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A REVIEW OF THE SIGNIFICANCE OF FEEDWATER TEMPERATURE ON THE HEALTH OF A STEAM BOILER

Davis F.[1], Okwabi R.[2] and Oman E. K.[2]
[1]Department of Mechanical Engineering, PMB, KNUST, Kumasi, Ghana
[2]Department of Mechanical Engineering, Accra Technical University, AP, Ghana
E-Mail: okwabirichard@yahoo.com

ABSTRACT

This paper presents a review of the significance of feedwater temperature on the health of the steam boiler. Feedwater temperature was identified as one of the main parameters that influence the health of the steam boiler dueto its strong correlation to performance. This review is influenced by the fact that considerable knowledge abounds in research work about the effect of feedwater temperature on the health of steam boilers but they are scattered. In this review an attempt is made to assemble the information in a compact manner to call attention to the importance of feedwater temperature in relation to the health of steam boilers to assist in boiler design and maintenance by engineers and technicians. The effect of other factors, examples; quality of feedwater on boiler performance have also been captured in this review. From the study, a minimum increase in boiler feedwater temperature is recognized as a progression to improve the steam boiler efficiency (a minimum rise in boiler feedwater temperature of about 20 degrees Celsius is estimated to improve boiler efficiency by 3 to 4 per cent). By using deaerators whose main purpose is to remove dissolved gases in the feedwater and in the process increasing quality of the feedwater and its temperature, we succeed in reducing the temperature gradient between the feedwater and its tubes resulting in reduction of thermal fatigue and shocks in the alloyed steel walls. This improves the health of the steam boiler.

Keywords: feedwater temperature, steam boiler, efficiency, steam boiler health, Oxygen corrosion, scale deposit.

Nomenclature:

CHP	Combine Heat and Power
pH	Potential of Hydrogen
SCC	Stress Corrosion Cracking
$CaSO_4$	Anhydrite
$Ca_6Si_6O_{17}(OH)_2$	Xonotlite
$NaCu_2Si_3O_8(OH)$	Pectolite
PHL	Percentage of Heat Loss.
Q	Quantity of steam (dry) (kg/hr)
q	Quantity of fuel consumed (kg/hr)
h_g	Enthalpy of steam (kJ/kg)
h_f	Enthalpy of feedwater(kJ/kg)
GCV	Gross Calorific Value (kJ/kg)
MW	Mega Watts

1. INTRODUCTION

Steam has for decades had wide application in the power and processing industries. In power production, superheated steam is used to drive the turbines to produce electricity[1], while in the processing industry, technical processes such as drying, disinfection, sterilization, and distillation are performed with saturated steam to improve product quality for human safety [2-4]. Other processes such as heating, cleaning, and pasteurization also require quality steam [5,6]. During the brewing process, steam can be used to enhance complex chemical reactions of raw ingredients into beer. Additionally, steam is more effective in the sterilization of bottling surfaces, since it can effectively deliver heat into nooks and crevices where it is difficult to get hot water to[4]. Generally about 35 percent of the industrial energy demand is provided by steam generation [7,8].

The immense application of steam augments the importance of its generation source, the steam boiler. In the case of electrical energy used by the world, 67 percent is generated by fossil fuel steam boilers [9-11]. Steam boilers are pressure vessels that use heat from the flue gas to convert liquid water into saturated and super-heated steam through conduction, convection and radiation [12]. Figure-1 demonstrates a simple operational principle, with waste flue gas disposed into the atmosphere while steam is supplied to the production floor to do work. A breakdown of the steam boiler will have severe impact on the cost of production and/or have fatal consequences in situations of boiler explosion[13]. Specifically, there will be negative returns on investment, equipment damage and loss of human life. Periodic monitoring of the steam boiler health will improve performance and prolong the steam boiler useful life. An effective way to ensure a steady health of the steam boiler is to identify parameters that influence steam boiler performance and manipulate these parameters to optimize efficiency and improve health of the steam boiler. Feedwater temperature is one such critical parameter that influences the health of the steam boiler.

This review is influenced by the fact that considerable knowledge abounds in research work about the effect of feedwater temperature on the health of steam boilers but they are scattered. In this review an attempt is made to assemble the information in a compact manner to call attention to the importance of feedwater temperature in relation to the health of steam boilers to assist in boiler design and maintenance by engineers and technicians. The effect of other factors, examples; quality of feedwater on boiler performance have also been captured in this review.

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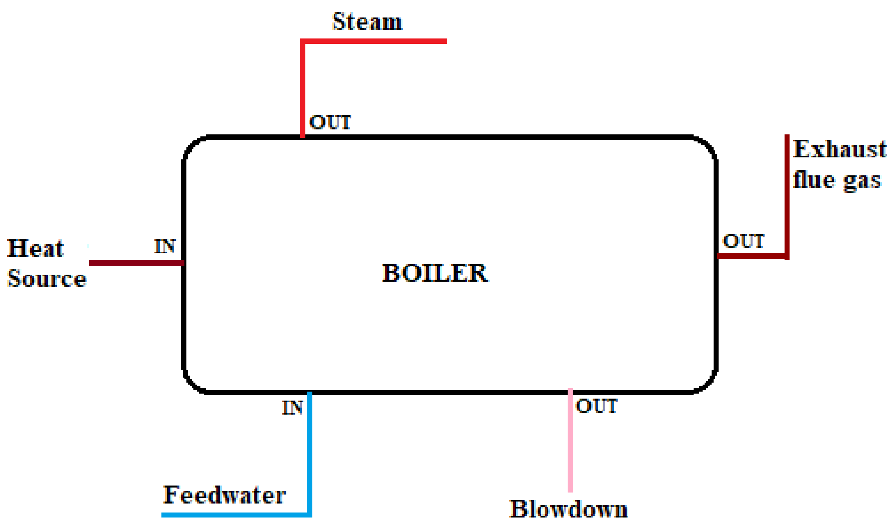

Figure-1. Operation principle of steam boiler.

2. SIGNIFICANCE OF FEEDWATER TEMPERATURE

The influence of various independent parameters of the steam boiler affects its operational performance. According to Berku [14], the increase in gas-to-steam mass ratio and other parameters can optimized the steam boiler efficiency to about 10 percent. The indispensable medium for steam generation is the boiler feedwater. Proper handling of boiler feed water increases the efficiency maintains the health and ultimately prolongs the service life of the steam boiler. Feedwater temperature is constituted as one of the parameters that can affect the steam boiler's performance and consequently, its health. [2,15] Typically, a minimum rise in boiler feedwater temperature of about 20 degrees Celsius is estimated to result in 3 to 4 percent increased boiler efficiency [16,17]. In another research to analyze Combined Heat and Power (CHP) system Ahmadi *et al.* [18] stress the significant increase in steam boiler efficiency at 34.08 and 38.5 percent when boiler feedwater temperatures were at 100 and200-degree Celsius respectively. However, a steam boiler supplied with cold feedwater under normal operating temperature can lead to severe damage and affect the health of the boiler and its service life. Continuous operation of steam boiler with a decreased feedwater temperature may result in reduction of boiler efficiency, upsurge corrosion in boiler tube, frequent feedwater treatment, and alarming temperature changes in the metals of the steam boiler, all of which consequently deteriorate the health of the boiler and shortens its useful life [17,19,20]. The sections below establish the correlation between feedwater temperature, related steam boiler operational challenges and the steam boiler health.

3. EFFICIENCY-RELATED PROBLEMS

Steam boiler efficiency reflects boiler operation condition which reduces also with time due to heat transfer fouling, poor operation, poor combustion, and maintenance [21]. Heat transfer fouling on the internal wall of tube-scan reduce the temperature of feedwater and prolong the liquid-steam transformation process. Monitoring steam boiler efficiency is critical to diagnose steam boiler health and schedule predictive maintenance. Steam Boiler efficiency is usually rated on combustion efficiency, thermal efficiency, and overall (fuel-to-steam) efficiency [21,22]. Henderson [23] indicates 0.15 per cent increase in boiler efficiency when feedwater to the steam boiler advances 20 degree-Celsius in temperature

Steam boiler efficiency can be calculated using Direct (equation 1) or Indirect (equation 2) [24,25] methods with the latter being more accurate. To obtain a reliable result with the direct method, accurate determination of the fuel flow and steam generated is crucial [21]. From equation 1, low feedwater temperature will maximize the quantity of steam to be produced, but the enormous amount of fuel to heat the low temperature feedwater to the dry steam temperature can cause the steam boiler efficiency to decrease.

3.1 Direct (Input-Output) Method

$$\text{Boiler Efficiency } (\eta) = \frac{\text{Heat Output}}{\text{Heat Input}} \times 100$$

$$(\eta) = \frac{Q \times (h - h_f)}{q \times GCV} \times 100 \quad \text{.................(Eq. 1)}$$

3.2 Indirect (Heat Loss) Method

From the indirect method reducing heat losses may upsurge the overall efficiency of the steam boiler. The heat loss to dry flue gas (i) is the major loss which when reduced can increase system efficiency (see Appendix A). Often maximum efficiency of the steam boiler is attained at dryflue gas temperature between 100 and 200-degree Celsius. However, when dry flue gas gains temperature above 200-degree Celsius, heat is lost to the exhaust flue gas. Typically 10 to 30 percent of heat energy is lost to the atmosphere [26-28]. According to Bruckner *et al*. [29], temperature above 200-degree Celsius is a usable waste heat source [30]. In order to maintain the maximum efficiency of the boiler system the waste heat must be captured to elevate the feedwater temperature. In addition to increasing the feedwater temperature, the overall efficiency and steam boiler health will also be improved [28]. Table-1, explains the effect of these heat losses in relation to efficiency and health of the steam boiler.

Table-1. Heat losses equation in steam boiler.

Heat Loss	Description	Equation (Percentage of Heat Loss. PHL)
Heat loss due to dry flue gas	Heat is loss to the dry flue gas at temperature above 200-degrees Celsius as efficient steam boiler flue gas operate between a temperature of 100 and 200-degreeCelcuis.	$\text{PHL} = \left(\frac{m \times C_p \times (T_f - T_a) \times 100}{GCV\ of\ fuel} \right)$ ...(i)
Heat loss due to evaporation of water from combustion of hydrogen in fuel	Heat loss due to evaporation is the present of water in flue gas evaporating in a form of steam through the chimney.	$\text{PHL} = \left(\frac{9 \times H_2 \times \left\{ 245.8 + C_p \times \left(T_f - T_a \right) \right\} \times 100}{GCV\ of\ fuel} \right)$ ...(ii)
Heat loss due to moisture in fuel	Fuels mostly contain a minimum amount moisture. The heat loss is characterized by the amount of moisture percentage in the fuel	$\text{PHL} = \left(\frac{M \times \left\{ 2452.8 + C_p \times \left(T_f - T_a \right) \right\} \times 100}{GCV\ of\ fuel} \right)$ ...(iii)
Heat loss due to moisture in air.	The amount of heat loss produce by this is mostly insignificant.	$\text{PHL} = \left(\frac{AAS \times Humidity \times C_p \times (T_f - T_a) \times 100}{GCV\ of\ fuel} \right)$ ...(iv)
Heat loss due to incomplete combustion	This type of heat loss is as a result of inadequate oxygen accompanying the fuel at the combustion chamber	$\text{PHL} = \left(\frac{CO(ppm) \times 10^{-6} \times m_f \times 23746.8 \times 100}{GCV\ of\ fuel} \right)$ ...(v)
Heat loss due to blow down	Heat loss occurs when a blowdown process is performed to reject the impurities settled in steam boiler.	$\text{PHL} = \left(\frac{m_s \times 0.02 \times h_g \times 100}{m_f \times CV} \right)$ ...(vi)
Heat loss due to Radiation and Unaccounted loss	Generally, a total of 2 percent heat is loss due to heat from the wall of the steam boiler to the atmosphere, and conduction and convection processes which occur in the steam boiler.	PHL = 3% ....(vii)

Boiler Efficiency (η) = 100 - (i + ii + iii + iv + v + vi + vii) ...(Eq. 2)

The quantification of i, ii, …, vii can be found in the Appendix.

3.3. Cost

One fundamental problem associated with the steam boileris the cost of operation. The major cost of operation is the energy consumed by the steam boiler plant.A healthy steam boiler has a significant influence on heating-related energy savings [18, 31]. The study of Montazeri Steam Plant by Ahmadi and Toghraie [32] revealed over 85 percent loss of fuel energy of the plant losses was recorded by the boiler. A group of researchers also determined some potential losses that can affect energy efficiency of the steam system. From the study of Chowdhury *et al.* [33], it was revealed that only 52.7 percent of fuel energy is transformed into useful work and implementing energy-saving recovery measures will reduce energy demand, improve the overall efficiency and health of the steam boiler [34,35]. Sustainable energy utilization has been a priority in the production industry post World War II [24]. The early steam boilers were inefficient with maximum boiler efficiency of approximately 34%. The introduction of Trevithick's steam boiler, however, increased the efficiency of the boiler and reduced the cost of coal from 1000 euros to 612 euros in a year [17]. In Kuprianov [36] review paper of cost-based method in thermal efficiency improvement and environmental performance of steam boiler it was emphasized that the major part of internal boiler cost is the extra-fuel consumed due to boiler heat losses. In addition the waste exhaust gas has negative impact on the environment and human [37].

Several efforts to investigate the relationship between cost and efficiency which is influenced by the feedwater temperature have been pursued [27,38]. A typical example is the research conducted by Ohijeagbon *et al*. [39] where the cost of fuel which is dominant among the energy waste evaluation parameters is estimated to account for approximately ninety percent of the total variable cost in steam generation is reduced due to feedwater temperature rise [26,39,40]. US Energy research team[2] on the other hand analyzed the benchmark of fuel cost in steam production, and established that there is a relatively reduced cost of energy required to produce steam with an elevated temperature of boiler feedwater.

Another work by Bhattacharya and Banerjee [41] optimized the boiler feedwater temperature to maximize boiler efficiency, concluding that, a substantial loss in boiler efficiency will result from improper heating of boiler feed water. It can be inferred from the study that; a positive correlation exists between an increased feedwater temperature and improved efficiency which subsequently impacts the boiler health. Accordingly, proper control of the boiler feedwater temperature leads to accelerated processing of feedwater resulting in energy saving and sustained boiler health.

Shaposhnikov *et al*., [16]mathematically modelled the steam boiler TGM-94 to test its performance, capability, and effectiveness under varying conditions in operational mode. The analysis revealed an absolute increase in fuel consumption from 42.5 to 47.7 thousand nm^3/h, as feedwater temperature reduced under constant steam production. The change in system efficiency was however insignificant. Typically, an increase in feedwater temperature decreases fuel consumption by 1.74 thousand nm^3 /h[16]. Barma *et al*. [26] and Pagan *et al*. [40] in aseparate research also recognized that an increase in boiler feedwater temperature can result in a reduction of fuel cost in steam production.

3.4 Waste Heat Recovering

Thermal efficiency of steam boilers is largely dependent upon the temperature difference between the cold and heat sources; thus, increase in temperature difference may lead to significant increase in efficiency and the steam generation of the steam boiler. The best approach to enhancing boiler efficiency, making significant energy savings, and reducing emissions is to make use of heat recovered from the exhaust flue gases [34,35,42]. From an economical point of view, preheating boiler feed water using combusted air are the primary choices to improve boiler efficiency. Alizadeh-Kheneslu *et al*. [43] mention that maximum energy and exergy losses occurs within the steam boiler and condenser. The total is about 48 and 56 percent of electricity generation cycle. In the case of boiler feedwater, an economizer which is among the dominant passive technologies in waste heat recovery is used to elevates the temperature, thereby reducing fuel consumed by the steam boiler by five to ten percent[44]to improve steam boiler efficiency [33,45]. In analyzing the efficiency of the B_1 unit of the 620 MW lignite-fired Power Plant with parallel connection of two economizers, Stevanovic *et al*., [46] established that the recovery of 30MW heat from the waste flue gas to elevate the feedwater temperature increase the gross efficiency of the steam boiler by 0.53 percent This is in charp contract to the study performed by Abdollahian and Ameri [47] using supplementary firing to increase power generation and improved the energy efficiency by 2.43 percent.

According to Lahijani [48], a steam boiler with an attached economizer to increase the feedwater temperature will acceleratesteam production and save energy and hence increase steam boiler efficiency by approximately10 percent more than a steam boiler without an attached economizer. The study of Tzolakis *et al* also concluded on a fuel reduction of 2.06 percent (11.5 t/h *Corresponding author, ignite) when the overall thermal efficiency is improved by 0.55 per cent [49].

Another way of recovering waste heat is through the blowdown method. Energy is often wasted when boiler water is blowdown to remove unwanted impurities. Hence, capturing this energy in a form of heat to increase the feedwater temperature can leads to about one percent increase in the overall boiler efficiency and health of the steam boiler [50,51].

3.5 Feedwater Heating Methods

Several methods to elevate the temperature of boiler feedwater for a sustained boiler health have been published in literatures [17,20,52]. Generally, these methods can be grouped into two, direct heating and indirect heating.

3.5.1 Direct heating

This process allows the boiler feedwater to be mixed with the supplementary steam to increase its temperature. The preheating process is mostly achieved with the deaerator for larger facilities and the Blowdown heat-recovery system[17,52].

3.5.2 Indirect heating

In the indirect heating method, the boiler feedwater and the heating medium move in separate pathways. Through the conventional process, the heat exchanger elevates the incoming feedwater temperature to boiler water temperature. The functional unit that preheats the feedwater is the Economizer. A boiler economizer is installed in the exhaust flue gases path to recover exhaust waste heat by utilizing exhaust flue gas heat to elevate feedwater temperature [16,45,53–55].

This preheating unit was reported to elevate the feedwater temperature three time more than with feedwater heater by Akpan and Fuls [56].

4. QUALITY FEEDWATER-RELATED PROBLEMS

The health of the steam boiler can be maintained through properly conditioning boiler feedwater temperature to prevent corrosion, scale, and other deposits in the steam boiler plant. Operating steam boiler on quality feedwater can increase efficiency, sustain thehealth, and prolong the service life of the steam boiler. Severe problems such as malfunctioning of the steam boiler plant or unscheduled maintenance are possible to develop if boiler feedwater is not properly treated. Typical water treatment flow in a generic steam system is shown in Figure-2.

Generally, the subject relating to poor-quality feedwater can be harmonized under corrosion and scaling effect. Often the steam boiler experiences corrosion and scaling problems simultaneously since the two are interrelated. It is important to avoid both problems if the steam boiler is to operate at optimum efficiency, steady health and last longer.

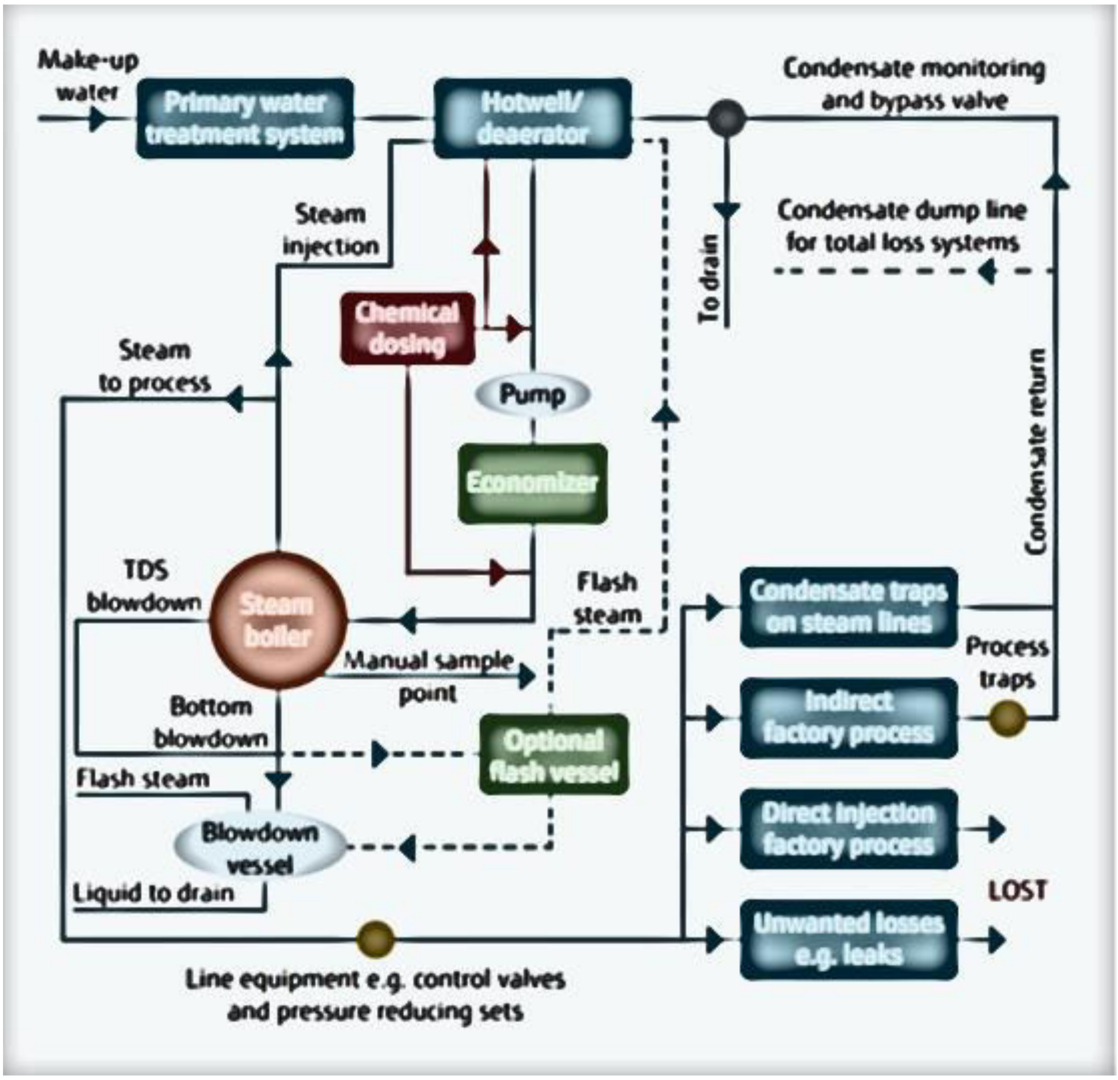

Figure-2. Scheme of a generic steam system [17].

4.1 Corrosion Effect

4.1.1 Oxygen attack

Oxygen corrosion can be attributed to the presence of oxygen in boiler feed water, where an increase in solubility of corrosion product is a result of decrease feedwater temperature [19]. Thus, a decreased feedwater temperature increases the rate of oxygen corrosion and invariably decreases the health of the steam boiler and the overall boiler efficiency [57-59]. The presence of dissolved oxygen interacts with the internal surface wall of the metallic tubes and forms pitting which can eventually penetrate the metal [48, 60]. In time the localized semispherical corroded pit becomes large in shape and size and can cause leakage in the tubes, thereby compromising the boiler health. Oxygen corrosion pitting was identified as one of the ten top causes of corrosion in steam boiler tubes by Kumari *et al*., [61] as illustrated in Figure-3.

Corrosive damage can be extensive in the boiler system when dissolved gases are agitated by heating, compelling a boiler shutdown. The control of the dissolved oxygen present in the boiler feedwater by setting optimum feedwater temperature is necessary to prevent pitting corrosion on the steam boiler tubes [62] for a sustained boiler health. The incorporation of regenerative heaters and particularly deaerators simultaneously reduce dissolved oxygen and raise the feedwater temperature.

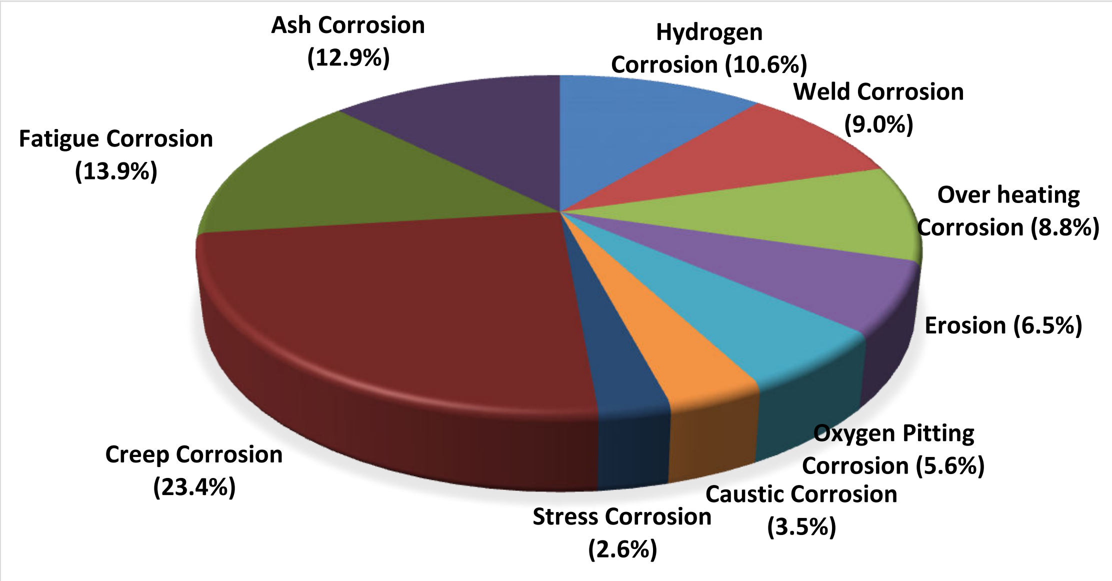

Figure-3. Graphical presentation of 10 top corrosion mechanisms occurs in steam boiler tubes [19].

4.1.2 Treatment processes of boiler feedwater

The treatment processes of dissolved gases present in boiler feedwater can be divided into two groups. The Mechanical process is estimated to provide a better deaeration process through manipulation of physical characteristics such as temperature and pressure of the feedwater [63]. The process applies heat to elevate the incoming feedwater temperature thereby suppressing the dissolved gases [17, 39, 64]. This is illustrated in Figure-4 where the elevated feedwater temperature from 10 ^{o}C to 82 ^{o}C reduces the oxygen level from 8 ppm to 2 ppm [65]. The process is also reliable and economical in the sense that the initial cost is often recovered as a result of prolong service life of steam boiler and accessories, reduction in maintenance cost, and downtime [65]. Moreover, the mechanical process can be used to treat the impurities in the boiler feedwater. According to Leunig [65], the mechanical process can remove about 90 to 97 percent of feedwater impurities with only 3 to 10 percent remaining for chemical processing. Thus, reducing the amount of environmentally harmful chemicals needed for boiler feedwater treatment [66]. The process provides the most desirable and reliable means of reducing unwanted materials and gases from the feedwater before entering the steam boiler [63,67].

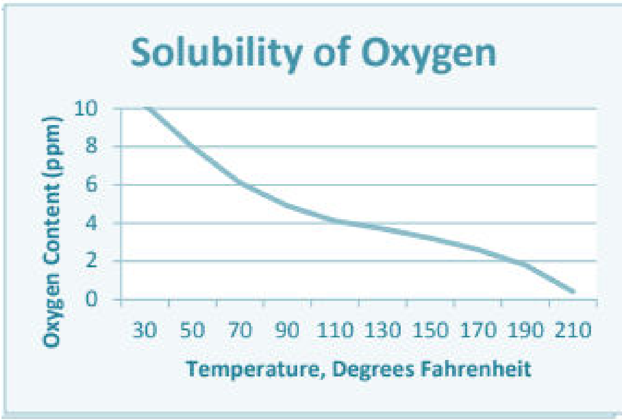

Figure-4. Feedwater temperature against oxygen content [65].

4.2 Scale-Effect

The health of the steam boiler is affected by scale deposit on boiler tubes which can be attributed to poor conditioning of boiler feedwater such as the feedwater temperature and pH. When feedwater is not properly treated/conditioned, the dissolved salts (chlorides, magnesium, sulfur, and calcium bicarbonates) from untreated feedwater passing through the tubes settle on the internal walls and forms a hard scale. This, in effect, reduces the efficiency of the steam boiler, negatively affect boiler health and subsequently shorten its service life [19]. The drop in efficiency is estimated to be between 10 to 12 percent [68]. The accumulation of scale deposit can also cause steam boiler tubes to fail.

Localized overheating in boiler tube material can be caused by scale deposit. When heat flow is obstructed the metal temperature increases, and if this persists for a long period, would result in major damages which will affect the health and service life of the steam boiler [69,70]. The rate of temperature increase in metal tubes relative to scale deposit is demonstrated in Figure-5. Scale deposition also promotes heat loss. A scale deposit of 3mm is evaluated to cause 2 to 3 percent heat loss in both fire and water-tube boilers [68]. Estimation from another research team equally reveals that for every 1mm scale deposit, there will be a 5 percent increase in fuel consumed by the fire-tube boiler [15] and 2 percent fuel consumed by the water tube boiler [44,71]. Similarly, a 1.5 mm scale build-up can increase fuel usage to additional 4 to 9 per cent [72].

Scale deposit also reduces the cross-sectional area of the tubes leading to pressure drop within the system. Excess of 300-micrometre scale deposit can reduce boiler performance and may require reconditioning [73]. Kuriger *et al*., [74] explains how maintenance practices can be better implemented with an adequate understanding of scale deposit composition on heat transfer surfaces. The scanning electron microscopy and its accessories were used to analyze the feedwater with pH values of 7.5 and 9.0 and detected the presence of anhydrite ($CaSO_4$), xonotlite ($Ca_6Si_6O_{17}(OH)_2$), and pectolite ($NaCu_2Si_3O_8(OH)$) which acts as energy insulating layers. But at pH 10, the presence of anhydrite ($CaSO_4$) was absent allowing for maximum flow of heat.

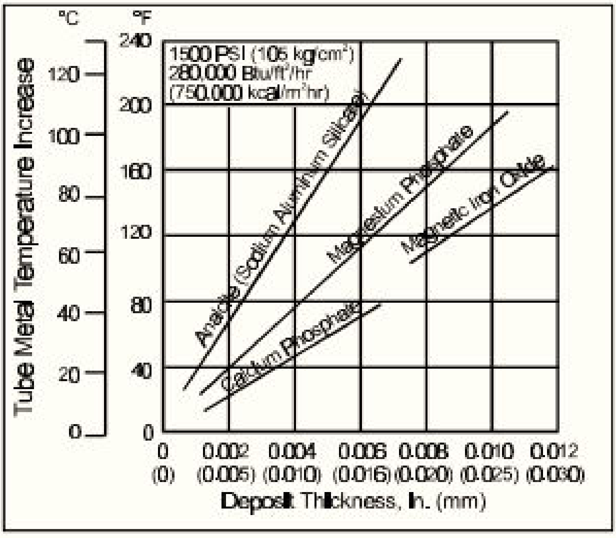

Figure-5. Effects of boiler scale on tube metal temperature[68].

5. BOILER METAL-RELATED ISSUES

Metals undergo structural changes when exposed to extreme temperature fluctuations. Similarly, a sudden change in temperature or uneven temperature within the steam boiler can cause thermal fatigue or shock in the metallic components and compromise the health of the steam boiler.

5.1 Thermal Fatigue

Repeated heating and cooling of metals can generate large temperature gradient between the core and external surface. The established constraint due to thermal strain and stress caused by changes in feedwater temperature is termed as thermal fatigue or [75,76]. At a certain point, the alloy metal may develop cracks due to quick structural transformation from compression stress to tensile stress caused by the changes in boiler feedwater temperature. [77]. One of the influential failure mechanisms that mostly affects the performance of the boiler is stress corrosion cracking (thermal fatigue) [78-81].The strong relation between the crack caused by thermal fatigue and health of the steam boiler provides basic sign to boiler operator of possible part failure for prompt action. Failure of steam boiler can also be propagated by surface cracking and fatigue crack growth as reported by Citirik [82].

5.2 Thermal Shock

Thermal shock occurs when alloy metals of the steam boiler experience thermal load. The presence of thermal shock may initiate thermal shock crack and can promote steam boiler failure. Anon and Price [83, 84] realized that metal cracks and growth are introduced when metal is exposed repeatedly to heat at different temperatures. The stark difference between boiler feedwater temperature and the boiler water temperature can cause rapid expansion and contraction of boiler tubes and components. Thermal shock in the boiler system can also lead to a steam boiler explosion and property damage. An estimation by Rahman *et al.* on boiler tube failures in power plant caused by thermal stress amount to 5 billion dollars in a year[85].

Frazier [86] reiterated that most boiler shocks occur due to poor operation of the heating system. This happens frequently and therefore proper monitoring of the heating system and frequent maintenance can prevent boiler catastrophes. Another means to control thermal shock in steam boilers is to elevate the boiler feedwater temperature [17]. This will enable the incoming feedwater to attain a temperature equal or close to the operating system temperature and prevent uneven temperatures in the boiler system for a sustained boiler health.

The dire consequences of thermal fatigue and thermal shock failures in any part of the boiler requires that engineers design against these failures since heat transfer in the boiler presupposes the existence of temperature difference.

6. CONCLUSIONS

In this paper, the elevation in boiler feedwater temperature is established to have a significant effect on the steam boiler efficiency, the quality of boiler feedwater and the health and service life of the steam boiler. The primary performance parameters of the stem boiler are of relative importance to the health of the steam boiler. Studies have shown that when waste energy is recovered to preheat the boiler feedwater, the efficiency of the steam boiler is improved by approximately 3 to 4 percent with about 20-degree Celsius increase in boiler feedwater temperature.

The importance of quality boiler feedwater has also been reviewed and deliberated in this study. It was revealed that untreated boiler feedwater such as low feedwater temperature can cause the steam boiler tubes to corrode and deteriorate the boiler health. Another negative effect of poorly conditioned boiler feedwater with low temperature is the formation of scaling that prevent heat flow and causes localized overheating which reduces boiler health and shortens the useful life of the steam boiler. Preheating of boiler feedwater was established as the main solution to the problem. A cost-effective and harmless method for elevating boiler feedwater temperature can be employed to improve the quality of the boiler feedwater. This can be done by the mechanical process which applies mechanical devices such as economizer or deaerator to preheat boiler feedwater. The process reduces the harmful effect that chemical treatment process poses to the environment.

The study also establishes that, when an already heated steam boiler is supplied with low-temperature boiler feedwater, the metal of the steam boiler experiences internal structural changes due to the sudden temperature change. Thus, the strength of the metal is reduceddue to fatigue caused by such sudden temperature changes leading to system thermal shocks with associated structural damage, deteriorating health and shortened service life of the steam boiler.

RECOMMENDATION

This study ascertains the significant impact of boiler feedwater temperature on the health of the steam boiler. The boiler feedwater temperature is identified to promote optimum efficiency of the steam boiler, maintain a steady health and prolong the service life of the steam boiler. The study, therefore, recommends further study on the safety and efficiency optimization of boiler feedwater temperature and design a control mechanism for it.

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