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Characterization of Boiler Water from Various Industries

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A characterization study has been conducted for the boiler water of different industries that includes rubber, paper, textile, maize products and plastic industries. The water samples were collected individually from the industries and characterized by colour, turbidity, conductivity, TDS, SS alkalinity and hardness. It is a comparative study carried out to investigate the quality of boiler feed water and the outlet water of the industries. The quality of feed water if poor it would effect different parts of the boiler by producing contamination like corrosion, scale and foaming which would in turn effect the quality of the chemical process taking place inside the boiler and results in great loss to the expenditure and the economy of the industry. The poor quality of outlet water depends upon the feed water used and also the type of boiler along with the chemical process taking place inside the boiler. This water if contaminated enters the streams, rivers or crops and cause water pollution.

Key Words: Boiler, Pollution, Water.

INTRODUCTION

A boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. In the boiler furnace, the chemical energy in the fuel is converted into heat and it is the function of the boiler to transfer this heat to the contained water in the most efficient manner. The boiler should also be designed to generate high quality of steam[1]. Boiler receives feed water. The steam, which escapes from the boiler, frequently contains liquid droplets and gases. The water remaining in liquid form at the bottom of the boiler picks up all the foreign matter from the water that was converted to steam. The impurities must be blown down by the discharge of some of the water from the boiler to the drains. The permissible percentage of blown down at a plant is strictly limited by running costs and initial outlay. The tendency is to reduce this percentage to a very small figure. Proper treatment of boiler feed water is an important part of operating and maintaining a boiler system. As steam is produced, dissolved solids become concentrated and form deposits inside the boiler. This leads to poor heat transfer and reduces the efficiency of the boiler. Scale is caused by impurities being precipitated out of the

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water directly on heat transfer surfaces or by suspended matter in water settling out on the metal and becoming hard and adherent. This interferes with heat transfers and may cause hot spots leading to local overheating. The less heat they conduct, the more dangerous they are. Corrosion is basically the reversion of a metal to its ore form. Iron, for example, reverts to iron oxide as a result of corrosion. The process of corrosion is actually not so simple but it is a complex electro-mechanical reaction. Corrosion may generally be over a large metal surface but sometimes it results in pinpoint penetration of metal. Though basic corrosion is usually due to reaction of the metal with oxygen, other factors including stresses produce different forms of attack. Corrosion may occur in the feedwater system as a result of low pH water and the presence of dissolved oxygen and carbon dioxide. Corrosion in the boiler itself normally occurs when boiler water alkalinity is too low or too high or when the metal is exposed to oxygen-bearing water during either operation or idle periods. High temperatures and stresses tend to accelerate the corrosion. In the steam and condensate system and pipelines corrosion is generally the result of contamination with carbon dioxide and oxygen[2]. Scaling is mainly due to the presence of calcium and magnesium salts (carbonates or sulphates). Bicarbonates of calcium and magnesium dissolved in water break down under heat and give off carbon dioxide forming insoluble carbonates. These carbonates precipitate directly on the boiler metal and or form sludge in the water that deposits on boiler surfaces. Sulfate and silica generally precipitate directly on the boiler metal and are much harder to condition. Silica (sand) if present in water can form exceedingly hard scale[3]. The pH contains alkaline (hydroxyl, OH^-) ions and hydrogen (H^+) ions. The product of the concentrations is always *ca.* 10-14. The pH value of the water is the log of the reciprocal of the H ion value. If the water is neutral, the OH and H ion concentrations are each 10-7. Low pH in local areas is the second most common cause of corrosion in mild steel boilers above roughly 400°, mild steel corrosion results in the formation of magnetite, a tight adherent that acts as a barrier between boiler water and steel. The corrosion reaction stops after a uniform magnetite layer is formed. Rapid general corrosion can ensue if this protective film is disrupted, so water chemistry must be carefully controlled to maintain the film. An acidic condition can destroy the magnetite film. Therefore boiler water is maintained in the alkaline range of a pH of 9.0 to 10.5. Foaming is the formation of bubbles or froth on the water surface. It is caused by a high amount of total and suspended solids. Foam will fill the free surface area of a separating device increasing local velocities and promoting a serious carryover of boiler water. Priming is a violent and spasmodic discharge of water with steam into the steam space. Slugs of water are thrown over with the steam causing damage to the steam boiler[4].

EXPERIMENTAL

The samples were collected from various industrial units in triplets. Random sampling was done for the collection of five samples. Samples (**S1**, **S2**, **S3**, **S4**, **S5**) consist of inlets or boiler feed water and their corresponding outlet samples. Samples were refrigerated at 4 ºC. Samples were analyzed by various physical and chemical parameters.

Sample analysis: Samples collected were analyzed[5] by colour through naked eye, pH and temperature were determined with Crison-micro pH meter-2001. Turbidity meter (Hanna Lp 200-11) was used for the measurement of turbidity. Conductivity was measured in ms/cm through Jenway-4010 at specific temperature 25 ºC. Total dissolved solids (TDS) and settle able solids (SS) were measured by weighing the residue after filtration and proper drying of the samples. Total hardness was determined by using (NH_4Cl + NH_3) as buffer solution and 0.2 g of solid erichrome black-T, indicator and titrating slowly with standard EDTA solution. In case of calcium hardness NaOH, replacing buffer and ammonium picrate mixed with NaCl as calcium indicator. Magnesium hardness obtained by subtracting the calculated value of calcium hardness from total hardness. Phenolphthalein alkalinity determined by using phenolphthalein as indicator and by titrating with 0.02 molar H_2SO_4. Methyl orange was used as indicator in methyl orange alkalinity.

RESULTS AND DISCUSSION

The result from the characterization of boiler water given in Table-1 reveals that the inlet samples were mostly clear and colourless while the outlet samples showed various colours. The inlet water of **S1** and **S5** was slightly coloured indicating the presence of suspended or dissolved solids. Feed water with suspended solids is not suitable for boiler feed, since it results in deposits of mud within the boiler and may be a cause of foaming and priming of boiler water and can produce scale. All the outlet samples were coloured showing the presence of suspended solids consist of wastes and contaminants, serious corrosion may also be experienced. The coloured samples also indicate higher value of turbidity, which considerably rose in the outlets of all the samples as shown in Table-1. Turbidity in water also indicates the presence of soluble organic and inorganic substances. These are objectionable in varying degrees, as related to boiler efficiency. The total dissolved solids (TDS) showed a different trend, the TDS value as shown in Table-1 decreased in **S1** from 798-436.1 ppm, while increased in **S2** from 129.0-660.9. **S3** and **S5** again showed decrease while **S4** showed a gradual increase in the TDS values. Same results were seen in the case of Conductivity measured in ms/cm. The value of TDS and conductivity depends upon the quality of feed water and also the type of boiler in addition with the process taking place inside the boiler. These two values are interrelated *i.e.*, with an increase in TDS of the sample, conductivity also increases. Evaporation in a boiler causes impurities to concentrate. These impurities settle down inside the boiler tubes and cause scale and corrosion. The impurities get mixed with steam and raised the value of total dissolved solids in the outlet samples, hence the conductivity also get increased by the increase in the number of dissolved solids. The settle able solids (SS) showed a great increase in outlet samples as compared to the

TABLE-1
ANALYSIS OF PHYSICAL PARAMETERS OF VARIOUS INLET AND OUTLET BOILER WATER SAMPLES

Sample No.	Colour		Turbidity (ftu)		Temp. (ºC)		Conductivity (ms/cm)		Total dissolved solids (ppm)		Settle able solids (ppm)	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
S1	Pale yellow	Dark brown	12.5	96.40	29.1	29.9	1180.0	623.0	798.0	94.0	3.00	77.87
S2	Colourless	Light yellow	3.80	27.60	29.0	28.8	190.40	941.0	128.0	374.0	2.90	16.40
S3	Colourless	Milky	2.23	33.00	29.0	29.3	167.00	112.0	113.9	123.0	2.90	150.6
S4	Colourless	Dark brown	2.75	36.05	29.3	29.3	112.00	202.0	90.0	122.0	2.93	169.4
S5	Light brown	Light yellow	6.63	23.50	29.1	28.6	471.00	499.0	319.0	279.0	2.01	20.60

inlets. The mud present inside the boiler in the passage of inlet water as sludge caused the increased amount of settle able solids. The value showed a great increase in the case of **S4**, showing the negligence in operating the boiler and also the improper temperature and pressure control. The dissolved oxygen oxidizes many substances during boiler operation and is corrosive if present in the feed, hence effective value of dissolved oxygen does not appear in the outlet water samples.

The boiler operation effectively showed a decrease in hardness value of boiler water. The hardness in the outlets was less than in the inlets and shown in Table-2. **S1**, **S2** and **S4** show a greater decrease of hardness. The level of hardness in boiler feed water is kept very low usually < 0.2 ppm. All the feed water samples have very high value of hardness *i.e.*, 110.0-32.5 ppm in case of total hardness, 24.0-1.6 ppm for calcium hardness and 3.0-2.01 ppm as magnesium hardness. Hence, the feed water in theses cases is not suitable for boiler feed and also is untreated or taken from natural source. Any natural source of water does not supply perfect feed water for boilers. The iron pipes inside the boiler get covered by a coating produced as a result of water hardness. This coating protects against corrosion but can be a cause of complete consultation depending on the operating conditions in the boiler, hard water produces scale which not only leads to considerably heat loses but can also cause explosion if the coating splits off. Further more, the carbon dioxide released on the formation of boiler scale is corrosive. The Ca and Mg salts which have limited solubility and are not totally insoluble usually form scale. Granular and porous deposits are of carbonate. Calcium hardness has greater value in all the feed water samples than magnesium hardness. The pH of all feed water samples as shown in Table-2 is slightly greater than the ideal value (7.0) of pH for boiler feed water. The feed water values as in the table are slightly basic. While the outlet water samples are mostly basic in nature. The pH levels in excess of 11.0 were obtained. In the presence of deposits of organic compounds in the form of corrosion or scale inside boiler tubes, the pH of water become acidic. The reason is breaking up of organic compounds and their mixing with CO_2 of water present in

TABLE-2
ANALYSIS OF CHEMICAL PARAMETERS OF VARIOUS
INLET AND OUTLET BOILER WATER SAMPLES

Sample No.	pH		Bicarbonate (HCO_3^-) (ppm) M-alkalinity		Carbonate (CO_3^{2-}) (ppm) P-alkalinity		Total hardness (ppm) (as $CaCO_3$)		Calcium hardness (ppm) (as Ca^{2+})		Magnesium hardness (ppm) (as Mg^{2+})	
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
S1	7.71	11.6	28.70	9.0	1.01	39.0	110.0	30.0	24.0	8.0	12.15	2.43
S2	7.55	10.7	34.44	12.8	3.2	48.0	90.9	25.0	1.6	3.2	3.85	1.70
S3	7.51	10.3	45.0	15.60	5.0	62.0	50.0	20.0	12.0	2.8	4.85	3.16
S4	7.31	10.3	20.20	8.0	3.8	62.0	70.01	23.0	16.0	12.0	7.29	3.94
S5	7.92	10.6	25.6	17.8	2.5	50.0	32.5	15.0	2.0	1.20	6.68	1.83

the steam or water used for cooling purposes inside the boilers, this result in the formation of carbonic acid and the pH of outlet water shifts toward acidic. The OH^- concentration in the outlet water raised and the pH moves towards basic. Boiler water contains both carbonate (CO_3) and hydroxide alkalinity. Both are derived from bicarbonates (HCO_3^-) in the feed water. The HCO_3^- alkalinity is very high in the inlet sample as shown in Table-2 and less in the case of outlet samples as (M-alkalinity). Similarly the P-alkalinity of carbonate is very much high in outlets as compared to the inlet samples. The reason is that the carbon dioxide as being insoluble in boiling water is removed with the steam. This causes an increase in pH and shift alkalinity from carbonates (CO_3^{2-}) to bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) to hydroxide (OH^-) under the extreme conditions and the pH level up to 11 are obtained.

Conclusion

From the results it is concluded that water from natural sources was used for boiler feed and was also untreated. The feed water caused contamination, corrosion, foaming and scaling that was obvious from the results of outlet water samples. The mean values of outlet and inlet samples, showing the percentage of different parameters (Table-3).

TABLE-3
COMPARISON IN PERCENTAGE OF DIFFERENT PARAMETERS OF
INLET AND OUTLET BOILER WATER SAMPLES

Parameters	Inlet samples (%)	Outlet samples (%)
Turbidity	4	18
pH	5	5
M-alkalinity	22	5
P-alkalinity	2	22
Suspended Solids	2	37
Total Hardness (as $CaCO_3$)	52	10
Hardness (as Ca^{2+})	8	2
Hardness (as Mg^{2+})	5	1

Data analysis: Data analysis was done by using the computer program 'Minitab', the results are shown in Table-4.

TABLE-4
STATISTICAL ANALYSIS OF THE INLET AND OUTLET BOILER WATER SAMPLES

Sample No.		Mean	Median	Standard deviation	SE Mean
Turbidity	Inlets	5.58	3.80	± 4.22	1.89
	Outlets	43.3	33.0	± 30.1	13.4
Temperature	Inlets	29.10	29.100	± 0.122	0.055
	Outlets	29.18	29.300	± 0.507	0.227
pH	Inlets	7.60	7.550	± 0.229	0.102
	Outlets	10.70	10.600	± 0.534	0.239
M-alkalinity	Inlets	30.79	28.70	± 9.47	4.23
	Outlets	30.79	28.70	± 9.47	4.23
P-alkalinity	Inlets	3.102	3.200	± 1.486	0.665
	Outlets	52.200	50.00	± 9.86	4.41
Conductivity	Inlets	424	190	± 445	199
	Outlets	475	499	± 334	149
Total dissolved solids	Inlets	290.0	128	± 298	133
	Outlets	198.4	123.0	± 122.2	54.7
Suspended solids	Inlets	2.748	2.900	± 0.415	0.185
	Outlets	87.000	77.9	± 71.3	31.9
Total hardness	Inlets	70.70	70.0	± 31.0	13.9
	Outlets	22.60	23.00	± 5.59	2.50
Ca-hardness	Inlets	11.12	12.00	± 9.54	4.27
	Outlets	5.44	3.20	± 4.46	1.99
Mg-hardness	Inlets	6.960	6.68	± 3.21	1.44
	Outlets	2.612	2.430	± 0.941	0.421

REFERENCES

1. J.O. Odigure, A.S. Abdulkareem and E.T. Asuquol, Effect of Water Quality on the Performance of Boiler in Nigerian Petroleum Industry, Leonardo Electronic Journal of Practices and Technologies, Issue 7, July-December 2005, p. 41-48.
2. http://www.lenntech.com/boiler/boiler-feed-water.htm
3. http://www.sedifilt.com/technical_library/boiler_feedwater_treatment_part_i_why_water_treatment_is_necessary.htmL
4. "Importance of Good Boiler Feedwater Treatment" Vogt Power International Inc., Technical Bulletin: January, 2001.
5. Standard Methods for the Examination of Water and Wastewater, edn. 22 (2005).

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