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RESEARCH ARTICLE

# Data Driven Technique for Palm Oil Mills Boiler Water Quality Monitoring in the State of Perak Malaysia

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Abstract A steam boilers are widely used in oil palm mills industries which physically convert the water into steam. However, heating water in the boiler allows solid waste such as potassium, calcium, magnesium, silica and ions to stay in the boiler and creates a solid waste layer that coats the tubes and boilers. This strong and thick coating would increase the heating surface of the boiler and decrease the efficiency of heat transfer. This situation will also increase the fuel consumption, causing the boiler to overheat, which leads to tube failure. The impact of this issue will cause losses to the oil palm plantation due to the shutdown of unplanned plants. Therefore, for this study, Statistical Process Control (SPC) has been utilized to monitor the quality of the six parameters of the boiler and boiler feedwater for palm oil mill in Perak State Malaysia to overcome the problem stated above. Boxplot has been utilized to continuously monitor the parameter based on the data's probability distribution according to ASME guidelines. This analysis shows that some palm oil mills can maintain their boiler quality accordingly; however, controlling the silica, hardness and total iron, need further improvement.

**Keywords**: Data-driven approach, Statistical process control, Boiler feed water, Data management, Boiler water quality.

## Introduction

Malaysia can be considered as one of the biggest palm oil producers, globally. This fact brings a lot of economic benefits to Malaysia as palm oil can be taken as the highly traded oil in the whole world because it almost consists of 35 % of the global vegetable oil market [1]. The efficiency and the versatility of palm oil massively contribute to this phenomenon. In comparison with rapeseed, sunflower and soya crop, palm oil exhibits a tremendously higher production capacity, approximate 10 tonnes per hectare of land. This made justification that the efficiency of palm oil production as it requires almost ten times lesser land in contrast to the remaining three major oil production in Malaysia. In terms of versatility, palm oil is greatly versatile. This is because several products possessing distinguishable characteristics can be formed by processing palm oil trees [2]. It is studied that Malaysia uses small boilers for the generation of electricity and processes for the extraction of palm oil. Usage of boilers is rising in the palm oil industry as years passed as it produces steam in huge quantities. The steam generated from boilers is mainly used for heating and in electric power supply stations as well as part of the process in the palm oil industry [3].

As stated, the palm oil mill in Malaysia most generally utilizes small boilers. Small boilers are boilers with low volumetric capacity. The most common boiler used in a palm oil mill in Malaysia is the water tube boiler. The water tube boilers are principally utilized for creating steam with high temperatures and pressure. Therefore, treating boiler feed water before it enters its boiler is a necessity in all industrial applications that is present globally. Water treatment acts as an essential technology that should be practised in any chemical industry. Poor water treatment of feedwater may lead to very unsafe scenarios, especially in terms of economic and environmental aspects. The demand for the quality of boiler feed water is constantly varying based on the type and working pressures of the boiler exhibits. In general, colourless and clear water should be ensured by averting suspended solids, contaminants, oils, aggressive and toxic chemicals [4]. Mostly, all feed water that enters the boiler in Malaysia is from raw sources such as raw water from rivers, wells or even lakes surrounding the plant. In specific for the

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State of Perak, most of the palm oil mill industry was nestled around natural rivers.

The amounts of suspended solids and dissolved gases available in natural waters vary with the source of the raw water and the location of the source is situated. The main reason behind the requirement for pre-treatment of water is to avoid deposition, and corrosion of the boiler system and to avert carryovers at all costs [5]. This is since the evaporation of water in the boiler leads to the concentration of impurities. Poor quality of feed water engenders the quality of steam being produced by the boiler and may reduce the quality of the product of a particular process. In many industrial applications, pre-treating the feed water has exhibited positive and successful operations [6].

Therefore, the boiler and boiler feed water (BWF) must adhere to the requirement of the Department of Occupational Safety and Health (DOSH) and the American Society of Mechanical Engineers (ASME). DOSH is a department under the Ministry of Human Resource of Malaysia and a primary government agency that deals with administrating and enforcing legislation that is related to occupational safety and health of Malaysia. Furthermore, ASME guidelines are extremely important in defining the quality of boiler and boiler feed water. Many problems can be emanated from boiler and boiler feed water that does not adhere to ASME guidelines [7]. These boiler feed water problems are inclusive of poor efficiency when dealing with the transfer of heat. Lower efficiency also leads to elevated fuel costs, and increasing temperature to achieve precise pressure, which can lead to tube failure and unplanned shutdown.

Thus, to monitor strictly the boiler and boiler feed water quality used in all these palm oil mills, a data-driven approach using statistical process control is proposed to investigate and analyze the data obtained from these palm oil mills qualitatively to identify the inadequate and insufficient treatments or maintenance done to the boiler feed water and the boilers [8].

The paper is organized as follows: Section 2 presents the case study which is the boiler water quality data for the State of Perak Malaysia. Section 3 presents the data-driven approach using the statistical Process Control (SPC) approach which consists of the box plot and correlation coefficient analysis. The result and discussions on the outcomes of the proposed technique are given in Section 4. Finally, the last section concludes this paper.

## Materials and methods

### *Case study: Palm Oil Mills Boiler Water and Boiler Feedwater Quality in Perak State, Malaysia*

This study focuses on the quality data analysis of boiler feed water of 39 palm oil mills in the state of Perak, Malaysia. In this case study, the parameters being investigated are inclusive of pH, total dissolved solids (TDS), hydrate alkalinity, total hardness, silica and total iron as tabulated in Table 1 with its respective units. The duration of the data of samples collection is monthly from the year 2017 to 2019. In this study, the minimum pressure of the boiler is 319 psig and the maximum is 450 psig, therefore the ASME guidelines for boiler and boiler feed water quality are based on the range of boiler capacity 300 to 450 psig. In addition, out of 39 plants, 28 plants use water from the river as raw water for their respective boiler. The remaining 11 boilers use a tube well and water supply by Perak water supply.

**Table 1** Parameters being investigated with their respective units (ASME)

| Attributes | Sample Location | Control limit (ASME) |
|---|---|---|
| Silica | Boiler | < 90 ppm $SiO_2$ |
| Total Dissolved Solid (TDS) | Boiler | 500- 3000 ppm |
| Hydrate Alkalinity | Boiler | 100-600 ppm $CaCO_3$ |
| Total Hardness | BFW | <0.3 ppm $CaCO_3$ |
| pH | BFW | 10-12 |
| Total Iron | BFW | < 0.05 ppm |

## Data-Driven Approach for Monitoring: Statistical Process Control (SPC)

What does SPC mean? SPC stands for Statistical Process Control where it does not apply to a specific method, algorithm or process, it is an optimization theory that discusses continuous process changes, using a collection of (statistical) data and process analysis methods to draw conclusions about the decision-making process behaviour. In total quality programs, SPC is a key component where SPC essentially strives to increase profit by improving the quality of goods, improving efficiency, streamlining procedures, reducing waste, reducing pollution, improving customer service, etc. Therefore, for this study, SPC has been utilized to monitor the quality of the parameter of the boiler and boiler feed water for the palm oil mill in Perak State Malaysia. Boxplot has been utilised to monitor continuously the boiler and boiler feed water parameters based on the probability distribution of the data [9,10]. The probability of a sample having a particular value is given by its location on the box plot. The main assumption is that the plotted statistic is normally distributed, the probability of a value lying beyond the:

1. Warning limits are approximately 0.025 or 2.5% chance
2. Control limits are approximately 0.001 or 0.1% chance,

This indicates that the variation is due to an assignable cause that the process is out-of-statistical control. This range should ideally be built into the design and operating procedures of the process aims to reduce or remove the effect of potential causes of process variability. As for this study, it should be the potential causes that contribute to the deviation of the parameter from its upper and lower limit and ASME guidelines. Therefore,

$$\text{Upper Control Limit (UCL)} = \mu + 3 * (\sigma/\text{sqr}(n)) \tag{1}$$
$$\text{Lower Control Limit (LCL)} = \mu - 3 * (\sigma/\text{sqr}(n)) \tag{2}$$

where

n is the subgroup size and for this case is based on the total number of the plant which is 39.

μ = mean

σ = Standard deviation

To cope with different magnitudes in the data, all the data were normalized to zero mean and unit standard deviation. On the other hand, the correlation coefficient parameter is used to analyse the correlation between the variables in boiler and boiler feed water and to determine what is the most significant parameter affecting the boiler characteristics [11]. Based on this data analysis, the boiler operator will be able to monitor the parameter closely and be able to determine the root cause of the problem.

## Box Plot

Boxplot analysis is a systematic method of displaying the distribution of data based on five summaries of numbers. The minimum, first quartile, median, third quartile and maximum are included in this five-number overview. Mainly, for this study, box plot analysis is utilised to provide a view of the tightness of the data grouped and data's skewness if exists. In this study, a Matlab$^{TM}$ box plot is used to generate the figure. The Matlab$^{TM}$ box plot analysis command is *boxplot(x)* where *x* is the data box plot is generated [12]. Therefore, in this study, *x* is the data for 6 parameters from the year 2017 to 2019, then from the boxplot, the variation of the parameters can be analysed whether it is within the limit required by ASME or not, then the conclusion can be made whether the operator who operates the boiler treated properly the raw water to ensure the quality of the boiler.

## Correlation Coefficient Analysis

The correlation coefficient varies between -1 and +1. The intensity and direction of the linearity between two separate variables are indicated by this coefficient and its comparison of the two variables is either negative or positive in the correlation. This coefficient sign serves as an indicator of the direction of the linear relation between the consistency of palm oil mill boiler feed water variables and ASME boiler guidelines whereas the value of the coefficient represents the strength between the variables involved. In this study, the Matlab$^{TM}$ function for the correlation coefficient analysis tool is used to compute the correlation coefficient for each variable and *corrcoef(A)* is the Matlab$^{TM}$ command for correlation coefficient analysis [13]. *A* consists of matrix data of the variables $x_1, x_2, .., x_n$ and the correlation coefficient of $x_1, x_2, .., x_n$ variables will be computed. Generally, for a data set of *x* and *y,* the correlation coefficient can be determined by computing the equation (3) below

$$Correlation\ coefficient, r = \frac{n\Sigma xy - \Sigma x \Sigma y}{\sqrt{n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2}} \quad (3)$$

# Results and discussion

## Overall Data-Driven Approach: Statistical Process Control (SPC)

Owing to problems of scaling, corrosion and foaming, boiler feed water quality is limited. The consistency guidelines from ASME and the heuristic have been implemented to prevent these problems. Table 2 shows the normalized statistical data for SPC analysis where the upper control limit (UCL) and lower control limit (LCL) were calculated for the boiler and boiler feed water characteristics.

It clearly shows in Table 2 that hardness and total iron, the variation of the parameters in boiler and boiler feed water is high where the normalised maximum values for both are 22.72 ppm and 9.83 ppm respectively. For example, the mean values for total iron should be -0.93 or less, but the normalised mean values of the data in plants show 0 ppm, which shows the variation of the data sample in all plants varies quite significantly. In other parameters, the mean values are within the UCL and LCL limit and close to values in ASME guidelines.

**Table 2** Normalized data for statistical process control (SPC) analysis.

| Sample Location | Attributes | Control limit ASME | Min | Max | Mean | Standard deviation |
|---|---|---|---|---|---|---|
| Boiler | Silica | < 0.34 | -1.77 | 4.58 | 0 | 0.77 |
| Boiler | Total Dissolved Solid (TDS) | -1.47 to 1.89 | -2.01 | 9.42 | 0 | 1.15 |
| Boiler | Hydrate Alkalinity | -1.41 to 1.11 | -1.82 | 7.64 | 0 | 0.9 |
| BFW | Total Hardness | <-0.33 | 0 | 22.72 | 0 | 10 |
| BFW | pH | -1.51 to 1.72 | -6.35 | 3.33 | 0 | 0.62 |
| BFW | Total Iron | < -0.93 | 0 | 9.83 | 0 | 1.48 |

As mentioned previously, the boiler feed water should exhibit a certain range of qualitative parameters to maintain the functionality, and improve efficiency and the total life span of boilers used in palm oil mills. Thus, if the quality of boiler feed water is adequate; the blowdown frequency of the boiler can be reduced and the cost of maintenance can be alleviated. Therefore, to closely monitor and observe whether the boiler water quality adheres to the ASME guidelines, SPC with the box plot and correlation coefficient is proposed.

## Box plot analysis

### Silica

The main goal of internal treatment for managing residual silica in the feed water is to keep it from volatilizing in the steam. If the silica content in steam reaches the normalised value of 0.34 ppm, problematic deposits can form in the boiler's steam drum. Silica volatility is proportional to the concentration of silica in the boiler water and the operating pressure, but inversely proportional to the pH of the water. Many operators tend to be cautious with silica concentrations because the drum sizes are so problematic. As a result, monitoring and estimating the concentration of silica in boiler water has become a valuable parameter to track. Under operating conditions, these silicate deposits adhere to the boiler tubes and bake to form a highly insulating and tenacious deposit with potentially damaging consequences [13]. In addition, the solubility of silica in steam increases with increasing temperature or density. Therefore, silica scales on engines, drum shells, and tubes are extremely difficult to remove. As for the silica, the ASME limit is within the UCL, but some of the silica values for plants 1,4,7,10,19,24,29, and 35 are above the ASME limit as shown in Figure 1. According to the data collected, the plants fed water from the river and a tube well and we can infer that the higher silica is due to the high silica concentration in feed water or variance of the silica from the source of the raw feed water.

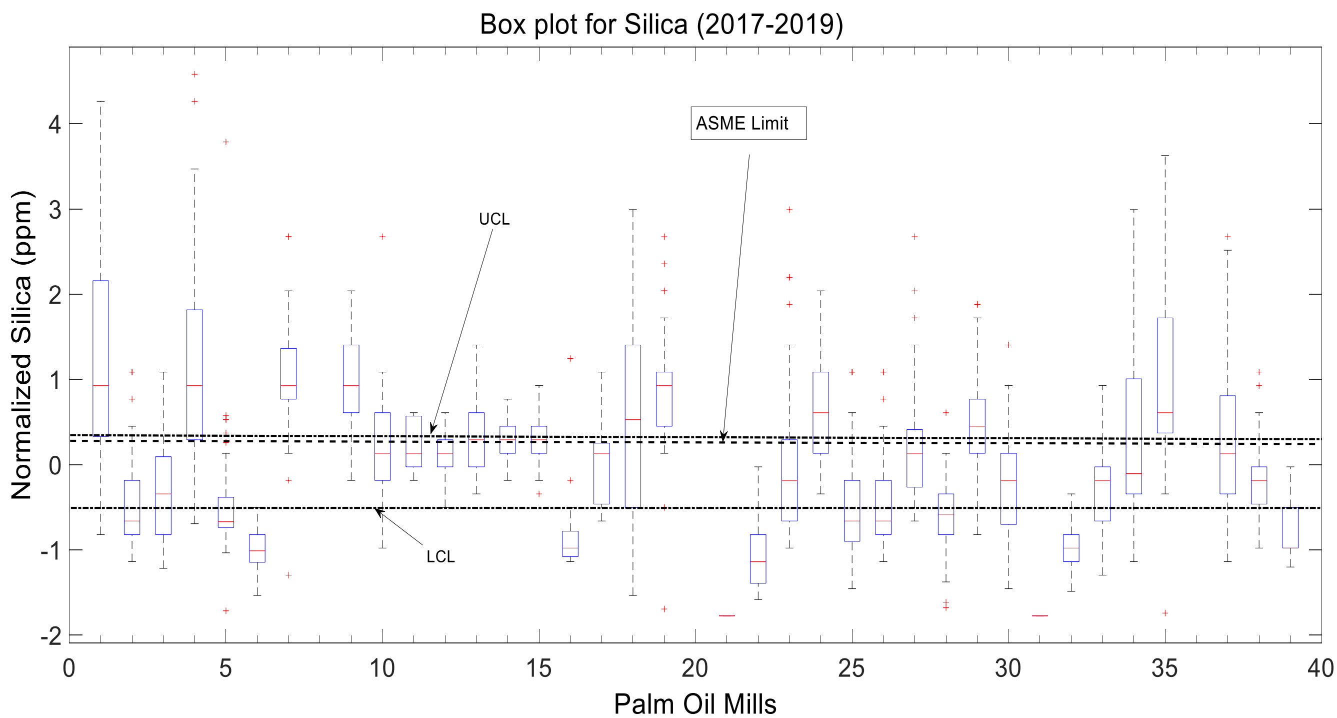


**Figure 1.** Plot Normalized Silica data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for Silica.

The operator of palm oil with a higher silica content could take countermeasures to minimise high silica levels in the boiler water. For example, they can install a silica remover tank at external water treatment but it is expensive to install and fabricate. The other way is to do blowdown based on the cycle of concentration of silica inside the boiler water to decrease the amount of silica in the water boiler and to prevent scaling at drum and tube.

## Total Dissolved Solid (TDS)

TDS or total dissolved solids is referring to the total volume of minerals and ions in the water. The amount of TDS in the water is another factor that needs to be considered when ensuring the full boiler water regulation. The amount of TDS is used to calculate the blowdown rate and it is depending on the temperature and pressures of the boiler, as well as the polymer chemistry. TDS monitoring efficiently is beneficial to the whole plant. Figures 2 shows the profiles of TDS in the palm oil mills boiler, it's clearly seen from the profiles that generally TDS values are in range except for plant number 10. It shows that the operator of the boiler is able to operate the boiler with good control of TDS which can enhance the boiler operation. A significant amount of energy savings can be achieved by allowing the TDS to rise to certain unacceptably high levels. In order to regulate TDS, a compromise has to be sought between a high TDS level with its associated operating economy and a low TDS level that minimises foaming. If the TDS boiler water rises, the steam bubbles become more stable and more hesitant to burst and separate. As the water boils, there will be steam generation. The dissolved solids may not be fully extracted, which means that the deposition of these solids may be deposited on the boiler which may contribute to the boiler scaling. The boiler will break down or the boiler tubes will be damaged as a result of scaling. Therefore based on the profiles in Figure 2, the operator for the whole 39 boilers manages to control the TDS accordingly.

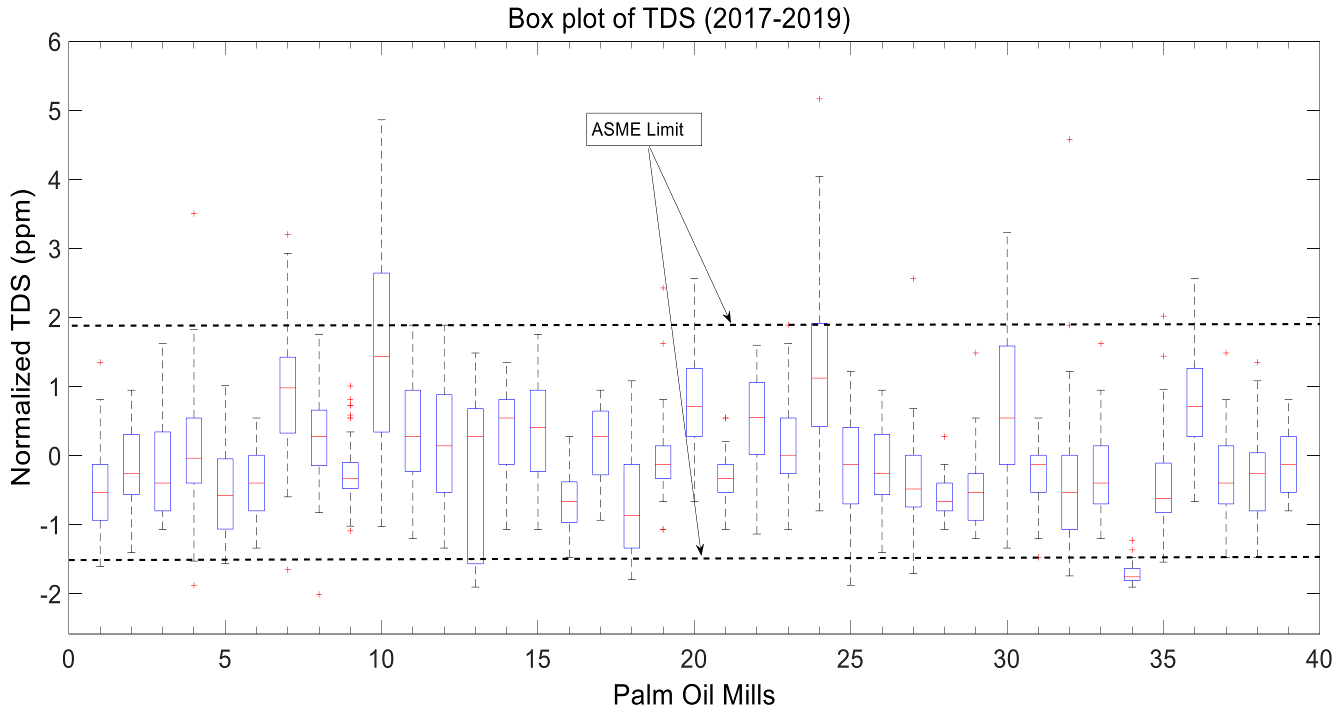


**Figure 2.** Normalized TDS data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for TDS.

However, to make it better in terms of controlling TDS, the operator is advised to calculate the period of concentration in order to perform sufficient blowdown to remove TDS from boilers [14]. It can assist the boiler operator in preventing scale accumulation in the drums and tubes, reducing high operating costs due to low heat transfer, and avoiding boiler damage.

## Hydrate Alkalinity

In the boiler, sodium hydroxide creates a highly alkaline atmosphere. This is probably the only place where water and steel get along. Heat accelerates chemical reactions, amplifying the naturally corrosive effect of water on steel. Water's highly corrosive impact is minimised by maintaining the proper alkalinity range. The addition of sodium hydroxide to the chemical programme is also the source of the majority of boiler water alkalinity [15]. Normal alkalinity present in raw water sources contributes to some of the alkalinity. Since alkalinity is the indicator of the presence of bicarbonate and carbonate ions in the boiler feedwater, it must adhere to ASME guidelines. In hot boiler water, carbonates and bicarbonates decompose to carbon dioxide and the hydroxyl ion. The former is carried away by the steam, while the latter remains submerged.

$$CO_3^- + H_2O = 2OH^- + CO_2 \tag{4}$$

The free caustic or caustic reserve method of alkalinity control is named after the hydroxyl ion produced by the reaction in equation (4), which produces a pH of 11-12 in the boiler water. To avoid unnecessary surface tension and concomitant carryover, it is critical to calculate and limit the total alkalinity of the boiler water under these conditions. The total alkalinity is maintained between 10% and 20% of the total dissolved solids concentration and can be adjusted by raising or decreasing the dosage used for chemical softening or changing the rate of acid addition before cation exchange softeners.

In the boiler, these ions can react with other cations to form scale. The alkalinity of boiler water should be high enough to prevent acidic corrosion of the shell and plates, but not high enough to cause carryover. High boiler alkalinity (greater than 700 PPM) should be avoided. Values higher than this will cause the steel to become brittle. Figure 3 below shows the profiles of the hydrate alkalinity of the plant and its shows that the boilers of the plant are in a good chemical programme except for plants 4, 10, 11, 12, 13, 14, 18,20, and 36. Most of the hydrate alkalinity is within the range of ASME guidelines.

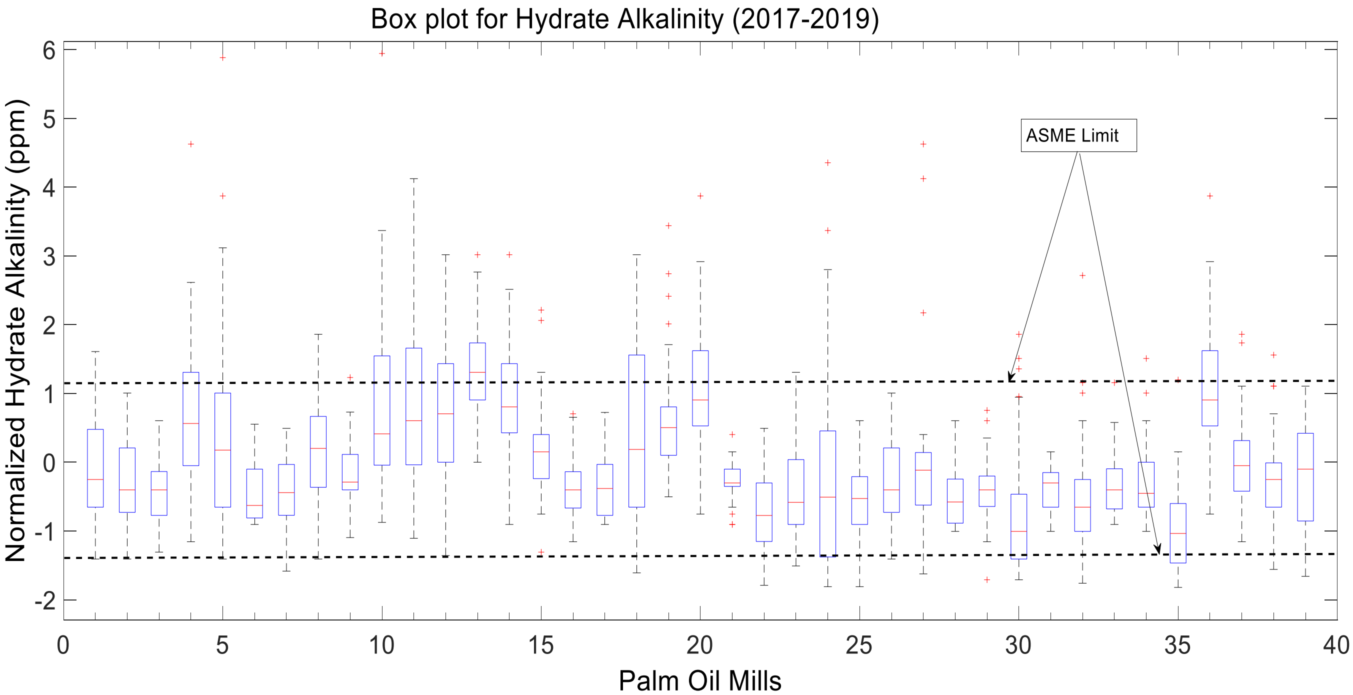


**Figure 3.** Normalized Hydrate Alkalinity data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for Hydrate Alkalinity.

This plant's operator should exercise greater caution when handling chemical programmes and ensure that ion hydroxyl values are within reasonable limits to avoid harm to boilers and the unusual corrosion pattern of caustic gouging. Thus, increasing carbonates and bicarbonates in the boiler water, it will also increase the TDS values and therefore without a proper blowdown program based on the cycle of concentration [16]. The deposit scales will accumulate in the shell and tubes of the boiler.

## *Hardness*

The compounds that cause water hardness are precipitated out of the solution during water softening. Hard water is described as water that contains significant amounts of calcium and magnesium compounds in solution [17]. Hard water is particularly unsuitable for use in boilers because calcium and magnesium salts accumulate on the tubes, forming a stone-like coating on the inner walls known as scale. This scale serves as an insulator between the fire and water sides of the tubes, preventing proper heat transfer which is clearly shown in Figure 4 for boiler in palm oil mills in Perak. The ASME limit is within the upper control limit (UCL) however some of the hardness values are beyond the ASME for most of the plants and it is obvious in plant numbers 5,10,30 and 35. The consequence of this variation of hardness is a significant increase in fuel consumption. Nevertheless, during operation, the boiler tubes may become overheated and burst as a result of severe scaling, which can be dangerous in a boiler factory.

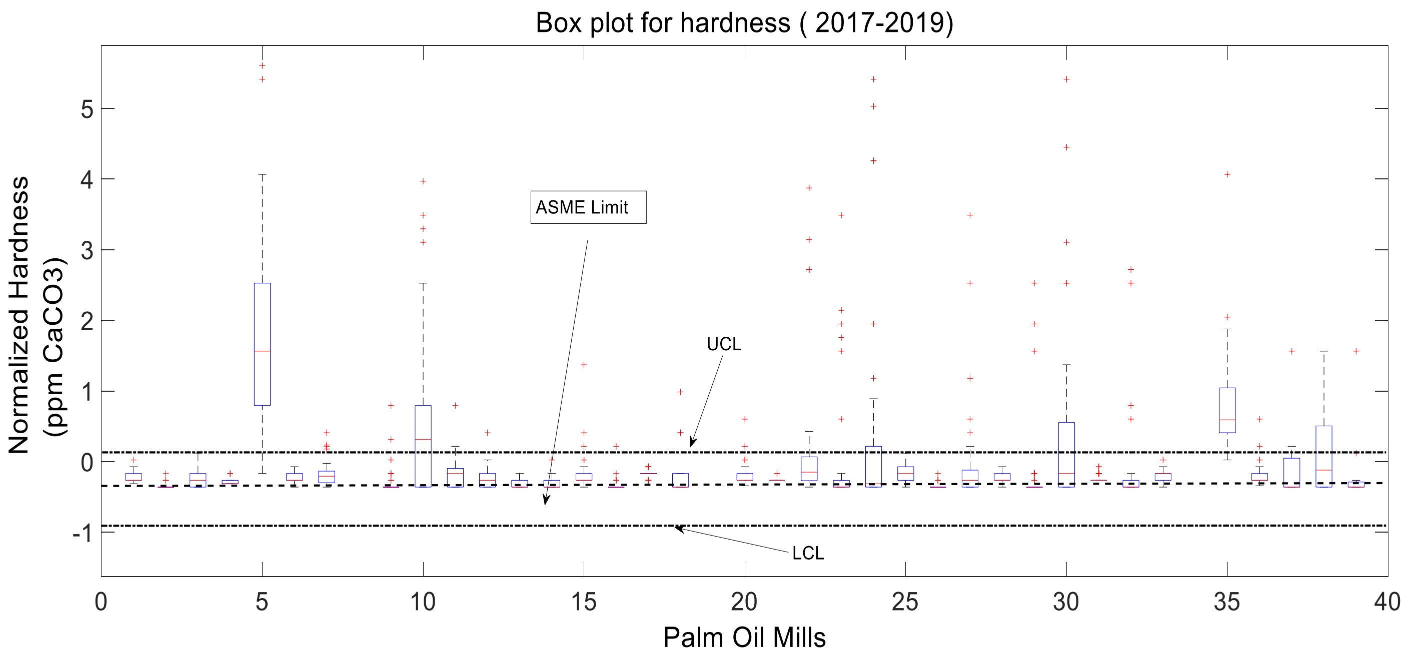


Figure 4. Normalized Hardness data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for Hardness.

It clearly shows that generally, boilers feed water external water treatment using softener it is sometimes not recommended. As shown for plants number 5, 10, 30, and 35, the calcium and magnesium seem carried over into the boiler water and it could be due to leaks within the softener. Therefore, in order to avoid accumulating scale within the boiler at the shell and tube, which can cause overheating and failure due to boiler damage, it is critical to strictly control the hardness of the boiler [18] which is not happen based on the profiles in Figure 4. Since hardness is monitored in boiler feed water to avoid an increase in TDS within the boiler, the operator should be conscious and take immediate action to avoid this situation. It could be due to the lack of adequate softener backwash, which can also be caused by stiffness carryover due to softener leakage.

## *pH*

The oxidation of iron in boilers is achieved by the reduction of hydrogen ions supplied by the hot water.

$$3Fe \ + 4H_2O \ = \ Fe_3O_4 \ + \ 4H_2 \tag{5}$$

The metallic surface of a boiler tube on the waterside is naturally covered by a thin film of magnetite created by the action of hot water on steel, as shown in equation (5). After this protective layer is formed, there should be no further oxidation of the metal. At pH 11-12, the lowest rate of corrosion is achieved. At lower pH levels, hydrogen ions are released, while at higher pH levels, the magnetite layer thickens, peptizes to some degree, and becomes porous due to ion diffusion from the underlying metal. Corrosion in the boiler can occur if the pH of the boiler feedwater is lower than the ASME recommended range where the scaling can form if the pH level is too high [19].

Low makeup or feedwater pH in the preboiler and boiler system causes an extreme acid attack on metal surfaces. Even if the pH of the original makeup or feed water is reasonably neutral, the system's contamination will cause the feed water to become acidic and cause an acid attack. An acid attack can cause general thinning in a boiler and feed water system, or it can promote high-stress areas like drum baffles, "U" bolts, acorn nuts, and tube ends to corrode. The impact is visible on the rough pitted surfaces. That why controlling pH within the range of ASME guidelines is very important as shown in Figure 5. All plants are within the range of ASME, where the UCL and LCL are within the ASME limit and its shows that the operator of the boiler is able to strictly monitor and control the pH accordingly. Apart from that, the presence of iron oxide deposits on boiler surfaces may aid this form of corrosion as well. Boiler feedwater leakage from sources such as hydrochloric or sulfuric acid from demineralizer and condenser leaks is the most common cause of a low boiler water pH.

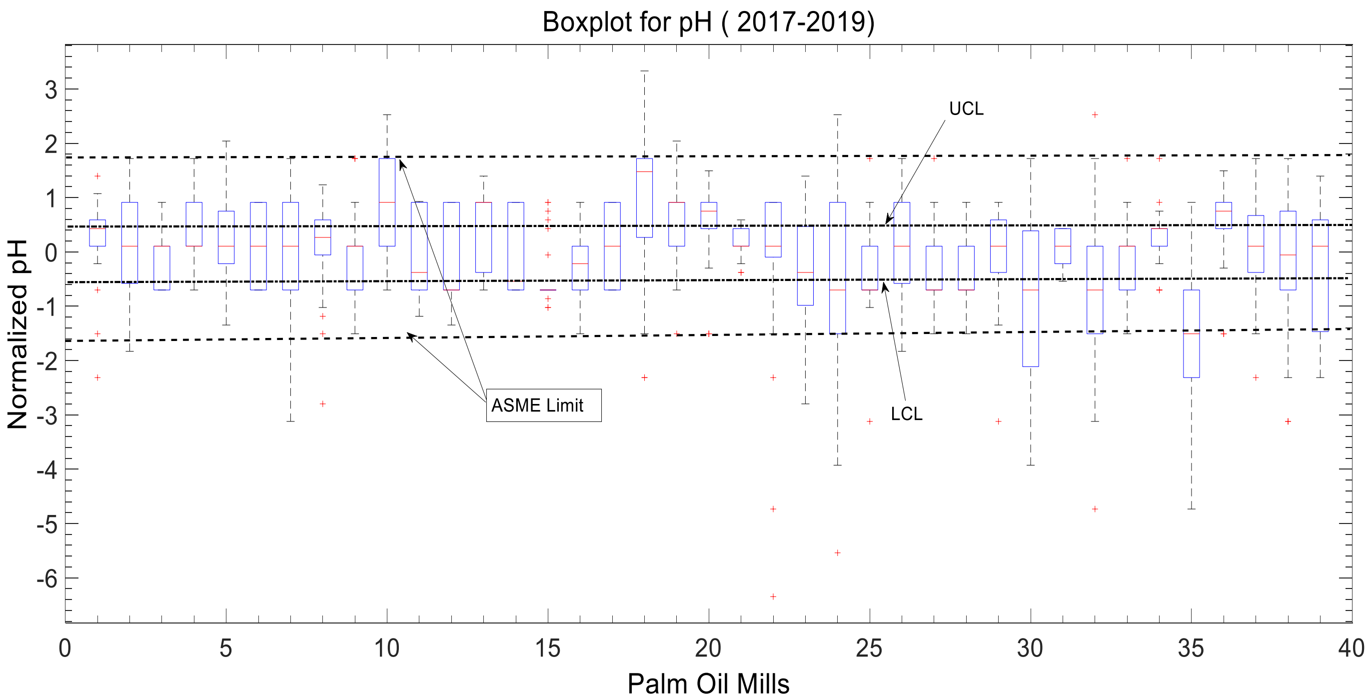


Figure 5. Normalized pH data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for pH.

This demonstrates that, with the exception of plants 30 and 35, the boiler operator followed a successful chemical program by maintaining a free acid condition in the boiler water. It's important to keep the pH of boiler water above 9.5 to avoid corrosion and pitting on the shell and tube surfaces, which can reduce thickness and cause cracks.

## Total Iron

Corrosion occurs when a metal is oxidised by an oxidising agent in the atmosphere. The anode is where the metal is oxidised, and the cathode is where the oxidation is reduced. At the water line in the steam drum and in the down comer tubes of boilers, scattered pitting in the presence of oxygen is sometimes observed. Corrosion of iron and copper in the condensate system causes porous deposits under which salts in the boiler water accumulate and damage the underlying steel [20]. When porous deposits form on the waterside of boiler tubes, serious corrosion occurs, particularly when the water contains free alkali. The presence of this deposit can also cause tube overheating and ductile gouging, which can lead to boiler failure. It is also possible for the steel to react directly with ferric oxide particles as shown in equation (6).

$$4Fe_2O_3 + Fe \rightleftharpoons 3Fe_3O_4 \tag{6}$$

As from the data on the total iron distribution, it shows that total iron for all plants is beyond the ASME range. Quality data for monitoring is not following the ASME guidelines. The severity of these effects can be mitigated to some extent by reducing the concentration of oxygen and free alkali, and by eliminating corrosion products introduced from the preboiler system. Therefore, the total control of total iron is quite poor for boilers for palm oil mills in Perak.

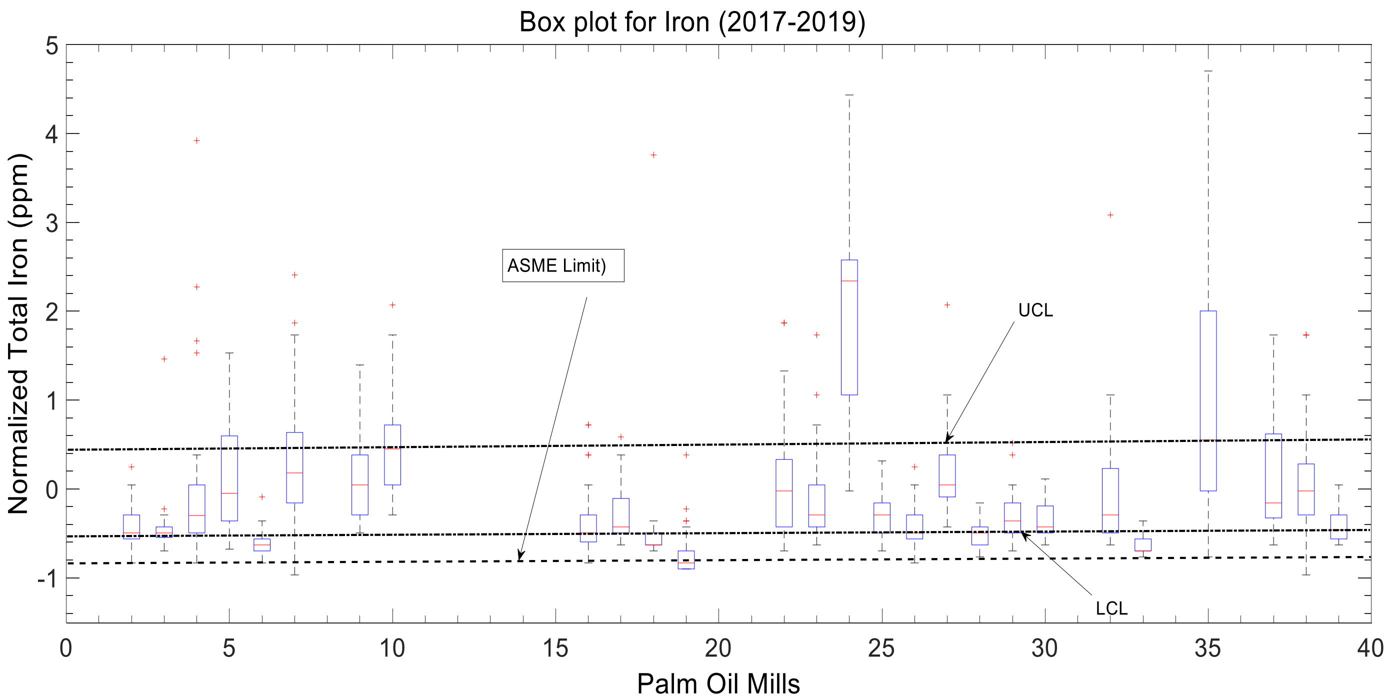


Figure 6. Normalized Iron data for 39 palm oil mills in Perak. The box plot shows the minimum value, the first quartile, the median, the third quartile, and the maximum value for total Iron.

It shows that the operator of the boilers left improperly treated iron for feed water that caused corrosion in shell and tubes. It can be assumed that the improper filter maintenance at make-up water treatment for boiler feedwater is due to improper backwash and carryover of iron.

## Correlation Coefficient Analysis

As shown in Table 3, the boiler feedwater quality is closely related to boiler water quality where pH and hydrate alkalinity have a strong correlation. Values of hydrate alkalinity can be controlled by controlling the value of pH for boiler feedwater.

**Table 3** Correlation coefficient analysis

| | pH | TDS | Hydrate Alkalinity | Hardness | Silica | Total iron |
|---|---|---|---|---|---|---|
| **pH (BFW)** | 1 | 0.34 | 0.65 | -0.21 | 0.24 | -0.16 |
| **TDS** | 0.34 | 1 | 0.44 | 0.11 | 0.32 | 0.24 |
| **Hydrate Alkalinity** | 0.65 | 0.44 | 1 | -0.08 | 0.34 | -0.02 |
| **Hardness (BFW)** | -0.21 | 0.12 | -0.08 | 1 | -0.02 | 0.22 |
| **Silica** | 0.24 | 0.32 | 0.33 | -0.02 | 1 | 0.19 |
| **Total Iron (BFW)** | -0.16 | 0.24 | -0.02 | 0.22 | 0.19 | 1 |

Therefore, to ensure hydrate alkalinity values are following the range from the ASME guidelines during operation for boiler water, it is recommended to raise or decrease the dosage used for chemical softening or changing the rate of acid addition before cation exchange softeners. Therefore, to maintain the quality of boiler feed water in terms of alkalinity, the operator must control the pH accordingly. This correlation was also observed for TDS and alkalinity with a correlation coefficient of 0.44. This correlation is supported by the scattered plot as shown in Figure 7 where pH, TDS and hydrate alkalinity have a strong correlation as compared with the rest.

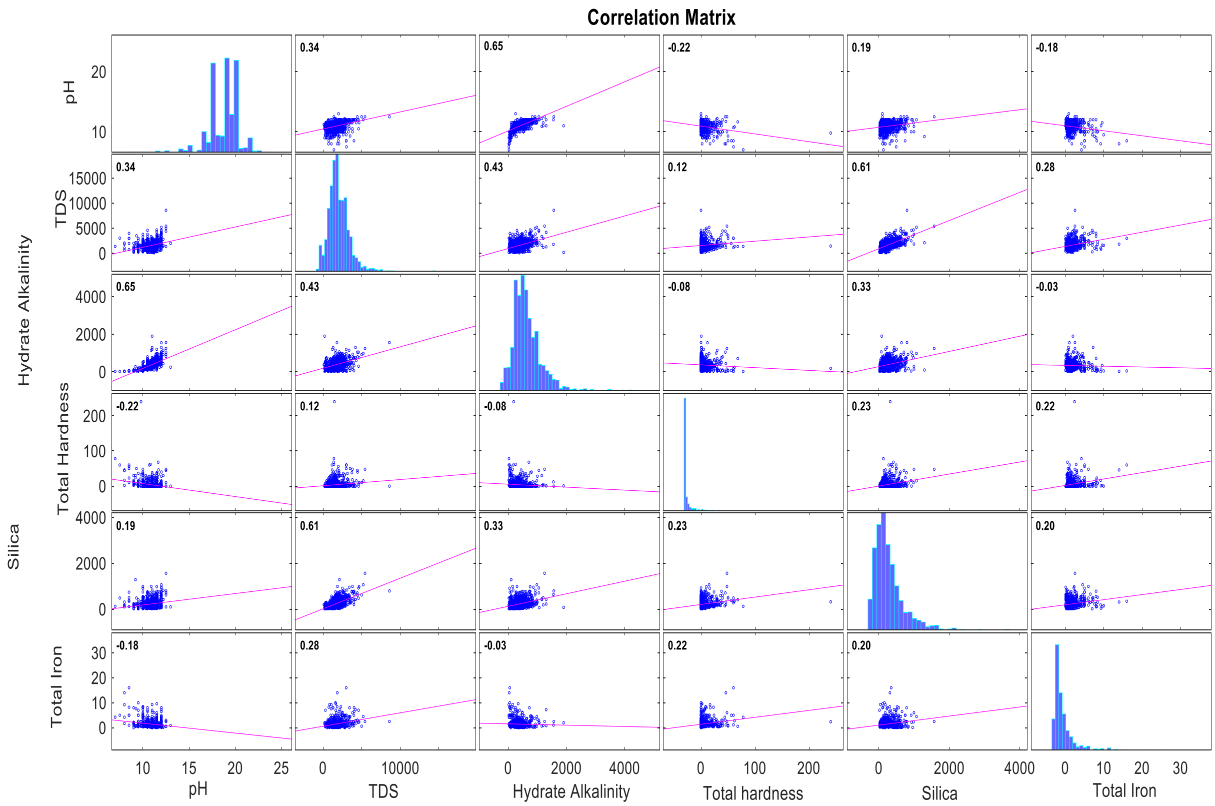


**Figure 7.** The plot of the correlation coefficient between hardness, silica, TDA, pH, hydrate alkalinity and total iron for data collected.

Figure 7 also shows that TDS have a strong correlation with hardness, silica and total iron. Controlling hardness, silica and total iron at preboiler can reduce the amount of TDS in the boiler water. TDS will increase in boiler water and can it be controlled by performing the blowdown due to the concentration of dissolved solids in the boiler water. At the same time, the loss of heat and chemical additives is also kept to a minimum. It is clearly shown in Figure 7, that all the data are normally distributed and in line with the SPC assumption that is only applicable when the data are normally distributed.

## Conclusions

In this study, a data-driven approach of SPC is proposed with the fundamental objective of improving the monitoring and the quality of the boiler and boiler feed water for palm oil mills in the State of Perak, Malaysia. All the parameters are related to each other and need to be controlled accordingly to follow the guidelines by ASME in order to ensure a reasonable boiler chemistry control. Therefore, a complete analysis of the raw and makeup water is the first step in establishing the correct program. From this analysis, the boiler operator in the palm oil factory can determine the suitable operating parameters for the program. The ASME guidelines specify the respective parameters to be followed when operating boilers to prevent any failure and operate in a good condition by maintaining all the parameters such as silica, TDS, Hydrate alkalinity, hardness, pH and total iron in range. Proper treatment of boiler feedwater and performing blowdown based on the cycle of concentration for boiler water effectively from scaling and corrosion of boiler in the shell and tubes. This severe scaling and corrosion can cause serious damage to the boilers and losses to the oil palm plantation. This is due to the unplanned shutdown of the plants. Therefore, based on this analysis, pH, TDS, and hydrate alkalinity quality control performance are reasonable compared to total iron, silica and hardness. Proper treatment or procedure needs to be implemented accordingly by the plant operator to ensure that the quality of those three parameters follows the ASME guidelines.

## Conflicts of interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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