ISSN 2250-3153

Physico-Chemical Studies for Boiler Water Treatment and Its Impact on the Quality of Final Industrial Product

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Abstract- The importance of water treatment before using it in boilers is extremely necessary to guarantee the quality of industrial product and its validity for human consumption. This study deals with this very subject on one of the textile industrial company in Al- Buhayrah governorate, Egypt, namely TETCO Company. Water was characterized before feeding it in to boiler and was found to be turbidity, hardness, T.D.S, alkalinity, organic matters, silica and pH are 0.72, 164, 396,146, 3.2, 2.5, 7.5 respectfully. The results indicated the inconsistency of the water with the needed standard ones. This was reflected on the quality of cotton Lycra collected after dying process specially its color homogenity (leveling and direction) when the treatment of water to be used in boiler was modified using carbon filter, sand filter, softener and R.O units, the results was greatly improved. The treated water was found to have Appearance, hardness, T.D.S, alkalinity, organic matters, silica and pH are, clear, zero, 20, 22, zero, 1.5 and 9 respectfully, these results were in accordance with both BS and ES standards and were reflected on the quality of the product very positively.

Index Terms- Total Dissolved Solids (T.D.S),), British Standard (BS), Egyptian Standard (ES), Reverse Osmosis (R.O)

I. 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 in to 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 for plant use [*Abdulrahamn, 2001*]. Two principal types of boilers are used for industrial applications: fire tube and water tubes boilers. In the fired tube boilers, products of combustion pass through the tubes, which are surrounded by water. In the water tube boilers, products of combustion pass around the tubes containing water. The tubes are interconnected to common channels or headers and eventually to a steam outlet for distribution to the plant system [*Brockman, 1988*]. The boiler feed water plant otherwise known as the ion exchange or demineralizer plant supplies water to the boilers. The boiler house or steam generation facility within any plant is frequently referred to as the heart of the plant. The flow diagram of the boiler is shown in figure 1:

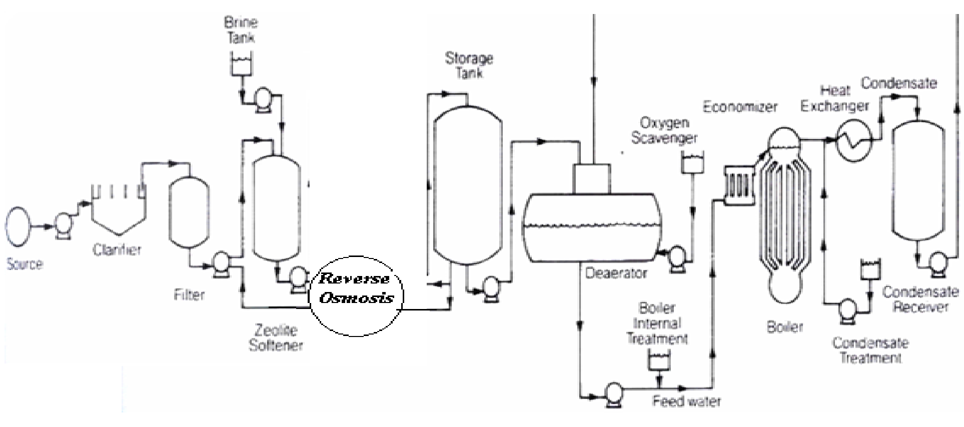


Figure1. Boiler plant flow diagram

Water in pure form has the following properties *[Edem, 2002]:* it is clear and odorless, it freezes at 0°C and 1 bar, it boils at 100°C at a pressure of 760mm Hg, its maximum density is $1 g/m^3$ at 4°C and it is neutral to litmus. Water is said to be polluted when it is unfit for the purpose for which it is intended. This is due to the presence of physical substances and biological pathogens that make water unfit for human consumption *[Sunday, 2003]*. Many of the inorganic cations that we find objectionable in surface and ground water come from natural sources. Water coming in contact with limestone ($CaCO_3$) or dolomite ($CaCO_3.MgCO_3$) picks up calcium ions and magnesium ions which makes it too hard for many households and industrial uses. Underground deposits of iron compounds are responsible for the presence of irons ions in certain ground waters. This ion reacts with hot water to form hydrated ferric hydroxide, which deposits as a brown stain on bathtubs and clothing *[Sunday, 2003]*. Another natural pollutant is silt, which consists of suspended minerals particles resulting from land erosion and other dissolved solids. Water, the most common and vital solvent for wet processes, such as dyeing, printing, rinsing, sizing, desizing, finishing, bleaching and many other purposes, has a great influence over textile processes. Water impurities affect the boiler, in which deposits/scale – like $CaSiO_3$, $CaCO_3$, $CaSO_4$, $Mg(OH)_2$ – formation occur, due to hard water as well as the properties of finished textile products. The extent to which the presence of impurities affects the boiler depends on the concentration of the impurities present in the water. Therefore, the quality of water should be necessarily maintained. In this context, water, containing high concentrations of the abovementioned impurities, much over the accepted limits, should be softened to remove them, for obtaining quality products and for minimizing the problem as much as possible. Water can dissolve so many elements and compounds, due to its covalent as well as polar nature and, ultimately, water can be affected by the presence of various impurities, e.g. suspended solids, by their properties (acidity, alkalinity, hard water), and by dissolved oxygen, all manifesting pronounced effects on textile dyeing processing. Out of these, acidity, alkalinity and dissolved oxygen are responsible for corrosion, usually occurring at high temperature, due to either $CaCO_3$ deposition or scale formation in the system. Calcium and magnesium chlorides or sulphates exist in water in soluble form, both in the presence and absence of carbon dioxide. Alkalinity is mainly caused by the presence of the OH^-, CO_3^{-2} and HCO_3^- ions, which induce hydroxide alkalinity, carbonate alkalinity and bicarbonate alkalinity, respectively. Carbonate alkalinity can occur along with that of either hydroxides or bicarbonates, although bicarbonate and hydroxide cannot exist together. Consequently, alkalinity may be induced by the presence of any of them, by a mixture of carbonate and hydroxide, or by the carbonate and bicarbonate. Usually, acidity is not measured like alkalinity. Undoubtedly, water is a vital solvent for textile dyeing processing; due to its ability to solubilize other compounds. To save industrial machinery, it is much more important to use high grade quality water.

This paper is aimed to study the impact of boiler water treatment on the quality of final product (cotton Lycra textile after dyeing process by reactive dye).

This could be achieved by the following objectives:

1. Carry out measurements on water before and after treatment.
2. Carry out measurements on the final textile product.
3. Compare the analysis results with the standards.

II. Materials and Methods

Experimental analyses were carried out on the water before, during and after treatment according to BS: 2486-1997 and ES: 2794-2005 to determine the following parameters; Appearance, pH, T.D.S, Hardness, electric conductivity, Total Alkalinity, Sulfite, Phosphate, Suspended matter, Silica SiO_2,Total Hardness Dissolved, Oxygen, Oils. In addition; Experimental analyses were carried out on cotton Lycra textile after dyeing process to determine the following parameters; pH, the color fastness to Washing was determined according to the test method ISO 105-C06:1994, the color fastness to Perspiration was determined according to ISO 105-E04:2008, the color fastness to Water was determined according to ISO 105-E01:1994, the color fastness to Rubbing was determined according to ISO 105-X12:2001, the Color leveling and Color direction determined by microscope(USA, jeol, jem-1010).

III. Results and Discussions

TETCO Company, Al- Buhayrah governorate, Egypt, as one of the textile industries, selected to study the impact of boiler water treatment on the final product.

Three studies carried out on it at 01/04/2014, 03/08/2014 and 02/12/2014 and included twelve samples, every study included four samples collected for chemical and physical analysis, first sample was raw water collected from water sources before treated, second sample collected from feed water, third sample collected from boiler water, fourth sample was cotton Lycra textile collected after dyeing process.

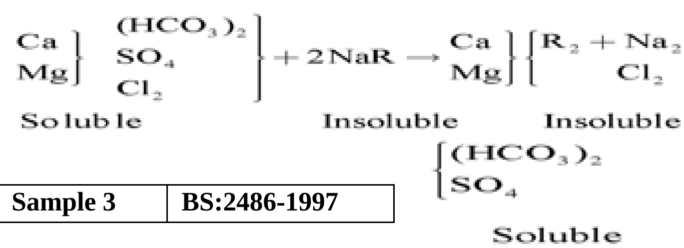
Raw water Samples collected from sources; river water and analyzed at the same day. The characteristics of raw water very importance to identifying impurities in water and suitable treatment process for it, table (1) show the results analysis of first, second and third samples of raw water which its characteristics didn't suitable to boiler because the first sample of raw water was characterized before feeding it in to boiler and was found to be Appearance, hardness, T.D.S, alkalinity, organic matters, silica and pH are turbidity 0.72, 164, 396,146, 3.2, 2.5, 7.5 respectfully. the second sample of raw water was characterized before feeding it in to boiler and was found to be Appearance, hardness, T.D.S, alkalinity, organic matters, silica and pH are turbidity 0.54, 180, 452, 149, 3.5, 2.7, 7.8 respectfully. The third sample of raw water was characterized before feeding it in to boiler and was found to be Appearance, hardness, T.D.S, alkalinity, organic matters, silica and pH are turbidity 0.33, 430, 150, 3.3, 3.1, 7.0 respectfully. The results indicated the inconsistency of the water with the needed standard. The effect of these various impurities or contaminants is to hinder the heat transfer and steam generation processes, to adversely affect the quality and purity of steam, and to act as primary instigators in the corrosion and wastage of boiler plant system materials of construction.A wide variety of chemical reactions and physical mechanisms can and will take place, including the deposition of various crystalline and non-crystalline scales on the waterside of heat transfer surfaces, the formation of sludge's, metal corrosion, and carryover of contaminants in to the steam and affect the quality of cotton textile after dying process[Aalto, J.S, 1994].

No	Testing Name	Sample 1 1/4/2014	Sample 2 3/8/2014	Sample 3 2/12/2014
1	Turbidity (NTU)	0.72	0.54	0.33
2	pH	7.5	7.8	7.0
3	Conductivity	792	792	800
4	T.D.S (mg/l)	396	452	430
5	Free Chlorine (mg/l)	1.55	1.70	1.62
6	Chlorides Cl(mg/l)	58	65	61
7	Total Hardness (mg/l)	164	180	190
8	Ca Hardness (mg/l)	94	105	100
9	Mg Hardness (mg/l)	70	75	90
10	Ca as Ca CO_3(mg/l)	39.5	42	45
11	Mg as Ca CO_3(mg/l)	15	17	20
12	Na (mg/l)	56.74	58	62
13	K (mg/l)	3.57	4.2	3.9
14	SO_4(mg/l)	37.6	39.1	40.5
15	Silica SiO_2 (mg/l)	2.5	2.7	3.1
16	F(mg/l)	0.52	0.57	0.59
17	Total Alkalinity (mg/l)	146	149	150
18	HCO_3(mg/l)	150.8	152	154
19	Fe(/mg/l)	0.0	0.0	0.0
20	Mn(mg/l)	0.0	0.0	0.0
21	Al(mg/l)	0.1	0.01	0.02
22	Organic matters (mg/l)	3.2	3.5	3.3

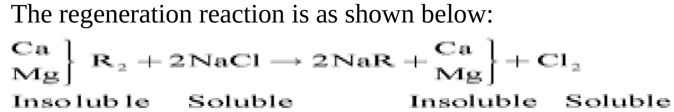
Table1: results the three samples of raw water analysis

Raw water was treated and modified using sand filter, carbon filter and softener; named external treatment. Sand filter is generally applicable for removal of suspended solids and colloidal particles; activation of sand filter does by Backwashing [Bar-Zeev, et al, 2012].Activated carbon filters are employed primarily as raw Water contaminant removal systems for chlorine (by chemisorption) and various organics, in addition using as prefilters for RO and ion exchange processes in the production of high purity Feed Water; Activation of carbon filter does by backwashing [Hasbrouck, 1986].Softener known as ion exchange, softener resin has essentially removed the calcium and magnesium ion to the limit capacity, the resin is regenerated to sodium form with salt solution [Illinois, 1973], and the reaction for softening is shown in the equations below [Walter, 1981].

No	Testing Name	Sample 1	Sample2	Sample 3	BS:2486-1997



Where: R represent the resin.
The regeneration reaction is as shown below:



the results of first sample was gradually improved, but its characteristics didn't suitable to boiler because its characterized before feeding it in to boiler was found to be appearance, pH value at 25°C, Total hardness P.P.M, Dissolved oxygen P.P.M, Total Alkalinity to pH 4.5, Oils and grease P.P.M, T.D.S are turbidity, 7.9, 2.5, 0.06, 35, Zero and176.9 respectfully as show in Table (2).

		1/4/2014	3/8/2014	2/12/2014	
1	Appearance	**turbidity**	Clear	Clear	Clear
2	pH	**7.9**	9.2	9.0	8.5 to 9.5
3	Total Hardness(mg/l)	**2.5**	Zero	Zero	2max.
4	Dissolved Oxygen(mg/l)	**0.06**	Zero	Zero	Zero
5	Total Alkalinity(mg/l)	**35**	22	20	25 max
6	Oils and grease (mg/l)	Zero	Zero	Zero	1max.
7	T.D.S (mg/l)	176.9	25	20	----

Table2: results the three samples of Feed water analysis

High value of hardness was due to the activation of softener wasn't continuously, low value of pH, high value of dissolved oxygen and high value of total alkalinity need adapted with standard value by internal treatment. So continually activated of sand filter, carbon filter and softener lead to hardness equal zero and conform to standard value which equal 2 max, and appearance was clear, reverse osmosis unit Constructed in external treatment which decrease and adapted total dissolved solids and Electrical conductivity, injection by sodium sulfite as oxygen scavenger adapted dissolved oxygen and injection by phosphate adapted pH and alkalinity, the results of second sample of feed water was improved and its characteristics was suitable to boiler because its characterized before feeding it in to boiler was found to be appearance, pH value at 25°C, Total hardness P.P.M, Dissolved oxygen P.P.M, Total Alkalinity to pH 4.5, Oils and grease P.P.M, T.D.S are clear, 9.2, Zero, Zero, 22, Zero and 25 respectfully as show in Table (2).Continually improved and following of internal and external treatment units lead to third sample of feed water was conform to ES: 2794-2005 and BS: 2486-1997 and its characterized before feeding it in to boiler was found to be appearance, pH value at 25°C, Total hardness P.P.M, Dissolved oxygen P.P.M, Total Alkalinity to pH 4.5, Oils and grease P.P.M, T.D.S are clear, 9.0, Zero, Zero, 25, Zero, 20 respectfully.

Feed water input boiler and transformed under pressure to steam and hot water by the application of heat, boiler type is fire tube and its pressure is 10 bars. Three sample of hot water collected from boiler at 01/04/2014, 03/08/2014 and 02/12/2014, and analysis as show in Table (3)

NO	Testing Name	Sample 1 1/4/2014	Sample 2 3/8/2014	Sample 3 2/12/2014	BS:2486-1997 ES:2794-2005
1	pHvalue at 25°C	**12.18**	11.1	11	10.5 to 12
2	Total alkalinity	**1120**	900	600	1000 max.
3	Caustic alkalinity	**364.07**	315	210	350min.
4	Sodium sulfite	40	37	35	30 to 70
5	Phosphate	**70**	30	35	30 to 60
6	Silica SiO_2	2.5	1.5	1.2	5max.
7	Suspended solids	**210**	175	20	200max.
8	T.D.S	**3640.7**	2000	1200	3500 max.
9	Electrical conductivity	**7430**	4000	2400	7000 max.

Table3: three samples of boiler water analysis

First sample of boiler water doesn't conform to BS: 2486-1997 and ES: 2794-2005;Because it's characterized was found to be pH value at 25°C, Total alkalinity, Caustic alkalinity (O or P_2 alkalinity), Sodium sulfite (Oxygen scavenger), Phosphate, Silica SiO_2, Suspended solids, T.D.S, Electrical conductivityat 25°Care 12.18, 1120, 364.07, 40, 70, 2.5, 210, 3640.7, 7430 respectfully. Low quality of first sample due to the poor of external and internal treatment of boiler water; the high value of, pH, T.D.S, Conductivity, total alkalinity, phosphate, suspended mater in boiler may be occur carry over and contaminate the hot water and steam which used in dyeing process, in addition; corrosion of boiler tubes. The improvement of external and internal of boiler water treatment by continually regeneration of sand filter, carbon filter and softener, using reverse osmosis unit, injection by chemicals as phosphate and sulfite and continually the blow down of boiler which removed T.D.S, alkalinity, suspended matter, hardness from it. These improvements lead to Second and third samples of boiler water are conforming to BS: 2486-1997 and ES: 2794-2005 and characteristics of second sample collected from boiler water was found to be, pH value at 25°C, Total alkalinity, Caustic alkalinity (O or P_2 alkalinity), Oxygen scavenger (Sodium sulfite), Phosphate, Silica SiO_2, Suspended solids, T.D.S, Electrical conductivityat 25°C, are 11.1, 900, 315, 37, 30, 1.5, 175, 2000, 4000 respectfully and characteristics of third sample collected from boiler water was found to be, pH value at 25°C, Total alkalinity, Caustic alkalinity (O or P_2

alkalinity), Oxygen scavenger (Sodium sulfite), Phosphate, Silica SiO_2, Suspended solids, T.D.S, Electrical conductivityat 25°Care 11, 600, 210, 35, 35, 1.2, 20, 1200, 2400 respectfully.

Dyeing process of cotton Lycra selected to study the impact of boiler water treatment on it because the water very important in dyeing process,Reactive dyes are water soluble dyes, which are anionic in nature. Since these type of dyes react with fibers and make covalent type of bonding with the fiber. These dyes are having very good fastness to washing, good fastness to light, and Good fastness to dry cleaning, perspiration. It is very easy to obtain level dyeing using reactive dyes. These dyes are primarily used for cotton and other cellulose fiber at an alkaline pH of 9-12. Ramazol is type of reactive dyes (Vinyl sulfone reactive dye) as show in Figure (1) and react in presence of base and under goes elimination reaction to form vinyl sulfone group,

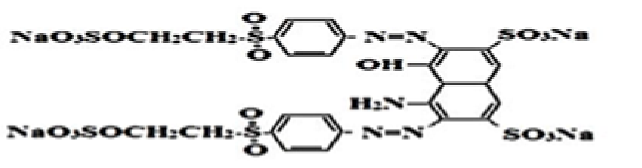


Figure 1.stracture of Remazol Black B da

$Dye\text{-}SO_2\text{-}CH{=}CH_2$ + O-R1- $\longrightarrow$ H (+) $Dye\text{-}SO_2\text{-}CH_2\text{-}CH_2\text{-}OR1$

Where (O-R1) is Cellulose O -, Remazols are reactive dyes based on Vinyl Sulphone system.

Dyeing Procedure:

1. Well dissolved remazol reactive dye in 10 times weight of hot water at 80°C and withdraw the dye gradually (dosing) for Cotton Lycra fiber and wait ten minutes.
2. Withdraw NaCl gradually (dosing) and wait 10 minutes.
3. Withdraw soda ash (Na2CO3) gradually (dosing).
4. Raise temperature gradually to 80°C, where 1°C/1minute and waiting for an hour where heat installed dye on fiber.
5. Cool, drain bath. Rinse cold.
6. Neutralization by acetic acid.
7. Washing by cold water and drain.

The characteristics of First sample of cotton lycra textile didn't conform to recommended standards as show in Table (4).; because the sample containing color leveling and color direction (color homogeneity) due to high values of pH, total alkalinity, Hardness, phosphate, suspended solids, T.D.S and conductivity in boiler water which caused carry over in boiler and contaminated hot water and vapor used in dying process, solids penetrate the active center of textile and lead to dye adsorption decreased; color specks and loss of depth.

The influence of water hardness, with the use of the calcium ion on cotton Lycra dyeing with reactive dyes was positive zeta potential of cotton Lycra was found to decrease and dye adsorption also decreased. Such a phenomenon could be due to the presence of cations in the dyebath, which increases the dyeing potential barrier at the interface between the fiber and dye solution. As a result, there is a higher resistance of dye anions passing through the interface. Under alkaline condition, the zeta potential on cotton Lycra was negative and resulted in a strong barrier for the dye anions. The calcium ion would result in an overall decrease in the absolute value of the zeta potential of cotton Lycra fiber with a resultant increase of dye. The cations had little effect on the zeta potential of the fiber, which was found to be around zero, and dye adsorption also was not influenced. These results showed that the calcium ion is able to produce strong electrolytic effects on dyeing, even in very low concentrations. Because the screening ability of the sodium ion was smaller than that of the calcium ion, when the concentration was low, the overall reduction in absolute values of zeta potential by the sodium ion was found to be smaller.Continually improvements in boiler water treatment lead to high quality of hot water and steam used in dying process of cotton Lycra textile and these results were in accordance with British and Egyptian Standards and were reflected on the quality of the product very positively, The characteristics of second sample collected from cotton Lycra textile conform to recommended standards; pH equal 6.2 and conform to standard value for ISO 3071 which equal (4 to 7.5), Color fastness to Washing; Straining equal 3.5 and Color change equal 4.3 and conform to standard value for ISO105-C06:1994 which equal (Straining = 3 and Color change = 4-5), Color fastness to Perspiration; Straining equal 3.5 and Color change equal 4.5 and conform to standard value for ISO 105-E04:2008 which equal (Straining = 3 and Color change = 4-5), Color fastness to Water; Straining equal 3.2 and Color change equal 4.3 and conform to standard value for ISO 105-E01:1994 which equal (Straining = 3 and Color change = 4-5), Color fastness to Rubbing; dry equal 4 and wet equal 2 and conform to standard value for ISO 105-X12:2001which equal (dry = 4 and wet = 2), Color Leveling and Color Direction aren't appear in sample. The characteristics of third sample collected from cotton Lycra textile conform to recommended standards as show in Table (4).

ISSN 2250-3153

NO	**Testing Name**	**Sample 1** **1/4/2014**	**Sample 2** **3/8/2014**	**Sample 3** **2/12/2014**	**Standard**
1	P^H	6	6.2	6.1	ISO 3071
2	Color fastness to Washing	Straining: 3.3 Color change: 4.2	Straining: 3.5 Color change: 4.3	Straining: 3.2 Color change: 4.1	ISO 105-C06:1994
3	Color fastness to Perspiration	Straining: 3.5 Color change: 4.4	Straining: 3.5 Color change: 4.5	Straining: 3.3 Color change: 4.2	ISO 105-E04:2008
4	Color fastness to Water	Straining: 3.1 Color change: 4.3	Straining: 3.2 Color change: 4.3	Straining: 3.4 Color change: 4.1	ISO 105-E01:1994
5	Color fastness to Rubbing	Dry:4 Wet: 3.5	Dry:4 Wet: 3.6	Dry:4 Wet: 3.1	ISO 105-X12:2001
6	Color Leveling	**found**	No found	No found	By microscope
7	Color Direction	**found**	No found	No found	By microscope

Table4: three samples of cotton Lycra textile

IV. Conclusion

Boiler water included nine tests while product included seven tests, if we absolute every test equal two degree; acceptable quality level of boiler water (AQL) equal eighteen degrees and acceptable quality level of final product (AQL) equal fourteen degrees. We can conclude the quality of first, second and third studies and the relationship between quality of boiler water and quality of final product.

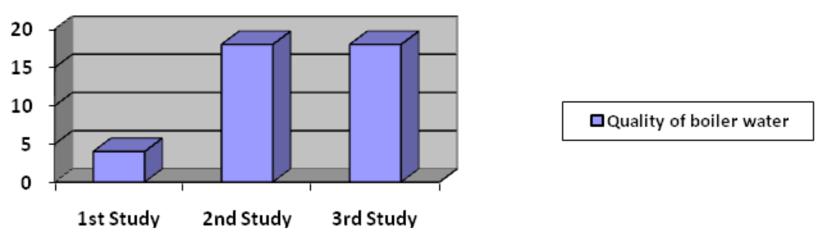


Figure2: quality of boiler water for three studies.

The quality of boiler water treatment increased from first study to second and third study.

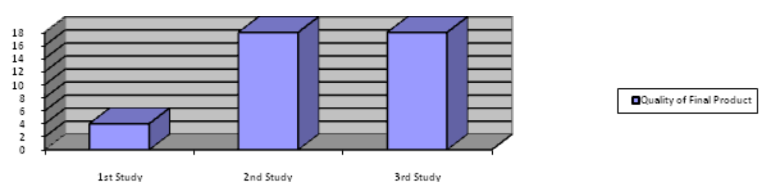


Figure3: quality of Final product for three studies.

The quality of final product increased from first study to second and third study.

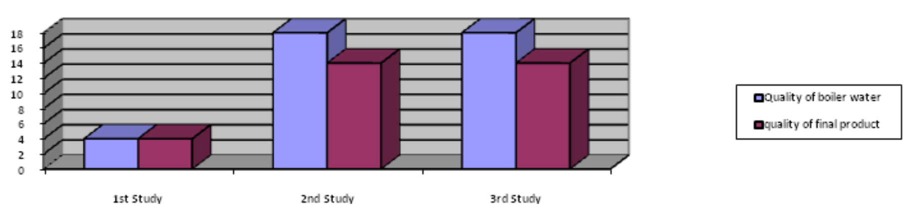


Figure4: Relationship between quality of boiler water and product.

The treatment of water to be used in boiler was modified using carbon filter, sand filter, softener and R.O units, in addition of injected by sodium sulfite and phosphate, the results was greatly improved, and these results were in accordance with both BS and ES standards. The high quality of boiler water reflected on the quality of the product very positively and the results of product in accordance with recommended standards. From these studies we can conclude the quality of boiler water reflected very positively on final products.

V. Recommendations

1. Awareness of the role and the importance of boiler water treatment in companies and the return of the application of it on owners.
2. Reverse Osmosis Unit is very important in boiler water treatment due to its ability removed solids from water and decrease blow down of boiler.
3. Contamination of boiler water by solids, alkalinity and silica caused foaming and carryover of boiler water and lead to contaminated of steam and hot water which used in dyeing process and affected on quality of textile.

As by adopting the above practices all major constructs of a research paper can be written and together compiled to form a complete research ready for Peer review.

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