IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Establishment of Method for Identification of Water Quality in Fire-Tube Boiler - A Case Study for UTHM Biodiesel Plant's Boiler

Kamal, N. M. A. N. M.[1], Nasir, N. F.[1,2*], Abdul Patar, M. A.[1], Seis, M. F.[1], Hariri. A.[1], Mat Isa N.[1], Nordin, N.[1]

[1]Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

[2]Plant Reliability and Process Technology Focus Group (PROTECH), Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia

*Corresponding author

DOI: https://doi.org/10.30880/ijie.2019.11.05.012
Received 5 March 2019; Accepted 26 March 2019; Available online 10 August 2019

Abstract: Water treatment process for a boiler is essential to ensure the boiler operates at an optimum condition. Accordingly, the present study aimed to introduce a water quality assurance method for a boiler at UTHM biodiesel plant. The water quality is investigated by experimental study, which includes the monitoring of total dissolved solids, potential of Hydrogen (pH), sulphate, iron and chloride content, total hardness, and alkalinity. The water sampling was conducted at three different points. Subsequently, for the purpose of water quality assurance, the amount and type of chemical needed for a boiler to maintain a substantial value of water treatment were also been determined. The results obtained in this study has revealed that most of the parameters investigated are within the allowable limits. Further work needs to be done to establish whether the steam produced by the boiler can be influenced by the boiler water quality.

Keywords: Fire-tube boiler, water treatment, biodiesel, water quality

1. Introduction

A boiler converts the chemical energy in fuel into the heat energy in steam, it also converts the heat energy of hot gasses into the heat energy of steam when no firing is involved [1]. Boilers are used everywhere, in office buildings, malls, factories, plants, industries, and even in residential houses [2]. It generates either steam or hot water. Steam is used for producing electric power, process applications or heating meanwhile hot water is used for building heating, portable water supply, or process applications. The complete process of boiler technology comprises heat transfer [3], thermodynamics, combustion technology, and mechanical engineering principles. As boilers operate under pressure, the potential for explosion is to be taken into consideration. To protect the public from boiler hazards, governmental authorities worldwide enforces laws, rules, and regulations on design, fabrication, inspection, and maintenance of boilers.

Nowadays, boiler is equipped with advanced technology and electronics and most boilers are fully automatic. They are equipped with the computerized control programmed and system. Although with all the latest technology which allows the person-in-charge (boilerman) to operate a boiler by practically sitting in front of a personal computer, the fully automatic operation does not eliminate the potential dangers of explosion. Boiler accidents still may occur and fatally harming people worldwide. Although a minimum supervision is needed to maintain the efficiency of the boilers, the water and steam quality treatment must be controlled properly.

The Boiler and Pressure Vessel Codes published by the American Society of Mechanical Engineers (ASME) are accepted internationally [4]. Boilers are classified into two categories based on design codes published by ASME. Table 1 shows the classification of boilers.

Table 1- Boiler classification

Classification	Types
Content of the tubes	a) Fire tube
	b) Water tube
Steam pressure	a) High pressure
	b) Low pressure
Type of water circulation	a) Natural circulation
	b) Forced circulation
Position of axis	a) Horizontal
	b) Vertical
Furnace position	a) Externally fired
	b) Internally fired
Type of fuel	a) Coal-fired
	b) Oil fired
	c) Gas fired

Generally, there two types of boilers, the fire-tube boiler and the water-tube boiler. This is the type of boiler used in nearly all steam locomotives. The heat source is inside a furnace or firebox that must be kept permanently surrounded by the water in order to maintain the temperature of the heating surface just below boiling point. As for the water-tube boiler, the water tubes are arranged inside a furnace in several possible configurations, often the water tubes connect large drums, the lower ones containing water and the upper ones, succession of coils. This type generally gives high steam production rates but less storage capacity.

This study focuses on fire-tube boiler that is in the biodiesel plant of University Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia. To ensure the boiler operates in its maximum efficiency, water quality that flows into the boiler must be in good condition. Water treatment has been measured to ensure that all the impurity content in the water will not affect the boiler system. As a result, appropriate chemical will be suggested to maintain the efficiency of the boiler**.** Figure 1 shows the UTHM Biodiesel Plant's boiler used in this research.

Fig. 1 – Fire-tube boiler located in UTHM Biodiesel Plant

By conducting the external and internal treatment, the presence of calcium, magnesium, silica and other impurities could be controlled. External treatment, also called as pre-treatment is a treatment used for the removal or reduction of some undesirable characteristics and addition of desirable characteristics in the water for end use. There are many methods to conduct this treatment which are clarification, filtration, and precipitation softening process. Internal treatment is carried out to chemically adjust or balance water inside the boiler to prevent scale formation, inhibit corrosion, steam contamination and embrittlement. On a previous study, a test was conducted by using two different chemicals to treat the biodiesel wastewater, which are ferric chloride and ferric sulfate. The result from the study indicated that ferric chloride was found to be superior in removal of suspended solids, colour, chemical oxygen demand, oil and grease [5]. Meanwhile, this study aimed to analyze water quality in boiler and to suggest an optimal amount of chemical substance to be added in the boiler for promising good water quality. Also, it is aimed to analyze the total dissolve solid (TDS), potential of hydrogen (pH), total content of sulphate, iron and chloride, total hardness and alkalinity and the chemical needed to maintain a good water treatment in UTHM Biodiesel Plant's boiler.

2. Methodology

The purpose water treatment plan is to produce and maintain the composition of the water within the ideal range that will be the most beneficial to both mechanical equipment and the boiler system. The importance of water treatment for the steam boiler is, it cannot be overstressed. In operation of the steam boiler, water quality is important and need to be ensured in good condition [6]. In this experiment, the water treatment is measured by several types of the test kits. Based on the objectives, the measurement of total dissolved solids (TDS), the potential of Hydrogen (pH), sulphate content, total iron, alkalinity, and the total hardness need to be taken during the boiler starts operating for at least one time per week. There are 3 major points to take water samples which are raw water (Point A), externally treated water (softener water) (Point B), and boiler feed water (Point C). Table 2 shows the testing schedule for the experiment and Table 3 lists the specification of UTHM Biodiesel Plant's boiler.

Table 2 - Testing schedule

Test	Raw Water (Point A)	Externally Treated Water (Point B)	Boiler Water (Point C)
PH	Occasionally	Weekly	Weekly
Total Hardness	Once every two weeks	Weekly	Weekly
Total Alkalinity	Once every two weeks	Weekly	Weekly
Sulphate	Depends on variability	Depends on variability	Weekly
Chloride	Weekly	Weekly	Weekly
Total Dissolve Solid	-	Weekly	Weekly

Table 3- Specifications of Boiler (MechMar)

Classification	Types
Serial No	MS62231
Model	AS 125/150 (1250 PPH)
Design Code	BS 2790 1992
Inspection Authority	LLOYD’S Register
Year Manufactured	2009
Working Pressure	1.034/150N/mm^2/PSI
Design Pressure	1.069/155N/ mm^2/PSI
Date of H. T	06/07/2009

The apparatus used in this study are 25ml syringe, laboratory spatula and 1000 ml beaker. Meanwhile, ammonia buffer solution, total hardness indicator, EDTA solution, sulfuric acid solution, soluble starch, potassium iodide solution, FerroVer Iron reagent, potassium chromate solution, silver nitrate solution, phenolphthalein indicator solution, barium chloride solution, acetic acid solution, total iron disc and total dissolve solids meter have been used.

Before starting the operation of boiler, few types of chemical need to be added into the boiler. The chemicals are sodium hydroxide, sodium carbonate, phosphate salts, sulphate salts, nitrate salts, alginate salts, starch and glucose solution. Figure 2 (a) – (c) show the images of methods to add chemical into the boiler water.

Fig. 2 – (a) Sodium hydroxide solution is added into a container

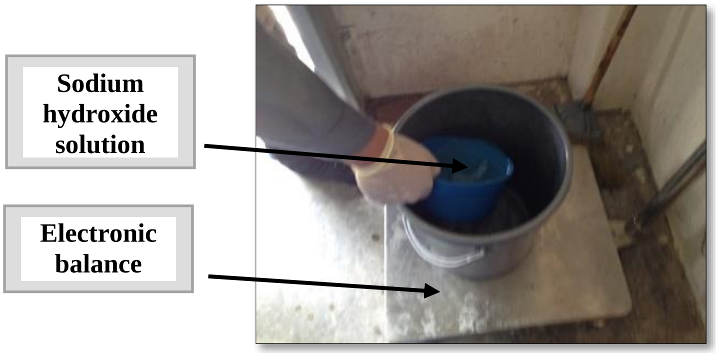

Fig. 2 – (b) Sodium Hydroxide solution is weighted by using electronic balance

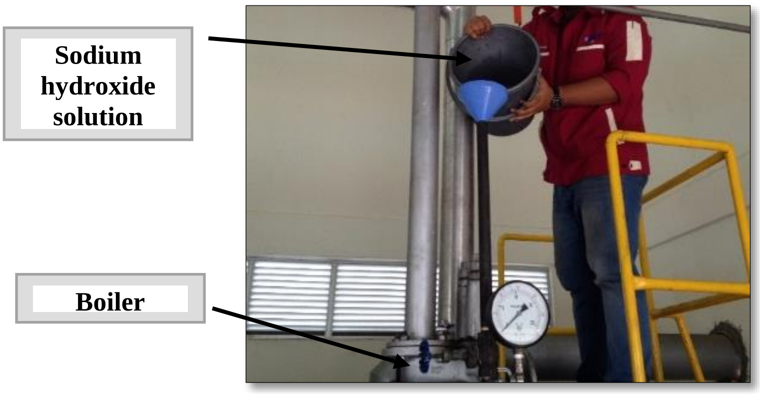

Fig. 2 – (c) Sodium Hydroxide solution is filled into the boiler

Initially, the boiler has been set up to raise steam at the required condition and allow the condition to stabilize. Next, water samples was taken when the boiler operated at 4 bars. After that, by using test kits, water samples were tested to determine the value of total dissolve solid, potential of hydrogen (pH), total hardness and other minerals that been mentioned earlier. Lastly, all the data was recorded in a data sheet.

3. Results and Discussion

The results were obtained from sampling process at three different places, which are raw water (Point A), softened water (Point B), and boiler feed water (Point C). All the data had been taken weekly by referring to previous study's recommendation. Water quality can vary tremendously from one region to another depending on the sources of water and local minerals. Before identifying the amount of chemical that need to be added, some factors such as pressure need to be considered. All the blow down process need to be discussed and understood, and it is necessary to take into account the condition of water and its impurities. Table 4 shows the values for boiler feed water as per the standard set by ASME (American Society of Mechanical Engineering) also the average quality of water value as recommended from ASME and ABMA (American Boiler Manufacturers Association).

Table 4- ASME Standard for Boiler Feed water

Recommended Boiler Water Quality					Recommended Boiler Feed water Quality		
Pressure (psi)	**Dissolved Solids (ppm)**	**Suspended Solids (ppm)**	**Alkalinity (ppm of CaCO3)**	**pH**	**Silica Range (ppm)**	**Dissolved Oxygen (ppm or mg/L)**	**Hardness (ppm of CaCO3)**
5-50	700-3500	50-100	150-700	8.0-10.0	15-25	<0.03	30
100	700-2000	10-50	140-500	8.0-10.0	15-25	<0.03	20
200	600-1500	5-10	120-400	8.0-10.0	10-20	<0.03	5.0
300	500-1000	3-5	100-300	8.2-902	7.5-15	<0.005	1.0

3.1 pH

The number of hydrogen when pure water dissociates is equal to number of hydroxyl ions. It also called as neutral solution. pH is defined as the negative logarithm of H+ ions. For the solution that having pH less than 7 are acidic and those greater than 7 are basic. Lower value of pH is corrosive but high value of pH can protect the pipe, but may cause scaling and deposits [7]. If the boiler water's pH value is too high, which is in alkaline region, it will have high tendency to form scaling. Meanwhile if it is less than 8.5, it will undergo acid attack that can cause pitting. Pitting can happen when iron oxide deposits on boiler surface. Low pH value happens by contamination of the boiler feedwater from hydrochloric and sulphuric acid that leaks in demineralizers and condenser of cooling tower water. Other than that, it also can happen when process leaks of acid materials into the return condensate system. Some water might experience turbidity due to suspensions of particles and this might also increase corrosion and might affect the pH values as well [8].

For extremely high pH value, which is around 12.90 it can cause caustic attack. Caustic attack is also known as caustic embrittlement. The material in boiler will becomes brittle due to present of caustic soda. It is usually found in phosphate treated boilers in deposits form of phosphate or other scaling occur in high heat transfer areas. If it is coupled with significant heat flux, the concentration of the boiler water occurs rapidly speeding the corrosion. The results of formation caustic-ferritic compounds through the dissolving of the protective magnetite film. Figure 3 shows the pH values for three sampling points which are, boiler water, softener water and raw water.

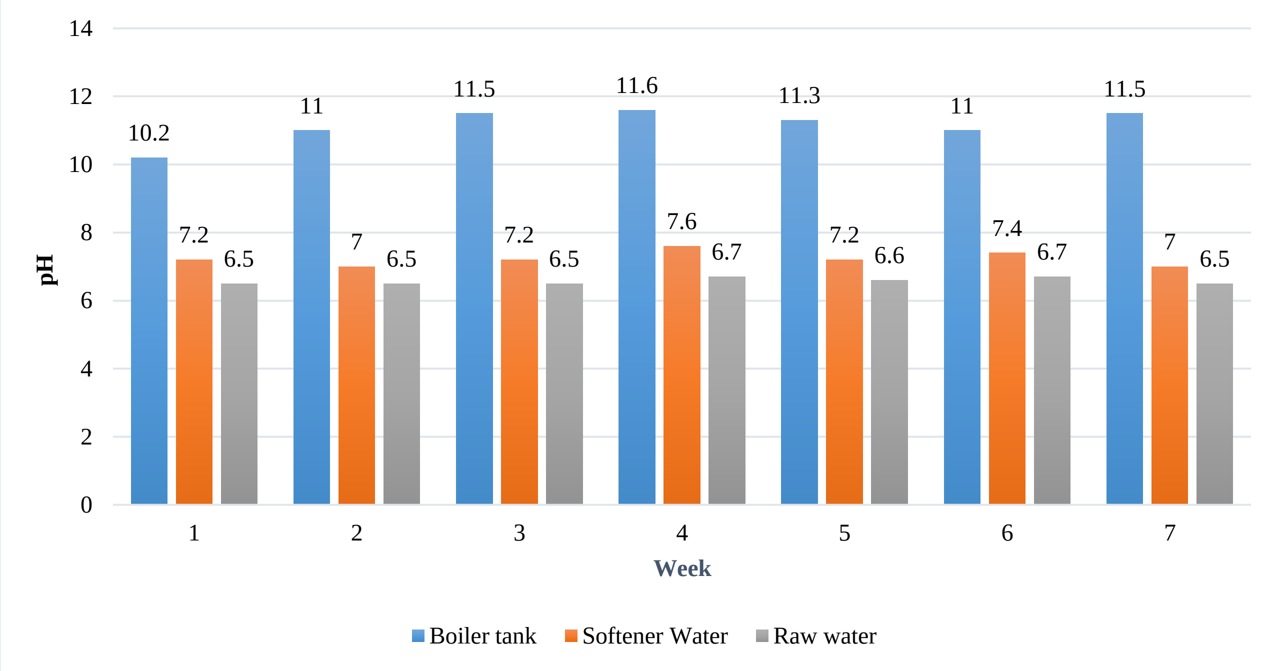

Fig 3 – pH values

According to Fig 3, the value of pH in boiler water is higher than others. The recommendation limit of pH value in boiler water is in between 10.0 until 11.50 range. Meanwhile, for softener water is in between 7.00 until 8.00 range and for raw water usually in 6.50 until 8.50 range. For the first week, the pH value is equal to 10.20. This is due to the boiler was set in standby mode and wet condition since the operation was shut down for 3 months.

To ensure the pH value will not decrease when the boiler is under operation, sodium hydroxide solution need to be added into boiler water. The recommendation amount of sodium hydroxide is 1.5 kg but if the value of pH is still not suffice, the amount is increased to 2.0 kg.

3.2 Total Dissolve Solids

Dissolve solid or salt content of water present as ions increases electrical conductivity of water. The higher the conductivity, the greater the potential for corrosion. Higher value of total dissolve solids will reduce heat transfer rates, increase scale deposits and will increase the heat losses. The suspended and dissolve solids are two different types of substance but accounted as total dissolve solid values.

When boiling process happens, it will produce bubbles. The bubbles that formed will reach to the surface of the water and detach themselves from the surface. The bubbles produced represent the total dissolve solid in boiler water, it carries solids and formed during boiling process that will cause reduction of the heat transfer rates. Figure 4 shows the TDS values in boiler water, softener water and raw water.

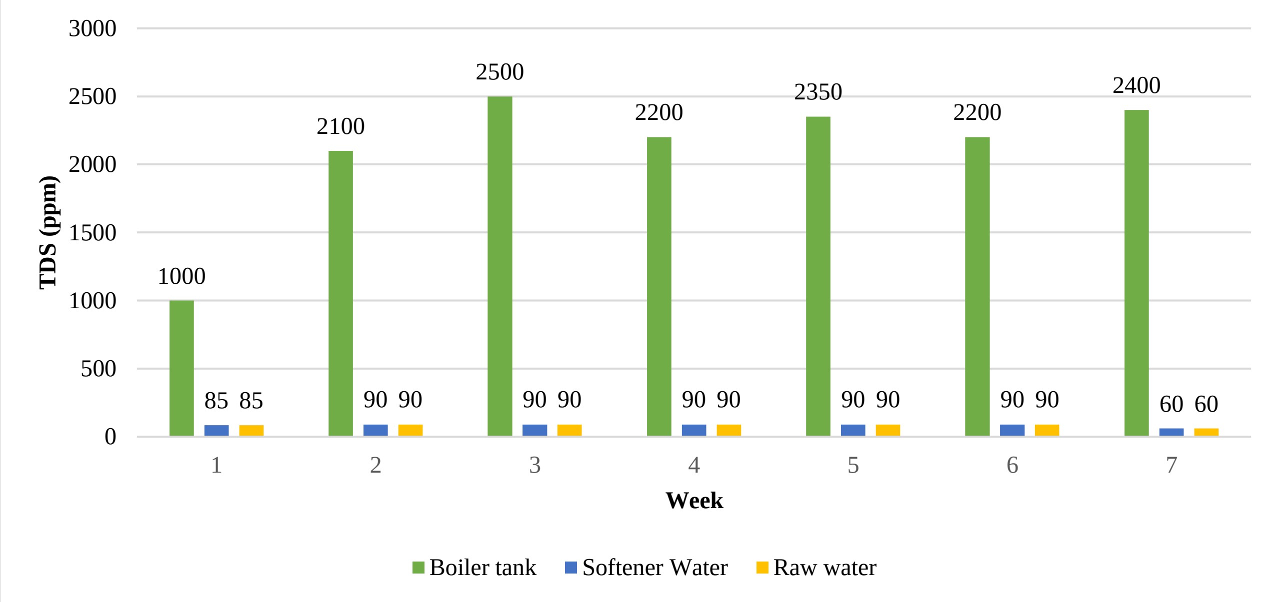

Fig 4 - Total dissolve solids values

Based on the Figure 4, TDS value of boiler water is higher than softener and raw water. This is because, there are forms of substance in the boiler water. For softener and raw water, the TDS values remain constant.

3.3 Total Hardness

Hardness is the formation of calcium and magnesium minerals. These two minerals can primarily be responsible for scale formations in boiler tubes. The main minerals for hardness is calcium and magnesium but there are also other metallic ions like iron and manganese. There are two categories of total hardness which are carbonate or temporary hardness and non-carbonate or permanent hardness.

For carbonate or temporary hardness, all the calcium and magnesium bicarbonate are in the form of alkaline hardness. The minerals that dissolve in water will form an alkaline solution. When boiling process started it will decompose and release carbon dioxide, soft scale or sludge. Meanwhile, for non-carbonate hardness, it is also in a form of salts from calcium and magnesium but in different ways, such are in the form of sulphate and chloride. This decreases the solubility as the temperature increases. Hard scale will be formed, and it will difficult to remove.

Between these two types of hardness, temporary hardness is commonly present in the boiler water system. Other minerals such as silica also can cause hard scale to the boiler surface tubes. It can react with calcium and magnesium salts and will form silicates. It can inhibit heat from transferring through the fire tubes and will cause them to overheat. Indirectly, this can reduce the boiler efficiency.

The recommendation limit for total hardness is below than 2.0 ppm, but in this experiment, the values obtained were zero for Point A, B and C at every weeks. This is due to the factors that the water supplied to the boiler was treated.

3.4 Chloride and Sulphate

Chloride and sulphate ions inhibit the formation of scale by keeping hardness ions in solution. Tracing the amount of chlorides, even with dissolved oxygen can cause corrosion in boiler. The chloride ion is one of important substance that need to be control. This is because, chloride ion will cause generation of scale formation.

Chloride ions has high degree of dissolution. If the value of chloride ion is not less than 250 ppm, possibility of scale formation is high. If the value of the chloride ion is uncontrollable, it will be difficult to remove them in the later stage. Other than that, chloride and sulphate ions has high corrosion rates in galvanic series. For this study, sulphate content is only being measure in boiler water (Point C), meanwhile for chloride content is being measured in all types of water. Figure 5 shows sulphate contains in boiler water and Figure 6 shows the values of chloride at Point A to C.

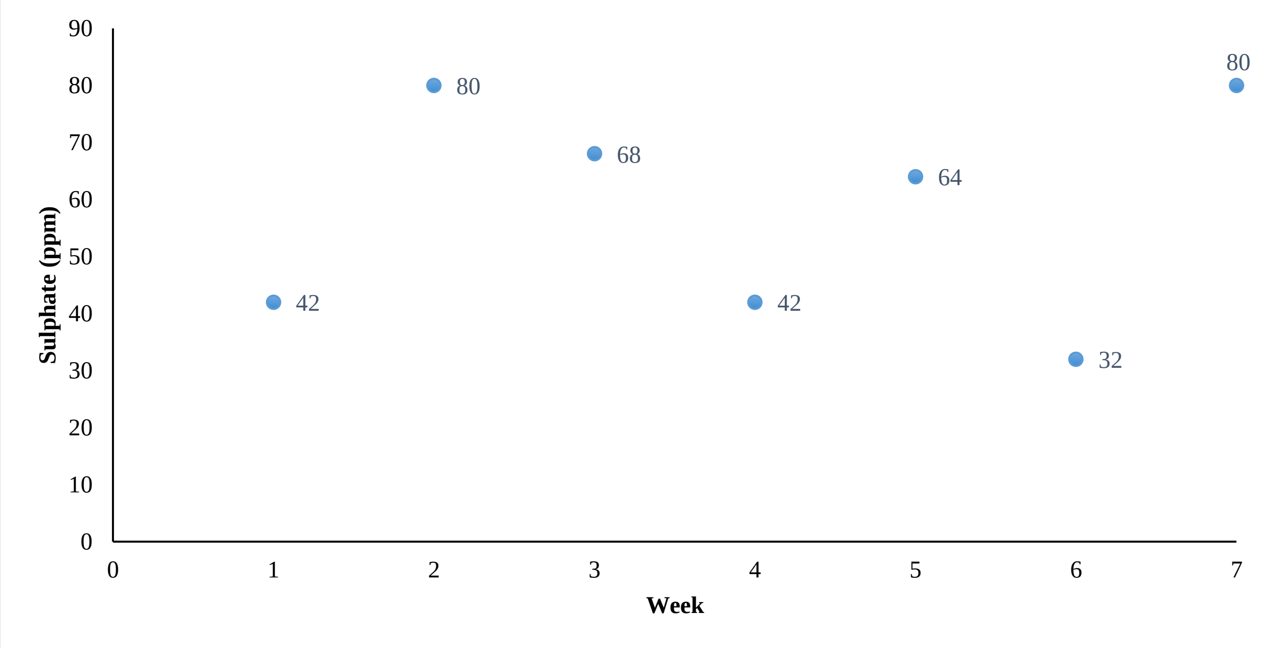

Fig 5 - Sulphate values at Point C

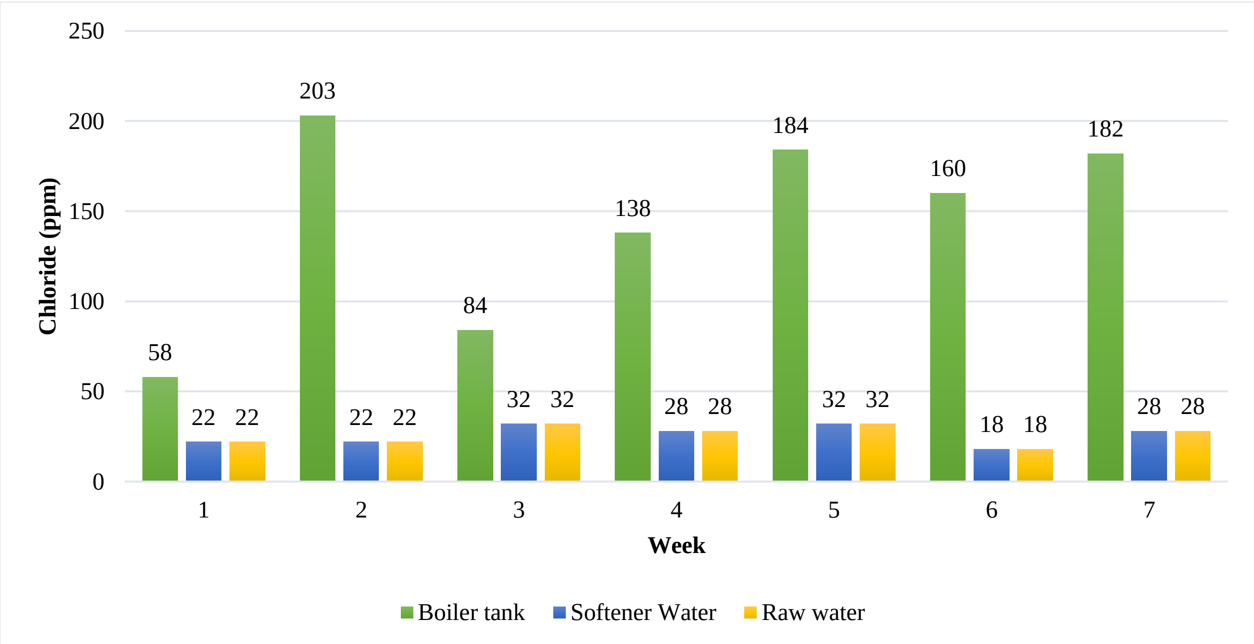

Fig 6 – Results of chloride test in boiler water, softener water and raw water.

The recommendation limit for sulphate content in boiler water is within 20 to 80 ppm. All the data obtained as shown in Figure 5 was within the accepted range. According to Figure 6, all the values of chloride is below than recommendation limit (250 ppm). If the values of sulphate ion are not in range, the pitting corrosion will occurs and it is recommended to conduct blowdown process.

3.5 Total Iron

The impacts of total iron come in two forms, which can be soluble or insoluble. Insoluble iron in boiler feed water may clog strainers and valves and can cause sludge build up in some areas of a water system. Other than that, boiler deposits and tube failure also can occur. Meanwhile, for soluble iron it will leave stains in domestic water system at very low levels. However, boiler surface has protective layer to lower the corrosion rate. If the value of iron is not controlled, the iron oxide will react with the protective film and will penetrate it due to the protective layer is very porous. When the protective layer has reacted with iron oxide, it will allow the boiler water to easily seep through and convert into steam leaving dissolve solids in concentrated areas. This problem will lead to metal failure and dissolution. Figure 7 shows the data collected for total iron.

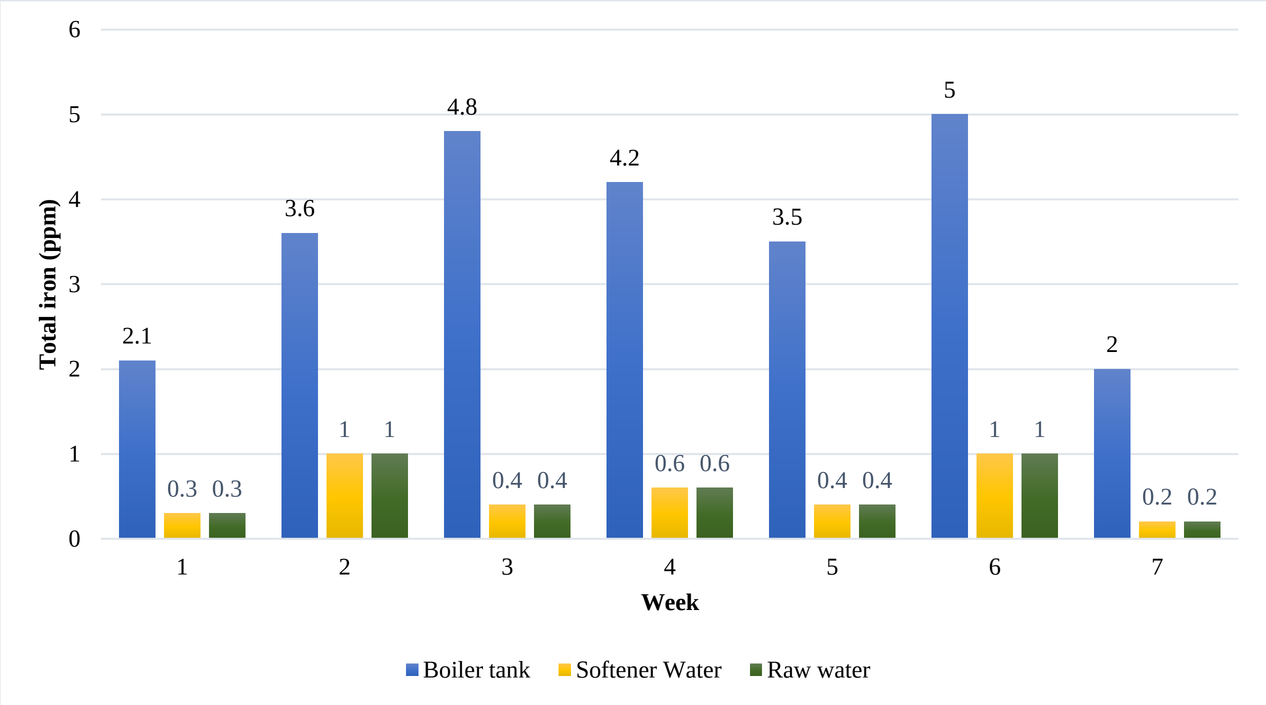

Fig 7 - Total iron values

According to Figure 7, the values of total iron in raw water and softener water is constant. This is due to the water supplied is well treated and flow through into the softener tank. The softener tank will not eliminate the presence of iron. The recommended limit for total iron is below than 5.0 ppm. For week 6, the total iron in boiler water is equal to 5.0 ppm. To ensure that the total iron will not keep increasing, alginate has been added.

2.6. Alkalinity

Alkalinity in water is due to presence of bicarbonates, carbonates and hydroxyl ions. Basicity in raw water is mainly due to bicarbonates and sometimes carbonates ions may also present. There are two types of alkalinity that needs to be control. For boiler water system, hydrate alkalinity needs to control.

Hydrate alkalinity value must maintain within the recommendation value as it will ensure the boiler water is soft and easy to remove deposits that formed in boiler water. The value of hydrate alkalinity must be in range to avoid excessively high concentration, this will result in foaming difficulties and caustic corrosion of boiler parts. Figure 8 shows the data for hydrate alkalinity content in boiler.

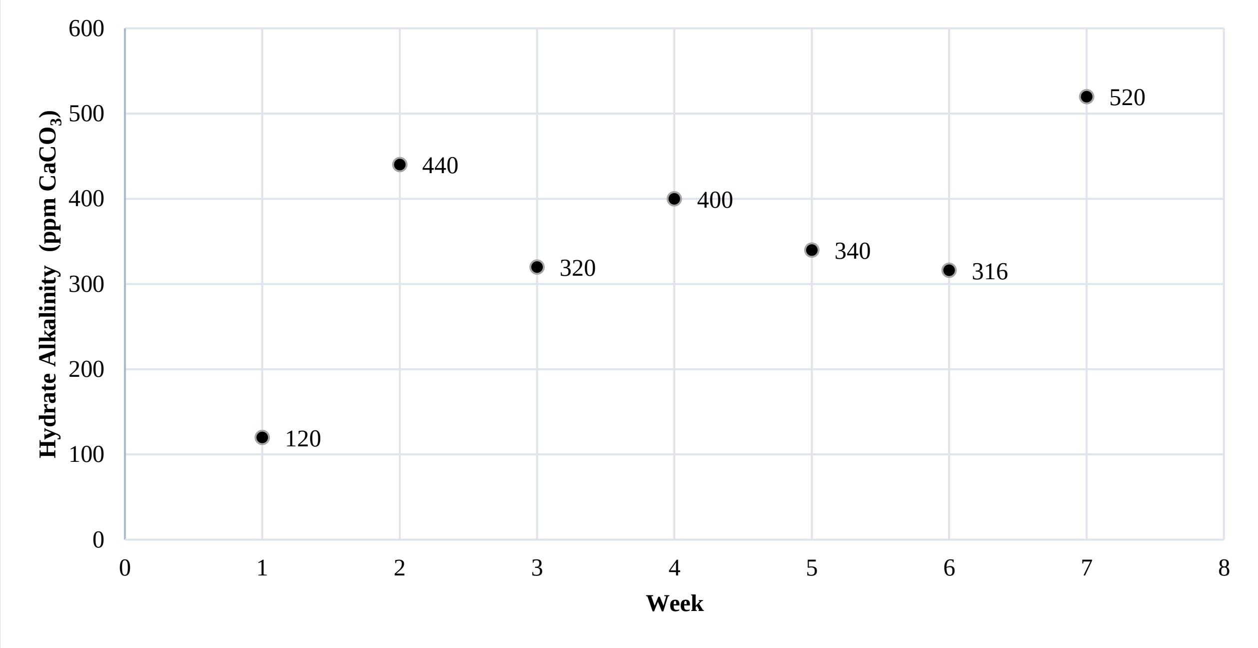

Fig 8 – Hydrate alkalinity values

The recommendation limit is in between 100 until 400 ppm. For week 2 and week 7, the value of hydrate alkalinity has reach beyond the limit. To reduce the value of hydrate alkalinity, blowdown process need to be done. Hydrate alkalinity was found increased because of the alkalinity presence in boiler water system is too high.

3.7 Type of Chemical Added

After analyzing the water quality analysis in boiler water, externally treated water (softener water) and raw water, the amount and type of chemical can be determined. Each of the element testing has its own type of chemical to be added to ensure the values are within recommendation values. The brand of chemical that has been added is bmSolution. Table 5 shows the type of chemical and its function.

Table 5 - Type of chemical for water quality treatment

Chemical	Function	Chemical Code	Amount
Sodium Hydroxide And Sodium Carbonate (Soda Ash)	• Increase alkalinity • Increase potential of Hydrogen (pH) • Decrease Magnesium ions	BL 210	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg
Phosphate Salts	• Decrease Calcium Ions	BL 802	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg
Sulphate Salts	• Eliminate presence of oxygen that can cause corrosion	BP 100	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg
Nitrate Salts	• Prevent caustic attack	BL 802	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg
Aliginate Salts	• Prevents deposits • To Produce contaminated sediment fluid that not easily	BL 802	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg

	attached on the boiler surface		
Tannis, starch, glucose	• Decrease forming of bubbles in boiler water	BL 802	Boiler Tank: 1.5 – 2.0 kg Softener Tank 0.5 – 1.5 kg

4.0 Conclusion and Recommendations

The aim of the present research was to examine the water quality in UTHM Biodiesel Plant's fire-tube boiler. It is important to maintain an excellent quality of boiler water to avoid negative effects to boiler system such as corrosion in boiler pipes [9]. There are certain parameter that need to be controlled such of potential of hydrogen, total dissolve solids, total hardness, sulphate content, chloride, total iron content and total alkalinity. This study has found that to maintain a good efficiency of boiler system, a properly schedule water treatment need to be carried out. A further study could assess the quality of steam by basic principal [10]. For example, the concentration of wet steam need to be measured to ensure that the undesired minerals were not carried by the steam. Although the current study is based on the UTHM Biodiesel Plant's boiler, the findings can be used for other boilers to for water treatment plan. Further research could also be conducted to determine the effectiveness of boiler and its relation to boiler water treatment plan.

Acknowledgement

The authors acknowledge the financial support from the Universiti Tun Hussein Onn Malaysia. The authors would also like to thank the Research and Management Centre of Universiti Tun Hussein Onn Malaysia for supporting this research under TIER 1 Grant Vot U869.

References

[1] Rayaprolu, K. (2012). Boilers: A Practical Reference: CRC Press.
[2] Rayaprolu, K. (2009). Boilers for Power and Process. (1st ed). Boca Raton: CRC Press.
[3] Seri, S.M., Batcha, M.F.M. & Raghavan, V.R. (2009). Heat Transfer Studies in Tube Banks with Integral Wake Splitters. International Journal of Integrated Engineering, 1, 23-29.
[4] Malek, M.A. (2004). Power Boiler Design, Inspection, and Repair. (1 ed): McGraw-Hill Education.
[5] Daud, Z., Nasir, N., Kadir, A.A. et al. (2017). Treatment of biodiesel wastewater using ferric chloride and ferric sulfate. International Journal of Integrated Engineering, 9, 54-57.
[6] Ahmed, M.A. & Babiker, M.E. (2017). Effect of Boiler Feed Water Quality in Textile and Other Industries. Gezira Journal of Engineering and Applied Sciences, 12, 1-15.
[7] Port, R.D., Herro, H.M. & Company, N.C. (1991). The Nalco guide to boiler failure analysis: McGraw-Hill.
[8] Asharuddin, S.M., Othman, N., Zin, N.S.M. et al. (2018). Performance assessment of cassava peel starch and alum as dual coagulant for turbidity removal in dam water. International Journal of Integrated Engineering, 10, 185-192.
[9] Ismon, M., Chai, R., Ismail, A.E. et al. (2018). Thermal Gradient Pattern of Shallow Pitting Via Active Thermography–Hot Water and Steam. International Journal of Integrated Engineering, 10, 138-142.
[10] Ganapathy, V. (2002). Industrial Boilers and Heat Recovery Steam Generators: Design, Applications, and Calculations: CRC Press.