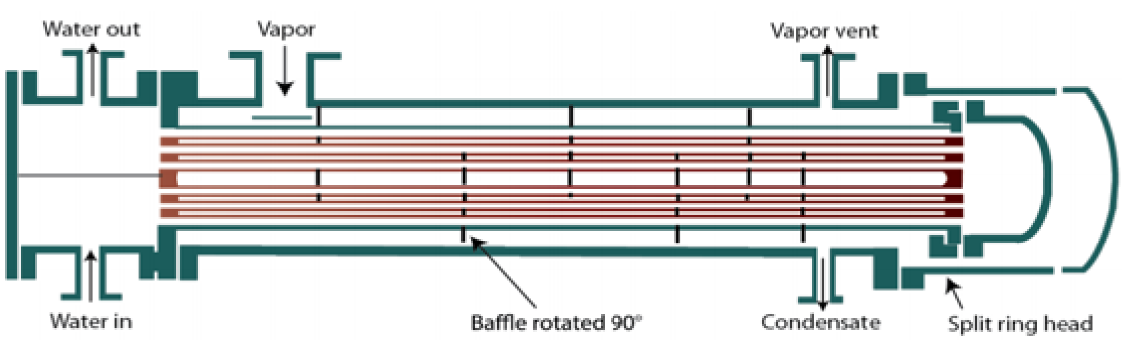


Figure 3. General schematic for a 2pass shell and tube

The condenser encompasses of baffles to prompt turbulence within the exhaust steam in the wet state so as to enhance heat transfer. Upon interaction with cooling water; the steam is condensed to liquid which sinks to the base of the condenser thus the hot well. A 400V/ 52Ampere extraction pump is utilized for the extraction of the condensate. The level of the hot well is dire as it affects the condenser vacuum. Cooling water at 25°C enters the tube side the condenser inlet side at high pressure due to the presence of the main cooling water pump. At 37°C the cooling water exits the condenser back to the cooling tower.

3.2 Cooling water circuit

Soft water is used for most cooling purposes around the plant. A closed suction duct containing soft water links the turbine house and the cooling towers in Figure 4.

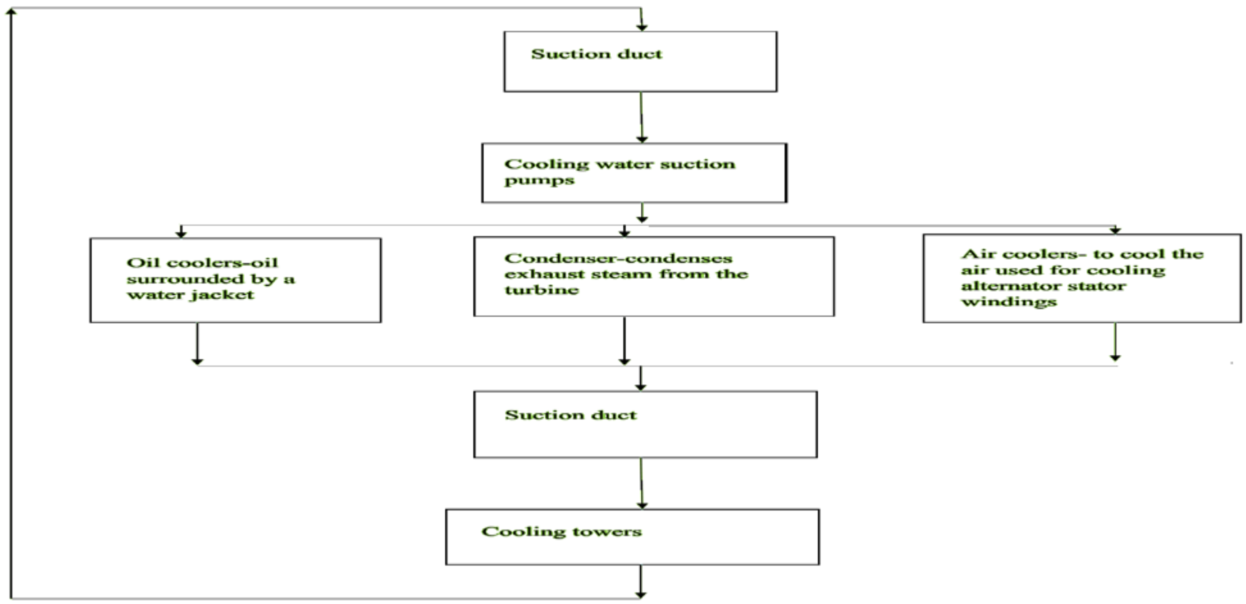


Figure 4. Cooling water circuit block diagram

The soft water is used to condense the exhaust vapour from the Low Pressure side of the turbine in the condenser. Cooling water suction pumps are used to pull soft water from the suction duct into the turbine. Some is used on chilling the air circulating within the turbo-alternator of the air coolers. This is of great importance since the temperature of the windings of the turbo-alternator has to be regulated since high temperatures disturb the soundness of the insulation of the windings leading to insulation damage which can consequently lead to serious faults in the machine. After cooling the water which is now at an elevated temperature is channelled into the other end of the suction duct which takes the water to the cooling towers. The water is sprayed at an elevated height in the cooling towers and as it falls down in the cooling tower it loses its heat to the air rising up from the bottom of the tower. Hence the water temperature decreases. This cooled water collects in the suction duct and is re-circulated back to the turbine house.

4. Plant observations and methodology

4.1 Plant observation and condenser parameters

A physical inspection of the case study thermal plant was carried out. As fouling is depended highly on the nature of the cooling fluid which is in contact with the pipe surfaces, an analysis was done to get the nature of the cooling water at the plant's laboratory. The nature of the Heat Exchanger process fluid was analyzed and it gave an indication that high magnitude of metal ions is in the cooling water (hardness) according to Table 1 of results, as shown in raw 4 total hardness is 440ppm (>limit value of 200ppm). Based on the result, the Cations that result in scaling are in high concentrations thus the high scaling in the condensers which implies that the chosen design has to effectively to eradicate that type of fouling.

Table 1. Raw and softened water properties

Property	Cooling Water sample analysis	Limits for cooling water	Soft water	Variance on Cooling water	Severity

De-aerator conductivity(μS)	1645	≤2000	250	+355	18%
pH	8.73	≤9.5	Softener 4 and 5<7, Softener 1 and 2>7.5	+0.77	8%
Total Hardness (Ca^{2+}, Mg^{2+})(ppm)	440	≤200	Acid MAX 20, Base max 10	-240	-120%
Chloride ions(ppm)	850	≤150		-700	-466%

Green: Normal
Red: Abnormal
Table 2 below gives the heat exchanger data from the thermal plant system.

Table 2. Heat Exchanger Data Specifications

Turbine Condenser	Type:1,2 shell and tube Heat Exchanger Duty=4343kw Shell side condensation
Tube Side Inlet Pressure:50psi(assumed) Fluid Handled: Cooling water Inlet Temp=(Mean 25 ˚C) Outlet Temp=(Mean 29 ˚C) Mean Bulk Temp =27 ˚C Number of tubes=9050 Diameter and length=16mm and 14m long Passes=2 Allowable Pressure Drop=5psi(0ptimum tube Drop)	Shell Side Temperature =37˚C
Main Cooling water Pipe Diameter 560mm 33Volumetric flow rate 2700gpm	

4.2 Selection of design concept

Combined rubber ball cleaning system with a magnetic water treatment system was selected for further development of the detailed design in Figure 4. The concept process entails launching rubber balls into the cooling water inlet flow towards the condenser inlet head. Due to pressure difference across condenser tubes, the rubber balls are forced to pass through the tubes with the flow thereby scrubbing and flushing the dirty off the tubes. Sieving strainer **(1)** traps the cleaning balls at the outlet side for their relaunch. An electromagnetic unit **(3)** reduces water hardness as salt precipitates of metal adhere weakly to surfaces for easy removal. The set up was recommended for its ability to handle all forms of fouling, require less labor, enable easy maintenance and achieve no ball to pump contact as its merits. Thus the design should result in a dramatic fall of condenser tube fouling in the heat transfer process to achieve the eradication of the scale formation to beat the cost of fouling challenge.

The concept of rubber ball cleaning system incorporates the use of a closed pipe loop which circulates the balls around the condenser system during cleaning sessions. Rubber balls are used to continually disturb the accumulation and settling of foulant on the heat transfer surfaces so as to attain greater efficiency in power generation. The technique seeks to maintain an increased induction period on the rate of fouling (Glade et al 2013).

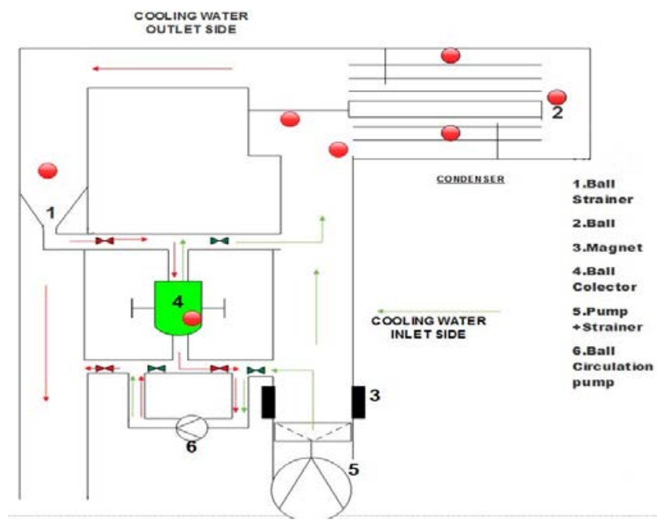


Figure 4. Combined rubber ball cleaning system with a magnetic water treatment system

The cycle begins initially as rubber balls are loaded in the ball collector (**4**) when the valves are all closed. The ball injections are shown by the green arrows. A PLC controls system valves to open (those in green only) such that some of the cooling water at the inlet side is bypassed by a small centrifugal pump (**6**) through to the ball collector (**4).** The balls in the collector are pushed by the pumped water thus out of the collector hence flushed into the main cooling water flow towards the condenser inlet head. At **(3)** is the magnetic water treatment occurs, while the intended tube cleaning happens at **(2)**. As the cooling water and ball mixture passes through the condenser tubes due to pressure variance, each ball generates turbulent layers round itself whilst in motion hence aiding the ball to push foulant off the heat transfer surface and disturbing settling of dirty as given in Figure 5.

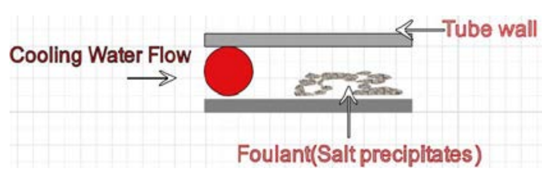


Figure 5. Rubber ball during foul removal

On exiting the condenser at the cooling water outlet side the balls are trapped by the perforated strainer (**1**) to avoid balls going downstream. Water passes through the perforations as balls stay trapped. Ball return to the collector follows the red arrow.The controller instructs the (red valves) to open at the same time as the (green valves) are closed. The pump then begins to draw water from the strainer (**1)** together with the balls back into collector (**4).** Balls stay trapped in the collector due to a strainer fitted in it, water passes through collector back to the main cooling water outlet flow. Then the cycle ends.

5. Detailed design

5.1 Preliminary calculations: Condenser tube size analysis

There was need to establish the parameters of the existing condenser unit prior modification, and this was done through preliminary calculations of essential initial parameters of concern in the project. Given the condenser specification data, the overall tube pressure drop before ball injected into the flow can be obtained empirically according to the procedures below:

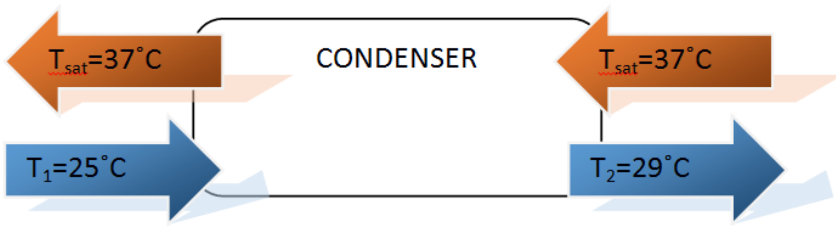


Figure 6. Condenser temperature

Heavily turbulent: *This increases ball mix-ability within the flow hence better distribution prior to entering condenser tubes.*

5.2 Determining strength of the foulant to be removed

This refers to the strength associated with the bonding. Knowledge of this strength magnitude helps in analyzing if the cleaning method offers the required force to remove the foulant off the heat transfer surface. The precipitate scaling was considered as a major threat of fouling according to the study undertaken at the plant's site.

Basing on this we shall consider a fouled but half sectioned pipe such that the foulant takes the same shape as the pipe curvature;

Figure 7. Foulant attached inside the tube surface

VDW interactions between two parallel cylindrical surfaces F_A of radii R_1 and R_2 separated by a distance Ơ is given by the Hammaker Summation Method(Ghosh, 2006).

Determining Electrostatic Forces F_E:

To estimate the electrostatic force between the cu alloys tube surface to the salt and that electrostatic force in-between the salt ions themselves, researcher will consider the below system of equal distanced charged ions:

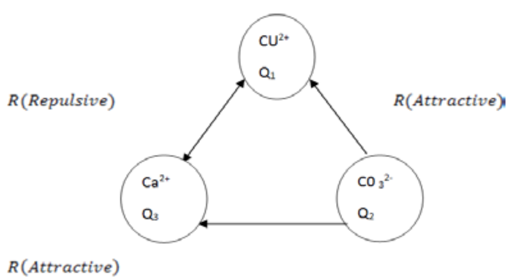


Figure 8. Ionic arrangements between salt and the tube surface.

5.3 Cleaning ball selection

The cleaning balls to be used for the tube de-fouling are of rubber material due to its merits as earlier explained. Taprogge produces cleaning ball in the range of 14mm to 44mm .The rubber ball type is going to be selected based on the Taprogge catalogue(Taprogge, 2017).

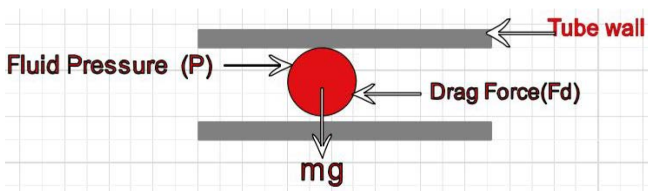
Expected Temperature Rise on the Ball

Basing on the 2nd law of thermodynamics; conduction heat transfer is observed whenever two bodies of different temperatures are involved so as to attain uniform temperature gradient. For the determination of how much the ball material is affected by exposure to high temperatures, the researcher will analyze the ball motion under worst conditions thus ball forms almost a tight seal to the tube surface.

Ball linear expansion when exposed to the condenser conditions is 0.60mm.
Basing on the above characteristics the high temperature corundum coated R160 or R130 Ball types of diameter 15mm were selected. Such that in case of expansion (Diameter)=15+0.60=15.60mm thus advantageous in that the ball and tube form an interference fit hence additional thoroughness in cleaning due to improved contact stability of the ball and tube surface. Selected balls are appropriate for hard metal scales, initial cleaning of new tubes, surface smoothing hence not damaging to the brass tubes.

5.4 Ball motion analysis

The cooling water forces the rubber ball through the tube length .As observed on the Condenser tube side analysis, the flow will turbulent which aids in agitating the foulant from settling. In the presence of the ball, the turbulence is even improved because as the ball moves the speed on the boundary layers in front increases sharply so as to generate jet effects that forcefully de-foul the tube.



The thrust force of propulsion, relative velocities and pressure drop across the ball can be determined which help us to ascertain if this thrust force is sufficient enough to push the foulant.

Assumptions:
Ball linearly expand to the tube size considering the worst conditions.
Ball is almost spherical along its motional flow
Since the ball is corundum (chromium impurities) coated for abrasiveness, co efficient of frictional contact (copper alloy to chromium steel) η=0.15 (from tables).
Cross Sectional Area of pipe (assume its equal projected area for the sphere), **A = 0.00020m²**

Drag Force; $\mathbf{F_D = 0.0442\,V^2}$ **Newton**

This force is associated with the frictional drag forces on the moving sphere (velocity V) when assuming stationary fluid property. In case of a random moving object and fluid, the differential velocity has to be determined so that the drag associated with the retarding frictional force on the ball is obtained.

Considering the pipe to ball direct contact:
Contact Frictional Force; $\boldsymbol{F_f} = \mathbf{0.0206N}$
Now let the sphere velocity be $\mathbf{V_B}$ such that it's less than the mean flow velocity of water V due foulant obstacles and surface roughness on the sphere when in motion.

The differential velocity across sphere $\mathbf{V_D = V - V_B}$

Frictional drag considering the differential velocity is equivalent to the contact frictional force due to surface roughness during the same flow (Ndlovu, 2016).

$$\mathbf{V_D = 0.68 m/s}$$

Basing on the sphere dynamics:

Thrust force(F_T)= Force due to pressure(F_P) –Drag force (F_D)

Force due to pressure(F_P);

Tube side pressure is assumed to be 50psi=350.6kpa

Pressure x cross sectional area of sphere = 350.7kpax0.0002 **= 70.11N**

Drag force(F_D) $= \frac{1}{2} C_D \rho A V_D^2 = \frac{1}{2} \times 0.44 \times 0.0002 \times 999.84 \times 0.68^2$ **= 0.020N**

Finally, thrust force on the ball =F_P-F_D = 70.11-0.02 **= 70.09N (>>Net Strength on the foulant)**

Net strength on the foulant = <u>0.000668N</u>

To displace the foulant the thrust force must be greater than the Net bond strength of the foulant.Therefore it can be concluded that the cleaning is effective enough to de-foul the dirty off the heat transfer surface.

5.5 Evaluating the total pressure drop in the tube due to the two phase flow

As calculated initially during preliminary tube side calculations, the total pressure drop in a tube was 2.2psi.
After adding the ball charge:
Pressure Drop per tube=2.2+ Pressure Drop across the Sphere;

ΔP =2.2+0.014

=2.214psi (<<Allowable Design pressure of 5psi)

The main cooling water Pump will be able to accommodate the ball charge added.

5.6 Equipment Design

5.6.1. Ball collector

This saves as a vessel which temporarily contains the water and ball mixture before injection and after collection cycles. A perforated steel sheet is fitted at the bottom vessel to avoid balls from escaping through to the pump but rather water alone.

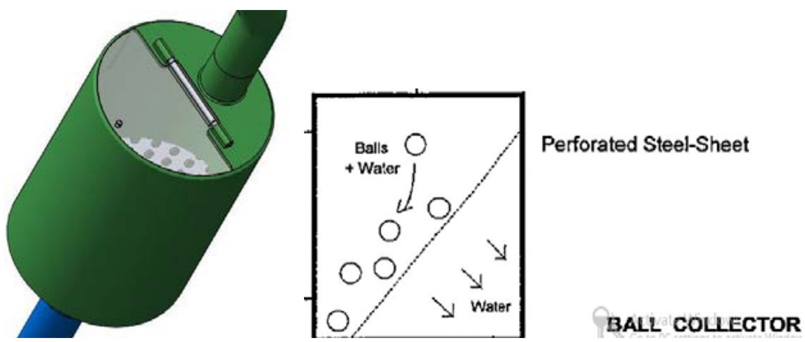


Figure 10. Ball Collector

Determining vessel size which can accommodate the balls by estimations:
Assume diameter of vessel D = 200mm
Height L= 300mm

Basing on the ratio; if these spheres were in liquid form; 4766 of them would fit into the cylinder of given dimensions; however since they are solid this estimate does not consider gaps formed on packing the spheres.
In this case, consider the packing factor (Greatest fraction occupied by spheres in 3D space using Kepler's Conjecture); for spheres its 0.74(Yamada, et al., 2009).

Actual Number of balls that can fit the cylinder space = 0.74x4766= 3 527

The researcher will opt for the assumed cylinder dimension since they accommodates almost thrice the expected ball number hence the cylinder is favorable as it offers a bigger volumetric space considering the balls will be in a water mixture before pushed into the main cooling water flow. Now that the dimensions of the vessel are known, the researcher is to determine the required thickness of the steel vessel material to withstand internal pressure due to pressurized water on agitating the ball load during cycles.

The thickness (t) shall be obtained using the thin cylindrical formula assuming the vessel can be thought to be a sudden pipe enlargement along the piping route in the system.

However mild steel material can be highly corrosive in moisturized environment hence on fabrication the epoxy coated steel can be used to resist corrosion.

5.6.2 Strainer type

The strainer will be working as a ball trap located at the condenser cooling water outlet pipe. This component ensures for the full recovery of the cleaning balls for the next cycle. Design is based on IPA (International Perforators Association) set standards.

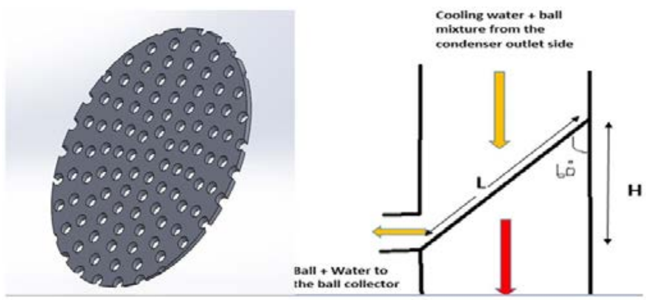


Figure 11.Elliptical perforated metal sheet and its orientation of the sheet in the cooling water pipe

Main cooling water flow rate: 0.691m/s, therefore strainer required has to allow water passage and avoid 15mm rubber ball from escaping. Basing on the requirements, holes diameter of the perforation has to be less than 15mm (ball diameter) whilst the spacing between the holes doesn't not cause high pressure drops.
Selected Metal (IPA Standards table):   Hole diameter D=1/4 inches
Hole spacing C=5/16 inches, staggered round holes types

Percentage open area,OA

$$= \quad 58\% \text{ Open Area(Area opened on the strainer)}$$

5.6.3 Magnetic unit

A copper wire solenoid is to be used to generate a uniform magnetic field concentrated in the center of the coils hence magnetizing the pipe such that as water flows past the magnetized portion it is magnetized. The researcher will determine the appropriate constraints required to produce the required magnetic flux to de-mineralize the cooling water.

5.6.4 Pump and pipe sizing

As given in the schematic diagrams (Figure 12), the recirculation pump shall be pumping in two distinct paths during ball injection and ball collection (follow blue line). For the pump sizing purposes the path that require most energy on discharge shall be used thus the jnjection cycle.

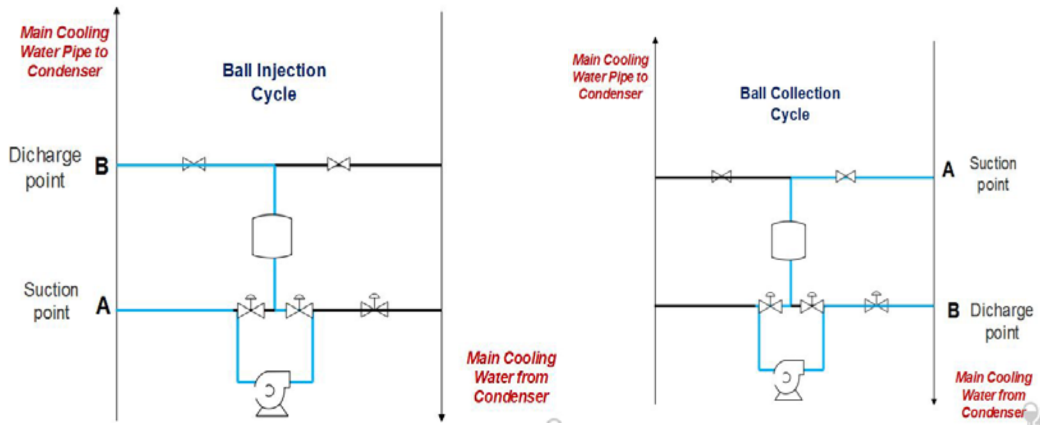


Figure 12. Pumping System schematic layout

The pumping system with a bigger pipe diameter (3times ball size) was selected. Although the cost associated with the bigger diameter in the five year run is higher; it is worth since at that diameter the pump operates more efficiently than when the pipe diameter is smaller

5.6.5 Strainer

This acts as the ball collector hence keeping the balls in the circulatory loop. Due to the cooling water passing through strainer, water impacts the strainer whilst in operation .Incase of failure on the strainer it means no ball is collected hence no ball circulation is achieved. This means thatthe system will not save for its intended purpose.

Determining Von Mises Stress on the strainer open area.

In this analysis the researcher will consider only a small fraction of the perforated area (25mm x25mm x 15mm) on the strainer. Using the known pressure within the pipe flow in the main cooling water tube(50psi), force expected on a unit area under analysis is obtained as (219N).

The overall analysis portrayed that Von Mises stress expected on the strainer plate is 1.9 x 10^6 Nmm^{-2}, thus less than the yield strength of the perforated material 3.650 x $10^7$$Nmm^{-2}$.

5.6.6 Condenser tube

The rubber balls in circulation are coated with abrasive materials. In cases of no foulant in the tube or ball expands towards tube walls, it implies that ball directly contacts tube wall along the flow. The effect of the ball contact on the tube has to be verified if it is impactful to the tube material hence avoid damages on the condenser tubes. In this analysis the thrust force on the ball as obtained from is to be considered as the same force also experience on the tube along its wall.

The resultant Von Mises stress after the FEA was found as 2.002 x 10^6 Nmm^{-2},hence less than the yield strength of the tube material,Brass,2.397 x $10^8$$Nmm^{-2}$. In conclusion, both designs are safe because the attained Von Mises stress of the models is lower than the corresponding yield strength in both cases.

It is of significant importance for the operators of the set cleaning system to be fully knowledgeable on the operational parameters and components available. This ensures for safety and ability to identify if the system is working according to its intended operation. Therefore an optimum performance is achievable since external disturbances can be avoided if the system is clearly known. An automated system is used to control the ball injection and collection cycles. The valves in the system receive set commands from the PLC at specified times in the cycles. This unit saves the labor of tiresome on off operations of the multiple pipe line valves. Sight glasses on the ball collector and the strainer site save for the inspection of ball availability and if any ball is stuck on the strainer. Control valves are incorporated in the system to allow for required flow path at different intervals of the cycles. This exercise ensured for the identification and eradication of hazards associated with the developed system. Potential hazards that may arise due deviation of the design from its expected operational conditions are noted.This depends on the contracted company but after consulting, a good average was found to be $4500 per condenser.

6. Recommendations and conclusion

As recommendations, there was need to improve on the reduction of ball losses, as well as to improve ball distribution on tubes. Further development of ball material with greater resistance to wear could be developed. Development of advanced system to control and monitor ball motion in the tubes such that no tube is missed needs to be investigated. In systems of low turbulence, the effect of adding an agitating component to improve ball distribution within flow has to be researched on. Although the design of a condenser rubber ball cleaning system which saves for the cleaning of the condenser tubes whilst in operation was done. The design paid consideration to cases of possible tube obstructions, missed tubes on cleaning and lessening of ball wear. The introduction of an online condenser cleaning system at the power station will be impact on the downtimes due to unexpected and scheduled shutdown are reduced during periodical cleaning thus yearly expenses due to downtime on condenser cleaning slashed by $475 200. Major improvement of the existing system to meet set objectives were on the addition of the magnetic water treatment to and alter the super molecules in water such the calcium cation precipitate so if a specific tube is missed in one cycle, it will be in the next cycle the while foulant will not be stubborn on removal. The number of balls per cycle were increased such that higher a probabilities that any tube is cleaned after multiple cycles. Reduced ball size was introduced to cover for thermal expansion on the balls when exposed to high temperatures.

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Biography

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