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A NEW APPROACH IN THE TREATMENT OF BOILER WATER

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ABSTRACT
The quality of boiler water is an essential part of increasing boiler efficiency. Nevertheless, the most frequent type of failure is the corrosion of the boiler tubes due to improper treatment of feed water. Also, it can affect its performance, life, and cost of maintenance, risking boiler efficiency, making the treatment of the boiler water a key in the marine industry. Thus, the boiler water should be treated chemically or mechanically to maintain the proper boiler operation. This report will guide you through the problems and solutions for boiler water treatment.
KEYWORDS: *Water Treatment, Boiler, Hot Water, Scale Transformation, Corrosion*

1. INTRODUCTION

A boiler is a closed vessel in which fluid (mostly water) is transformed into high-pressure steam by getting heated. Boilers are a very important system in the ship's engine room. Their main purpose is to provide the steam needed for various systems in the vessel. Because their use is essential for the ship, the importance of correct water treatment for economic operation and for extending the life of boiler and equipment cannot be over-emphasized. To ensure that the boiler will work properly boiler water is always tested and treated at regular intervals, externally and internally. External water treatment refers to the reduction or removal of impurities from water outside the boiler by chemical or mechanical treatment of the water source. The purpose is to improve the quality of the water prior to its use as boiler feed water. There are many types of external water treatments (softening, clarification, filtration, de-alkalization, dearation, de-mineralization, membrane contractors, etc.). These methods can be used to prepare make feedwater for a boiler. Even if all these methods are applied for the external treatment of the water, boiler feedwater still contains impurities that could inevitably affect boiler operation. This treatment is usually in the form of chemical dosage that is applied in the feedwater and its purpose is to minimize the potential problems and prevent any fatal failures. Its primary affects are mostly scale and corrosion. Boiler feedwater may contain a variety of impurities that's why it's essential to treat it thus avoiding damage to the boiler tubes and shell. A successful water treatment approach can be taken by following these steps [1]:

- Prepare the boiler water before it goes to the boiler.
- Maximize the potential of condensate.
- Provide internal boiler protection.
- Maintain clean internal boiler surfaces.
- Avoid problems and shutdowns.
- Extend equipment life.

2. PROBLEMS OF BOILER WATER

All raw water meant to be used for boiler operation contains various types and amounts of impurities. This water is divided into four main types. These are make-up water, feed water, blow down water, and condensate water. *Makeup water*- The softened water, raw water, or demineralized water which is needed for steam generation. This water is used in many rocedures in heating applications, because of its good heat transfer capacity.

Condensate water- After steam transfers its heat to the process, it returns to a liquid state called condensate. Condensate water is known for its purity and its ability to be reproduced into steam again without the use of any additional chemical treatments. *Blow down water*- The water that is drained because of the need to limit the impurities to an acceptable level. Because of the water loss makeup water is added. *Feed water*- The combination of total condensate returns and boiler makeup water that is aggregated and supplied to the boiler to create new steam. Some of the common impurities of the water before it goes through external treatment can be summarized below [1] [2] [3]:

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Table 1: Some Impurities of the Water

Dissolved solids	These are substances that will dissolve in water divided into two major categories. Substances which are non scale forming and substances that form scales when heated which are the most important ones (carbonates and sulphates of calcium and magnesium).
Dissolved gases	The gases that can be dissolved by water. Oxygen and carbon dioxide. These gasses are aggressive instigators of corrosion.
Color	The cause of this is mostly decayed organic matter changing the color from colorless to deep brown.
Cations	Positively charged ions such as magnesium, sodium, calcium, and potassium.
Alkalinity	Carbonate, hydrate, and Bicarbonate measured by titration. Alkalinity can convert to carbon dioxide in steam form causing corrosion
Hardness	Calcium and magnesium salts which are the main causes of scale formation.
Turbidity	Finely suspended matter which doesn't settle. Imparts and cloudy appearance to the water.
Silica	Normally exists in water as an anion or as a colloidal suspension.
Suspended Solids	Substances that exist in water as particles, they usually are minerals or organic matter.These kinds of particles can cause turbidity and can block tubes.
Anions	Negatively charged ions such as alkalinity, sulphate, chloride, and nitrate.

3. PROBLEMS OF BOILER OPERATION CAUSED BY IMPROPER FEEDWATER TREATMENT

Proper feedwater treatment is a major factor in the boiler's proper operation. The common problems that we face due to improper treatment of feedwater can be summarized below [1].

- Alkalinity and pH of the water
- Oxygen Content
- Hardness
- Scale deposits
- Boiler water carryover

3.1 Alkalinity and pH of the water

The pH scale ranges from 0 to 14. When at 0 the water is at its most acidic state and when at 14 is at its most alkaline state with number 7 on the scale being neutral. Control of pH is of outmost importance in many boiler water treatment programs because of corrosion and scale problems. During boiler operation the pH of the water must be in the range between 9.5 to 11.5 to ensure the proper reaction between the calcium and magnesium ions and phosphate molecules. In most cases if the pH drops below the recommended range the chances for corrosion increase while above this range the chances for scale formation increase. In addition, acids and alkalis can increase the conductivity of the water. For example, a sample of water with a pH of 12 has a higher conductivity than a sample of a pH value of 7.

Alkalinity on the other hand is the measurement of the carbonate, bicarbonate, and hydroxyl ions in the water, only the former two are found in natural water supplies. In boiler feedwater exists two forms of alkalinity. Carbonate and bicarbonate the latter is the most common. The combination of carbonate and bicarbonate together with calcium and magnesium can cause scale in the boiler water systems. When water with carbonate or bicarbonate alkalinity is heated the alkalinity transforms into carbon dioxide. The carbon dioxide released combines with the water and forms carbonic acid which can cause corrosion. In addition, calcium carbonate scale can be formed by the reaction of the corrosion products in combination with the alkalinity.

3.2 Oxygen Content

Dissolved oxygen is the most common type of corrosion inside the boiler water system. Even the smallest amounts of dissolved oxygen can cause severe damage. The presence of oxygen results in the formation of hematite or red iron oxide which as a result leads to pitting corrosion which can cause tube failure. The amount of oxygen present in the system is dependent on the feedwater temperature, the lower the temperature the higher amount of oxygen present and vice-versa. At higher temperatures dissolved oxygen causes faster corrosion on the internal surface of the boiler. Dissolved oxygen can cause damage to the steam drums, mud drums, boiler headers, and condensate piping.

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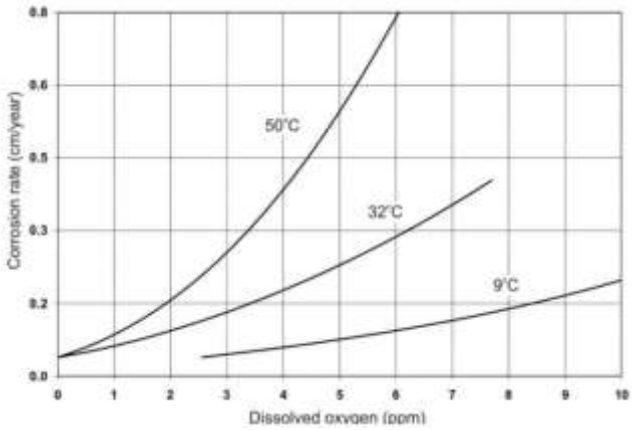

Fig. 1 Effect of oxygen concentration on the corrosion of steel at different temperatures.

3.3 Hardness

Water as a substance is referred to as hard or soft. Soft water contains little to no impurities while hard water contains various scale forming impurities. The primary minerals responsible for scale formation are calcium and magnesium. The sum of these two is the result of the total hardness. Total hardness is divided into carbonate or temporary hardness and non-carbonate or permanent hardness. Carbonate hardness is caused by carbonates and bicarbonates ions like calcium and magnesium that dissolve in water and form an alkaline solution which when heated it decomposes and releases carbon dioxide and soft scale. Noncarbonate hardness is also caused by the presence of carbonates and bicarbonates ions like calcium and magnesium but in the form of Sulphates and chlorides. As the temperature rises these salts due to their reduced solubility, they precipitate from the solution to form a hard scale which is very hard to remove. In addition, the presence of silica in the boiler water can also lead in hard scale. This scale can react with the existing salts, calcium and magnesium to form silicates which can inhibit heat transfer across the fire tubes and cause them to overheat.

3.4 Scale deposits

'Scale' is the result of water impurities such as calcium, magnesium and silica, found in water supplies. These impurities precipitate at high temperatures and form a dense coating of material on the waterside of the boiler tubes. This dense layer acts as an insulator, lowering the efficiency of the heat transfer in the boiler system thus increasing the fuel consumption. Fuel wasted because of scale varies from 2% for water-tube boilers up to 5% for fire-tube boilers. Scale typically has a thermal conductivity of an order of magnitude less than the corresponding value for bare steel. That's why even thin layer of scale act as insulators effecting heat transfer. In addition, to its high insulating values scale narrows pipe internal diameters over time effecting the proper flow of water. Another important problem is that scale also causes the tube's metal temperature to rise, which increases the flue gas temperature resulting in tube failure from overheating.

Scale Thickness, inches	Fuel Loss, % of Total Use		
	Scale Type		
	"Normal"	High Iron	Iron Plus Silica
1/64	1.0	1.6	3.5
1/32	2.0	3.1	7.0
3/64	3.0	4.7	–
1/16	3.9	6.2	–

Fig 2 Energy loss due to scale deposits.

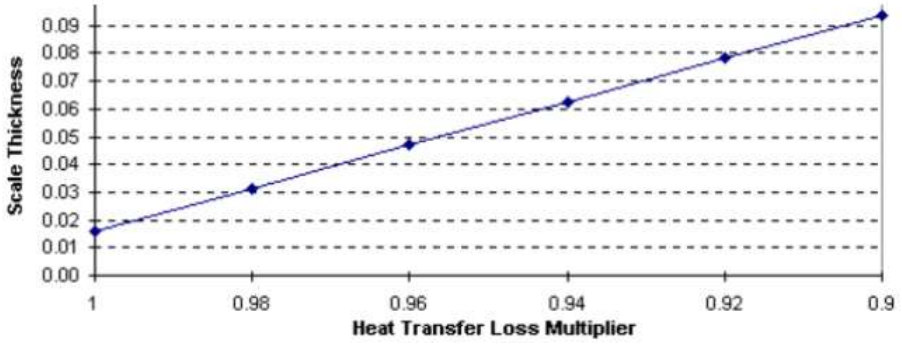

Fig 3 Effect of scale thickness on heat transfer.

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3.5 Boiler water carryover

This describes the contamination of steam caused by a relatively small quantity of boiler water solids. The carryover of droplets of water in the steam by foam or mist is called Priming. This can occur by sudden fluctuation in steam demand or excessive ratings. As a result, priming lowers the efficiency of the steam energy and creates crystal salts on the super heaters and in the turbines. Excessive boiler water carryover creates turbine blade deposits because of the steam carried solids in the boiler system. Priming relates to the viscosity of the water and its tendency to foam. These properties are controlled by the salinity, alkalinity and certain organic substances. Another type of boiler water carryover is foaming. Foaming is the formation of bubbles on the boiler water surface that pass out with the steam. It is caused by a relatively high concertation of boiler water solids. Substances like grease, oil, fats, alkalis, and suspended solids are especially conductive to foaming. In theory suspended solids collect on the outer layer of the steam bubble making it tougher, thus the steam bubble builds up foam. The finer the suspended particles the greater their collection in the bubble[6].

4. BOILER WATER TREATMENT METHODS

The treatment of the boiler water plays a very important factor in the boiler's proper operation. To achieve it we can take several approaches in the treatment of the boiler water. These approaches can be summarized below [2] [3] [5]:

- Makeup water treatment
- Recovered condensate water and treatment
- Blowdown water
- Feed water treatment and conditioning chemicals

4.1 Makeup water treatment

Makeup water contains the larger amount of impurities because it comes from natural sources, because of the variety of samples that we can find in nature we can't treat it with only a single method. One method is water softener, its purpose is to remove the hardness from the boiler makeup water without changing the pH or alkalinity. The softening media is called zeolite, in its composition inherits negatively charged ions which attract the positive ions from the water. As the water passes through the zeolite the calcium and magnesium salts are attached to the beads. During this process an exchange occurs in the zeolite heads, trading sodium for calcium and magnesium. As a result, the sodium with the 'soft' ions take the place of the calcium and magnesium 'hard' ions in the water producing 'soft' water.

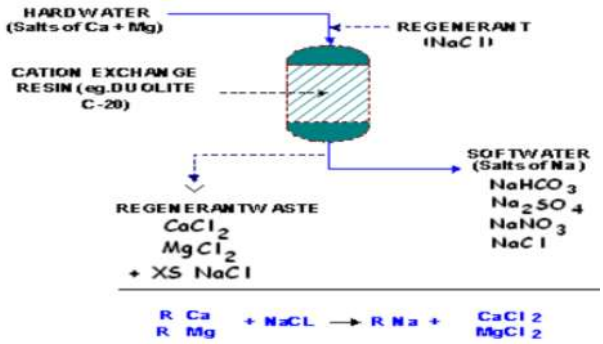

Fig 4 *Water softening scheme.*

Another method is de-alkalization by ion exchange. There are two types of de-alkalization split-stream and chloride. Splitstream de-alkalization implements two parallel cation exchange units of sodium zeolite. One is regenerated with salt and the other with acid. Makeup water passes through the first zeolite exchanging calcium and magnesium for sodium and the remainder passes through the acidified zeolite to remove hardness and alkalinity. These two flows then connect and pass through the aerator or de-carbonator. Because of the reaction that will take place during the connection of these two flows carbon dioxide and water will be produced. With this method we can achieve nearly zero levels of hardness in the water with the cost of alkalinity reduction.

Chloride de-alkalization use two ion exchange units operated in series regenerated with salt. The first is a zeolite softener containing cation resin and the second is a de-alkalization unit containing anion resin. The zeolite softener to remove hardness and the anion unit to exchange bicarbonate and sulphate for chloride. This process does not remove dissolved solids, but it removes nearly all alkalinity for that reason caustic soda is added to obtain the necessary hydroxide alkalinity in the boiler water.

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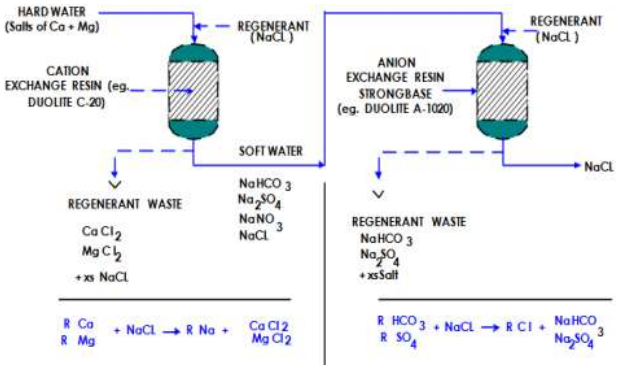

Fig 5 De-alkalization scheme.

De-mineralization by ion exchange is another treatment method. This process will remove the largest amount of salts from the water achieving a quality close to that of distilled water. Its mainly used where total dissolved solids (conductivity) is the limiting feedwater constituent. By using this method, the water goes through cation and anion exchange resins. It uses cation exchanger in the hydrogen form to exchange them for the positive charged ions from the water. The discharge from that unit then passes from the anion exchange resin and exchanges hydroxide ions for the ions in the water. This resin might be either a weak or a strong base resin. A weak base resin absorbs the entire acid molecule and not just the chloride ion. This process is an acid-base reaction.

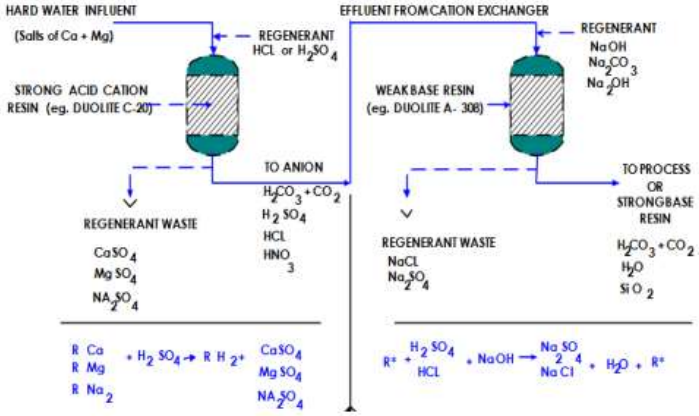

Fig 6 De-mineralization scheme.

One more method of water treatment is reverse osmosis plant. Reverse osmosis is the process of water purification by placing a semi-permeable membrane and letting water pass through it. This process can remove high concentrations of impurities rom the water such as ions, salts, and large particles to a lower concentration of them. This can happen by applying pressure between 400-2000 psig on the high concentration side of the membrane. This is an efficient and cheap method to produce high quality water.

4.2 Recovered condensate water and treatment

Condensate water has a very low concentration of dissolved solids thus it adds very few impurities to the boiler feedwater, most of the impurities in the feedwater come from the makeup water. The recovery of condensate water is important for the following two reasons. First, the more condensate is recovered the less the makeup water that we'll need to fill the boiler. So, we can minimize the contaminants that will go in the boiler system from the usage of makeup water. In return the water will need less treatment, external or internal. Second, we'll have less condensate discharge if we recover a percentage of it. This in return, will lower the blowdown water quantities. To top it off, condensate water is hotter than makeup water so losing it will cost us the heat that is equivalent to the temperature differential of the makeup water. If condensate gets contaminated it must be segregated from the pure steam otherwise it will lead to bigger and more serious problems. Condensate is generally very pure water but in certain cases it can be corrosive because it contains dissolved carbon dioxide which can dissolved and suspended iron to the feedwater. To prevent this, we can use neutralizing amines which are chemicals called morpholine and cyclohexylamine to break down carbonic acid and increase the pH of the condensate.

Another way is to use oxygen scavengers or filming amine which can scavenge oxygen and provide a coating to the ondensate system or provide a watertight barrier against carbonic acid and oxygen.

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4.3 Blowdown water

De-mineralization treatment isn't perfect there always exist a small amount of dissolved minerals in the boiler feedwater. The addition of dosing chemicals, makeup water in the boiler and the evaporation of it increases the concentration of these inerals and leads to accumulated solids in dissolved or suspended form. These solids promote carryover increasing the moisture level of the steam and damaging pipes, valves, and other equipment. Also, suspended solids cause sludge or sediment in the boiler that can directly affect heat transfer capabilities of the pressure vessel and lead to various problems like pressure vessel damage. To summarize everything these solids will form a sludge or sediment at the bottom of the boiler that need to be removed by the blowdown process to maintain the recommended values of dissolved solids in the system. This process has an indirect effect on the boiler water treatment because regulating and reducing the blowdown will reduce the amount of makeup water added to the system.

4.4 Feed water treatment and conditioning chemicals

Even after external treatment of the water we cannot get rid of all the impurities that will go in the boiler system, thus we need to treat the water internally. The objective of the internal treatment is to remove specific impurities that are present, prevent corrosion by maintaining chemical balance to remove oxygen, carbon dioxide and traces of other dissolved gases. The use of certain chemicals like sodium phosphate to prevent scale formation from the hardness of the water. This hardness precipitates at the bottom of the boiler where it can be blown down. Additionally, internal treatment allows as to control individual parameters of the water such as alkalinity, pH, sulfite, dispersant, condensate, and others by using certain chemical formulations. These formulations can change corrosion/scale salts to soft mobile sludges. Also, sludge conditioners can be used to keep these sludges into suspension and prevent them from depositing on metal surfaces. After the use of these chemicals the TDS in the boiler water will increases and we'll have a higher rate of blowdown. Feedwater can also be treated by a method called de-aeration. Mechanical de-aerators and eliminate oxygen, free carbon dioxide (while it is released with the steam) and other corrosive gases from the feedwater. There are two types of de-aerators, tray-type and spray-type. Trayheaters reduce the water into droplets and collect it over a several rows of trays by using dissolved gases. These droplets come in contact with the steam and they get heated thus removing all oxygen. Spray-type heaters use spring-loaded nozzles placed at the top of the unit and the spray the water into the steam. Because of the high solubility of the water and the levated temperatures oxygen is removed by the system.

5. CONCLUSION

Choosing the correct treatment method and chemical dosages depend on the water sample and its impurities and the condition of the boiler system. To achieve a proper boiler operation, we must maintain the pH, TDS, and alkalinity of the water to certain levels to limit corrosion and scale formation. The removal of dissolved solids (magnesium, calcium, etc.), dissolved gases (oxygen, carbon dioxide, etc.), and various salts from the feedwater is also very important. All these solids and gases will end up to the bottom of the boiler forming a sludge, to be removed by the blowdown process. Makeup water contains the largest percentage of impurities that's why it's quantity's must be minimized as much as possible. This can happen by getting more condensate recovered because it is a high-quality water and regulate the blowdown.

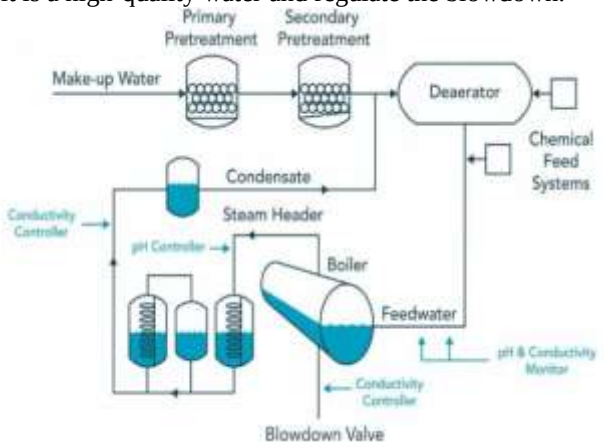

Fig 7 *Water treatment example.*

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