Experimental Investigation of Energy Efficiency and Saving Opportunities for an Industrial Boiler in Process Industry: A Case Study of a Textile Manufacturing Industry in Kenya

Isaiah kimutai[1] and Paul Maina[1]

[1]Department of Mechanical & Production Engineering, Moi University, Eldoret, Kenya

***Abstract*: Boilers are widely used in process industries to generate steam and hot water. Boiler systems represent a significant portion of total industrial energy use. A slight improvement of boiler efficiency reduces production cost which is necessary for textile industries especially in developing countries to remain profitable and competitive both locally and globally. This paper presents performance assessment of industrial Wood fire- tube boiler used in a textile industry. Performance test was conducted to determine actual performance and energy efficiency of the boiler by flue gas analysis of various flue gas samples exiting the boiler installation. The results displayed poor performance of the boiler with overall efficiency of 17.35% against design efficiency ranging between 75-77%. The major heat losses of the boiler found include dry flue gas loss (58.97%), heat loss due to moisture present in fuel (11.48%) and heat loss due to evaporation of water formed due to H_2 present in fuel (9.61%). Based on the results high energy potential lies on excess air control and reduction of moisture content present in wood fuel.**

***Keywords*: Boiler, Flue gas, Energy efficiency, Energy saving opportunities, Heat loss, Kenya.**

I. INTRODUCTION

Textile manufacturing is an energy intensive process starting from yarn making in spinning through to woven fabric treatment in wet processing. Energy remains one of the main costs of production besides raw material and labour in textile industry. Research shows that in textile industry energy cost range from 15% - 20% over the production cost and it stands next to raw material cost [1]. The rising energy costs demands adoption of opportunities that lower production cost without affecting production yield and quality of products by industrial plants in order to remain competitive both locally and globally. There are various energy saving opportunities that exist in textile industries, many of which are cost effective. However, even cost effective options often are not implemented in textile plants mostly because of limited information [2]. Studies show that with proper energy management,energy cost savings of 5-15 percent can be obtained quickly with little to no required capital expenditure when an aggressive energy management program is adopted. Usually savings of 30 percent is common, and savings of 50, 60, and even 70 percent have been obtained. These savings all result from modifying existing equipment and adoption of new technologies. For most manufacturing, industrial and other commercial organizations energy management is one of the most promising profit improvement and cost reduction programs available today [3].

Boiler system is one of the high energy consuming utility systems employed in textile processing besides motor system, lighting system, compressed air system and steam distribution systems. Boiler system steam generation accounts for 30% of the total industrial energy use [4]. These systems provide thermal energy in the form of steam and heat needed for process heating and production of hot water for process reactions, drying and washing. In the combustion chamber of the boiler, fuel is burnt and heat produced in form of hot flue gas is transferred via boiler tubes to surrounding water by convection.As the hot flue gas transfers heat to water, about 10-30% of heat energy is lost in the process. The temperature of flue gas exiting the boiler typically ranges from 150-250^{o}C. Other heat losses from a boiler are radiation, blow-down, fly ash and bottom ash losses. In order to run a boiler plant at its optimum efficiency, it is necessary to identify the major source of energy loss and recover the energy which is wasted [5].

Industrial plants that assess performance of boiler system uncover potential saving on energy use and cost saving that range from 10-15% through energy management programs [4]. Performance of the boiler reduces with time due to poor combustion, heat transfer fouling and poor operation and maintenance. Deterioration of fuel quality and water quality also leads to poor performance of boiler. Performance testing helps to determine the actual efficiency of the boiler against designed efficiency for necessary corrective action [6].

The efficiency of boiler is the ratio of the net amount of heat which is being absorbed by the generated steam to the net amount of heat supplied to the boiler. This can also be determined by subtracting the net amount heat lost from the boiler from the net amount of heat supplied to the boiler .Hence to improve the boiler efficiency, the amount of heat being wasted from the boiler needs to be minimized by optimizing some parameters such as excess air, fuel flow rate, steam demand and moisture content [7].For complete combustion, excess air is required which is more than the theoretical air requirement to avoid carbon monoxide build up, smoke and soot. The optimum excess air level for maximum boiler efficiency occurs when the sum of the losses due to incomplete combustion and loss due to heat in flue gases is minimum [6]. A typical heat balance in a boiler is shown in figure 1. The goal of heat balance is to improve energy efficiency by reducing avoidable losses such as; stack gas losses (excess air, stack gas temperature), losses by unburnt fuel, blow down losses, condensate losses and convection and radiation

From figure 1, it can be seen that major losses occur due to dry flue gas loss ranging from 10-30% since most of the heat is wasted due to high temperature in flue gas. The recovery of heat from high stack temperature can result in significant energy savings. The boiler efficiency can be improved by minimizing stack temperature by supplying optimum excess air using a variable speed drive. A variable speed drive is used on the fan motor to change excess air ratio [5].

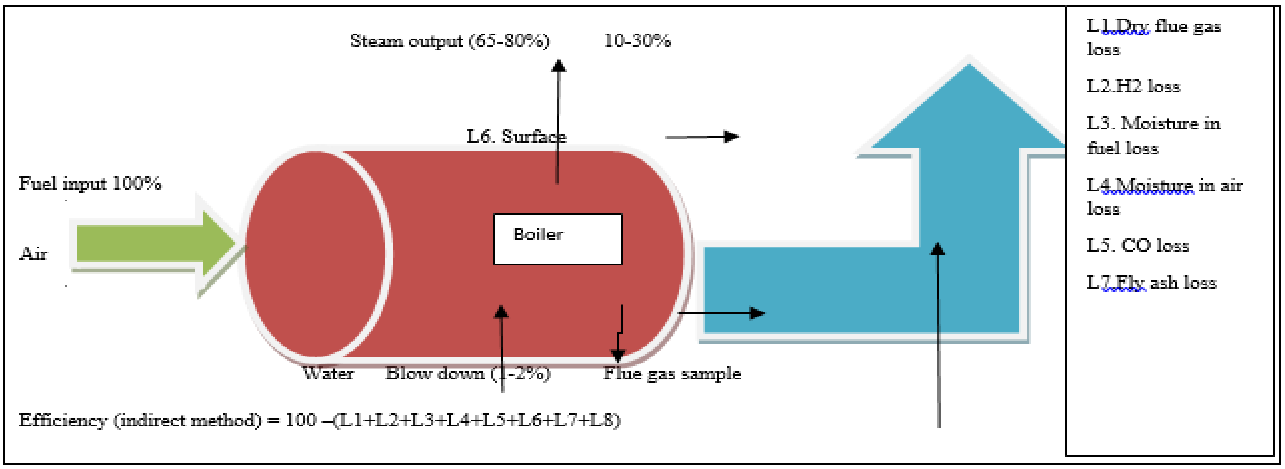

Figure 1: Typical heat balance of boiler [5].

In a textile plant, steam systems represent a significant portion of final energy use by end use. Figure 2 shows the Breakdown of final energy use by end use in the U.S. textile industry. The percentages may vary from one country to another but this figure gives an indication of final energy end-use in the textile industry.In the U.S. textile industry motor systems and steam systems represent the highest share of the end use energy use and each account for 28% of total final energy use in the industry.A significant amount of energy is lost in textile plants. Figure 3 shows that 64% of the energy is used in process while 36% of the energy input to the U.S. textile industry is lost onsite. Motor driven systems have the highest share of onsite energy waste (13%) followed by distribution and boiler losses (8% and 7% respectively). The share of losses could vary from one country to another but it gives a hint of where losses happen in textile industry[9].

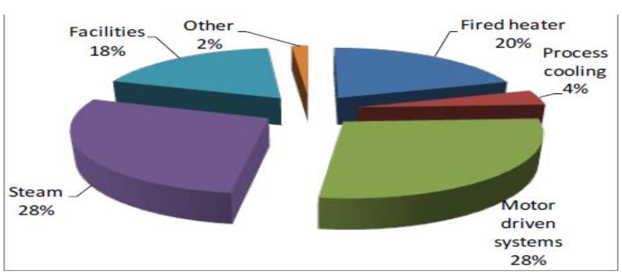

Figure 2: Final Energy End-Use in the U.S. Textile Industry [9]

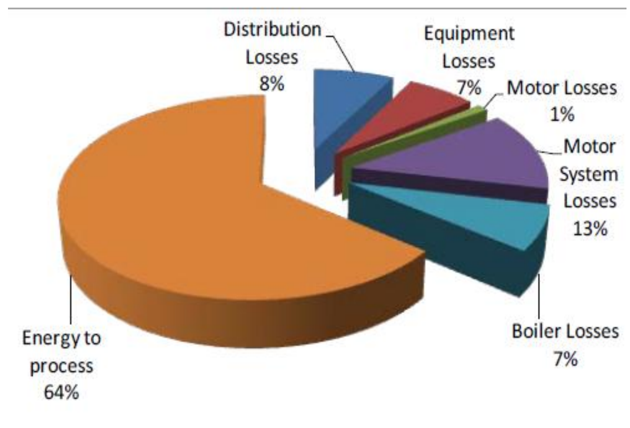

Figure 3: Onsite Energy Loss Profile for the U.S. Textile Industry[9]

For a composite textile plant that has spinning, weaving and wet processing all on the same site, spinning consumes the greatest share of electricity (41%) followed by weaving (18%). Wet-processing preparation (bleaching and finishing) together consume the greatest share of thermal energy (35%). A significant amount of thermal energy is also lost during steam generation and distribution (35%) for which 25% represent boiler losses. These percentages will vary by plant but it gives a hint of energy use in composite textile plants, figure 4[10].

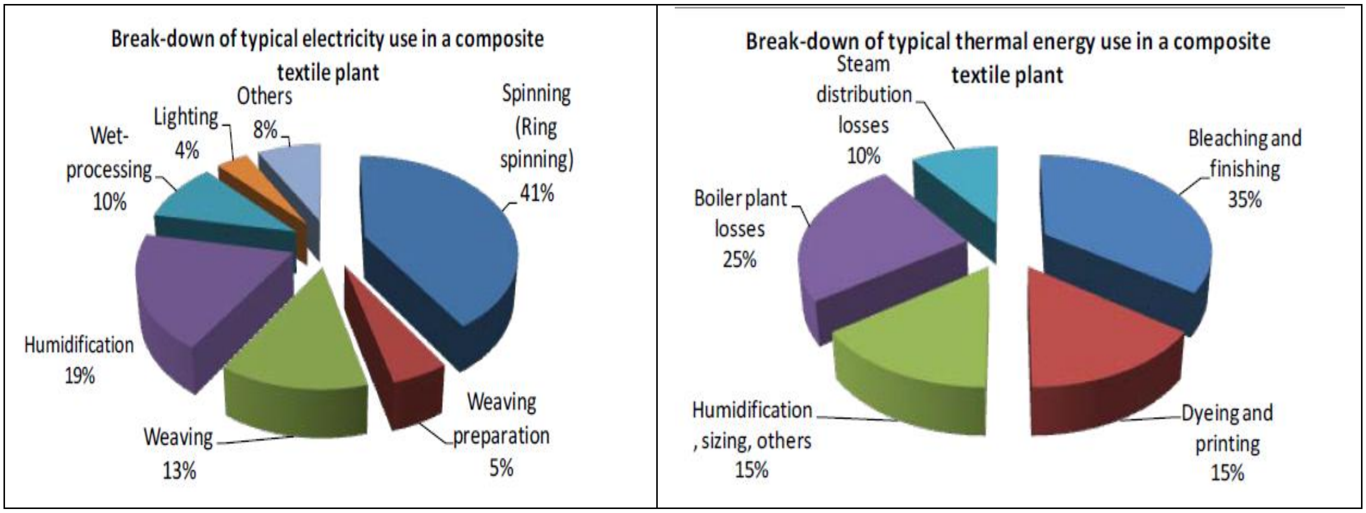

Figure 4: Breakdown of Typical Electricity and Thermal Energy Used in a Composite Textile Plant [10]

1.1 Energy audit

In order to reduce energy consumptions for sustainable and energy efficient manufacturing, continuous energy audit and process tracking of industrial machines are essential. Energy audit is a systematic approach to investigate industrial energy consumption and to exactly locate the source of energy wastage.Energy audit is the key to a systematic approach for decision making in the area of energy management. It is through energy audit that industrial plants understand how they utilize energy and help to identify areas where waste occurs and where opportunities for improvement exist. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. As per the Energy Conservation Act, 2001, of India, Energy Audit is defined as “the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption” [11].

The main aim of this research was to assess the performance of boiler system utilized in a textile industry and identify the energy saving opportunities and energy saving potential that existed, thus providing information needed to minimize energy costs for textile industry to remain competitive and profitable.

1.2 Performance assessment

Boiler efficiency can be determined either by direct method or indirect method.

1) Direct method- also referred to as input output method, compares the energy gain of the working fluid (water and steam) with the energy content of boiler fuel.
2) Indirect method- also referred to as heat loss method, is where the efficiency is the difference between the energy losses and the energy input.

Boiler efficiency testing-indirect method (Heat loss method)

Though direct method is simple and requires few parameters for computation of boiler efficiency, it does not give clues as to why efficiency of boiler system is lower and do not calculate various losses accountable for various efficiency levels. Due to the limitations boiler efficiency was determined using heat loss method.

For heat loss method the efficiency is the difference between the losses and the energy input. The efficiency was determined by subtracting percentage heat losses from 100. The principle heat losses determined are;

L1- Loss due to dry flue gas
L2- Heat loss due to evaporation of water formed due to H_2 in fuel
L3- Heat loss due to moisture present in fuel
L4- Heat loss due to moisture present in air
L5- Heat loss due to incomplete combustion
L6- Heat loss due to radiation and other unaccounted losses
L7- Heat loss due to unburnt in bottom ash
L8- Heat loss due to unburnt in fly ash

Boiler Efficiency by Indirect Method =100 – (L1+L2+L3+L4+L5+L6+L7+L8)

Boiler Efficiency, η= 100- (Total Loss in %)

II. METHODOLOGY

Experiment

To determine the efficiency, measurements were made by sampling the gas at the boiler end. In order to determine the composition and temperature of the combustion gas, portable flue gas analyzer was used as shown in figure 5 below. The measurement was based on combustion gas composition, excess air and the temperature of the combustion gases out of the installation. Parameters collected for boiler efficiency calculation are;

- Percentage of Oxygen in the flue gas
- Percentage CO2 in the flue gas
- Percentage CO in the flue gas
- Flue gas temperature in °C (T_f)
- Ambient temperature in °C (Ta)
- Humidity of air in kg/kg of dry air
- GCV of fuel in kCal/kg
- Percentage combustible in ash
- GCV of ash in kCal/kg
  1kcal/kg = 4.1868 KJ/kg

Figure 5: Flue gas analyzer data measurement for wood fire-tube boiler

Table 1: Wood fired tube boiler flue gas analysis experiment data

Flue gas analysis data- Testo 310				
	Sample 1	Sample 2	Sample 3	Average
Flue gas temperature, T_f	395.1°C	329.7°C	389.3 °C	371.4 °C
Oxygen, O_2	17.7%	15.0%	16.5%	16.4%
Carbon monoxide, CO	33 ppm	28ppm	29ppm	30ppm
qA[1]	80.9%	79%	80%	80%
Undiluted CO	213 ppm	188ppm	206ppm	202.3ppm
Carbon dioxide, CO_2	3.19%	5.8%	3.8%	4.3%
Ambient temperature, T_a	23.0 °C	24.6 °C	24.0 °C	23.9 °C
Combustion efficiency, EFF	19.0%	21%	20%	20%
Lambda (Air ratio)	6.36	3.50	4.3	4.72
Relative humidity				50%
Dry bulb temperature(°C)				23.9°C
Humidity of air kg/kg of dry air[2]				0.009
Specific heat of flue gas in kCal/kg°C (C_p)[3]				0.25
Specific heat of superheated steam in kCal/kg°C (C_p)[4]				0.48

Source: Researcher's experiment, 2018

[1]Flue gas loss without due consideration of the calorific value range[2]psychometric chart[3]steam table (dry air) [4]steam table (vapour)

Table 2: Wood fire tube Boiler data

Boiler data	
Fuel	Wood
Capacity	3TPH
Steam pressure/temperature	5bar/151.8°C
Quantity of wood fuel	2,000kg/h
Feed water temperature	80 °C
Enthalpy of steam at 151.8°C, h_g	2749 KJ/kg
Enthalpy of feed water at 80°C, h_f	335 KJ/kg
Wood moisture	40%
GCV of wood (40% moisture)	2,615 kcal/kg or 10,950 KJ/kg
GCV of bottom ash	900 kcal/kg or 3771 KJ/kg
GCV of fly ash	650 kcal/kg or 2724 KJ/kg
Ratio of bottom ash to fly ash	90:10

Table 3: Ultimate analysis of wood

Content	%
Carbon	30.18
Hydrogen	3.72
Oxygen	25.85
Nitrogen	0.02
Sulphur	0.00
Ash	0.23
Moisture	40

Source: Isidoro Martinex, 1995-2018

Boiler efficiency calculations-indirect method [6]

Step 1- The theoretical air requirement

The theoretical air requirement = [(11.6×C) + {34.8 × (H_2-O_2/8) + (4.35×S)}]/100kg/kg (1)

of fuel (from fuel analysis) = [(11.6×30.18) + {34.8 × (3.72-25.85/8) + (4.35×0.00)}]/100 **= 3.67 kg of air/kg of fuel**

Step 2 – The percentage of excess air supplied

% Excess Air Supplied (EA) = [O_2% / (21-O_2%)] ×100 (from flue gas analysis) (2)

= [16.4 / (21-16.4)] ×100 **= 356.5%**

Step 3- The actual mass of air supplied

Actual mass of air supplied/kg of fuel (AAS) = [1+EA/100] × Theoretical Air (3)

= [1+356.5/100] × 3.67 **= 16.75 kg of air/kg of fuel**

Mass of flue gas (m)/kg of fuel = mass of actual air supplied/kg of fuel + 1 kg of fuel

= 16.75 + 1 **= 17.75 kg/kg of fuel**

Step 4- The boiler losses (L1)

i. *Dry flue gas loss*

% heat loss due to dry flue gas
= m×C_p× (T_f-T_a) ×100 /GCV of Fuel (4) Where,
m =Mass of dry flue gas in kg/kg of fuel
C_p =Specific heat of flue gas in kCal/kg
T_f=Flue gas temperature in ^oC
T_a=Ambient temperature in oC
= 17.75×0.25 (371.4-23.9) ×100 /2,615 **= 58.97 %**

ii. *Heat loss due to evaporation of water formed due to H_2 in fuel (L2)*

% heat loss due to hydrogen in fuel
= (9×H_2× {584+C_p (T_f-T_a)}/GCV of fuel) ×100 (5) Where,
H_2 =kg of hydrogen present in fuel on 1 kg basis
C_p =Specific heat of superheated steam in kCal/kg^{o}C
T_f =Flue gas temperature in ^{o}C
T_a=Ambient temperature in ^{o}C
584=Latent heat corresponding to partial pressure of water vapour
= [9×3.72/100× {584+ 0.48(371.4-23.9)}/2,615] ×100 = **9.61%**

iii. *Heat loss due to moisture present in fuel (L3)*

% Heat loss due to moisture present in air
= (M× {584+C_p (T_f-T_a)} /GCV of Fuel) x100 (6) Where,
M=kg of moisture in fuel in 1 kg basis
C_p=Specific heat of superheated steam in kCal/kg^{o}C
T_f =Flue gas temperature in ^{o}C
T_a=Ambient temperature in ^{o}C
584=Latent heat corresponding to partial pressure of water vapour

= 40/100× {584+0.48(371.4-23.9)} /2,615) x100

= **11.48%**

iv. *Heat loss due to moisture present in air (L4)*

% Heat loss due to moisture in air
$= \frac{\text{AAS} \times \text{humidity} \times C_p \times (T_f - T_a)}{\text{GCVoffuel}} \times 100$ (7) Where,
AAS=Actual mass of air supplied per kg of fuel
Humidity factor=kg of water/kg of dry air
C_p=Specific heat of superheated steam in kCal/kg^{o}C
T_f =Flue gas temperature in ^{o}C
T_a=Ambient temperature in ^{o}C (dry bulb)

$= \frac{16.75 \times 0.009 \times 0.48 \times (371.4 - 23.9)}{2,615} \times 100$ = **0.96%**

v. *Heat loss due to incomplete combustion(L5)*

% heat loss due to incomplete combustion
$= \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{\text{GCV of fuel}} \times 100$ (8) Where,
CO= volume of CO in flue gas (%)
CO2 = actual volume of CO2 in flue gas (%)
C= carbon content kg/kg of fuel
$= \frac{0.003 \times 30.18/100}{0.003 + 4.3} \times \frac{5744}{2,615} \times 100$ = **0.05%**

vi. *Heat loss due to radiation and other unaccounted losses (L6)*

For industrial fire tube boiler surface loss and other unaccounted losses ranges from **1.5** to 2.5% based on literature.

vii. *Heat loss due to unburnt in bottom ash (L7)*

% heat loss due to unburnt in bottom ash

= (Total bottom ash collected per kg of fuel burnt ×GCV of bottom ash/GCV of Fuel) ×100 (9)

= (0.00207 ×3771/10,950) ×100 **= 0.07%**

viii. *Heat loss due to unburnt in fly ash (L8)*

% heat loss due to unburnt in fly ash
= (Total ash collected per kg of fuel burnt ×GCV of fly ash /GCV of Fuel) ×100 (10)
= (0.00023 ×2724 /10,950) ×100 **=0.006%**

Boiler efficiency by indirect method

= 100 - (L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8)

=100- (58.97+9.61+11.48+0.96+0.05+1.5+0.07+0.006)

= 17.35 %

III. RESULTS AND DISCUSSION

Table 4:Summary Of Heat Balance For Wood Fire-Tube Boiler

Input/output Parameter		kCal / kg of fuel	%
Heat Input in fuel	=	2,615	100
Various Heat losses in boiler			
1. Dry flue gas loss	=	1,542	58.97
2. Loss due to hydrogen in fuel	=	251.6	9.62
3. Loss due to moisture in fuel	=	300.2	11.48
4. Loss due to moisture in air	=	25.1	0.96
5. Partial combustion of C to CO	=	1.3	0.05
6. Surface heat losses	=	39.2	1.5
7. Loss due to Unburnt in fly ash	=	1.8	0.07
8. Loss due to Unburnt in bottom ash	=	0.17	0.006
Total Losses	=	2,161	82.65
Boiler Efficiency= 100 - (L1+ L2 + L3+ L4+ L5+ L6+ L7+ L8) = 17.35%			

The boiler under study displayed poor performance since most of the measured parameters showed significant deviations from theoretical values as shown in table 5 below. From table 5, it can be seen that the percentage of excess air and oxygen measured are 356.5% and 16.4% instead of theoretical 30% and 5% respectively which contributed mainly to low boiler efficiency.

Table 5: Summary of Wood fire tube- boiler performance

Parameters	Theoretical	Measured
CO2 in dry flue gas (%)	15.5%	4.3%
Flue gas oxygen content (%)	5%	16.4%
Air fuel ratio (kg of air /kg of fuel)	5.8	27.38
Mass of flue gas (kg of flue gas/kg of fuel)	6.4	17.75
Excess air (%)	30	356.5
Boiler efficiency (%)	75-77 (expected)	17.35

Energy Saving Opportunities

The boiler heat loss results calculated earlier indicates that the major losses in the system are due to dry flue gas 58.97%, followed by losses due to moisture 11.48% and loss due to hydrogen in fuel 9.62%. According [12] typical fire tube boiler efficiency range from75-77%. Improving the efficiency of the boiler under study is a clear opportunity to conserve energy in the industry. The clear options of improving boiler efficiency are discussed below;

1. *Excess air control*

If the percentage of excess air is adjusted to optimum levels as per table 6 below to obtain the required CO_2 percentage (15.5%), oxygen (5%) and excess air (30%), then recalculating boiler efficiency, the efficiency would improve from 17.35% to 56.98%.

Table 6: Optimal flue gas composition [13]

Fuel	O_2 (%)	CO_2 (%)	Excess Air (%)
Natural Gas	2.2	10.5	10
Liquid petroleum fuel	4.0	12.5	20
Coal	4.5	14.5	25
Wood	5.0	15.5	30

Source: EPA, 2001

Therefore the fuel savings achieved by improving the boiler combustion efficiency to be 56.98% is estimated as follows;

Fuel saving = [1- (η before/ η after)] Where,

η before: combustion efficiency before improvement

η after: combustion efficiency after improvement

Fuel saving potential = [1- (η before/ η after)]

= [1- (17.35/ 56.98)]×100 **= 69.55%**

To manage excess air, on-line oxygen analyzer and variable speed drive should be installed to regulate air automatically.

2. *Reducing moisture content of wood fuel*

The efficiency of boiler is greatly affected by the quality of fuel. Proper drying and preservation of wood fuel is necessary to improve quality. Moisture free fuel should be fed to the boiler so that no amount of heat is lost in removing the moisture from fuel and all the heat can be efficiently used to convert water to steam. Proper drying of fuel also improves fuel properties and gross calorific value thus improving boiler efficiency. Firewood should ideally have a moisture content of below 25% of total weight by the time it is used. Figure 6 shows the fresh wood logs utilized in the industry under study.

Figure 6: Wood fuel used.

The cheapest way to dry firewood is by natural drying. The logs are cross cut and then split into firewood as soon as possible after harvesting and stored in an open place where sun and wind can dry the fuel. Firewood needs to be covered on top or preferably stored under a roof

to keep out rain and should be lifted out of direct ground contact. This will improve the air flow through the wood. If the moisture content of wood fuel is improved to 20%, then the savings is calculated using equation 6 as follows;

Table 7: Wood composition (% wt) and GCV

% wt water (moisture content)	0	**20**	40	60
C	50.30	**40.24**	30.18	20
H	6.20	**4.96**	3.72	2.7
O	43.08	**34.46**	25.85	17
N	0.04	**0.03**	0.02	0.01
S	0.00	**0.00**	0.00	0.00
Ash	0.37	**0.31**	0.23	0.15
Total	100	**100**	100	100
GCV(KJ/kg)	19,900	**15,400**	10,950	6,500

Source: Isidoro Martinez, 1995-2018

% Heat loss due to moisture present in air = (M× {584+C_p (T_f-T_a)} /GCV of Fuel)x100

M=kg of moisture in fuel in 1 kg basis

= 20/100× {584+0.48(371.4-23.9)} /3,675) x100

= **4.09%**

Improving moisture content of wood fuel used from 40% to 20% reduces losses due to moisture from 11.48% to 4.09%, and boilers efficiency improves from 17.35% to 24.74%, therefore provision of wood drying is necessary before supplying to the combustion chamber. Wood logs should be split to smaller sizes and placed inside a properly designed shade which allows proper stacking. It is important also to use dried wood on first come first serve basis to ensure that most dry wood are used first.

Estimated fuel saving on drying of wood fuel is calculated using equation 3

Fuel saving = [1- (η before/ η after)]
Fuel saving potential = [1- (17.35/ 24.74)] ×100
= 29.87%

Other Energy saving opportunities identified includes;

Proper insulation of the boiler walls and piping's to reduce radiation and convection heat losses to the surrounding. The boiler insulation should be assessed and replaced where it is insufficient or showing signs of degradation.

Boiler maintenance should be done regularly and removing the scale and ash deposits on the fire tubes should be given priority as these deposits act as insulation thus preventing heat transfer between flue gas and boiler water. High percentage of heat losses is due to the high temperature of dry flue gases leaving the boiler. Figure 7 shows blocked fire tube of the boiler by ash deposits causing high flue gas temperature of 371.4°C.

Leakages of hot water and steam are significant source of heat loss from the boiler causing unnecessary consumption of extra wood fuel. Fixing leakages by repairing pipes is essential to minimize steam losses.

Waste heat recovery should be employed to utilize high temperature of flue gases (371.4°C) which is currently vented to the atmosphere. Flue gas temperatures above 200°C can be used to increase boiler feed water temperature or dry wood fuel to achieve moisture content below 25°C. Significant energy savings can be achieved from the reuse of the high temperature condensate.

Figure 7: Blocked fire tubes of wood boiler due to ash deposits

IV.CONCLUSION

In this paper energy management is explored for energy efficiency and energy conservation in textile industry. Energy investigation presented enormous saving potential that exist in the boiler system used. The major heat losses affecting the boiler system are heat loss due to dry flue gas and heat loss due to moisture present in boiler fuel. It has been shown that reducing dry flue gas loss and moisture present in fuel improves significantly the overall efficiency of the boiler system. The overall net effect is cost saving in fuel which reduces cost of production in textile industry.A substantial amount of energy can be saved by adopting energy saving measures and by improving the overall boiler efficiency. In addition, a small improvement on the boiler efficiency will help to save forest cover and environment from CO_2 emission causing global warming.

REFERENCES

[1] Khude, P (2017). A Review on Energy Management in Textile Industry. Innovative Energy &Research.

[2] Hasanbeigi, A. (2010). Energy-efficiency improvement opportunities for the textile industry. Berkeley, CA: Lawrence Berkeley National Laboratory.

[3] Capehart, B.L., Turner, W. C. and Kennedy, W. J. (2012). Guide to energy management. Seventh Edition. The Fairmont Press, Inc.USA

[4] United States Department of Energy (U.S. DOE) Industrial Technologies Program (ITP), Steam Tip Sheets, January 2006. Industrial technologies Program, Office of Industrial Technologies, U.S. Department of Energy, Washington, DC, USA. 2006

[5] Barma, M. C., Saidur, R., Rahman, S. M. A., Allouhi, A., Akash, B. A., & Sait, S. M. (2017). A review on boilers energy use, energy savings, and emissions reductions. Renewable and Sustainable Energy Reviews, 79, 970-983

[6] Bureau of Energy Efficiency-India (BEE), 2008. Energy Efficiency in Thermal Utilities-Chapter 2. Energy performance assessment of boilers.

[7] Kouprianov V, Chullabodhi C, Kaewboonsong W. Cost based optimization of excess air for fuel oil/gas-fired steam boilers. Int Energy J 2007; 21(2).

[8] Jayamaha L. Energy-efficient building systems: green strategies for operation and maintenance. McGraw Hill Professional; 2006

[9] United States Department of Energy (U.S. DOE), 2004. Energy Use, Loss and Opportunities Analysis: U.S. Manufacturing & Mining.

[10] Sathaye, J.; Price, L.; de la Rue du Can, S.; Fridley, D., (2005). Assessment of Energy Use and Energy Savings Potential in Selected Industrial Sectors in India. Report No. 57293, Berkeley, CA: Lawrence Berkeley National Laboratory

[11] Hasanbeigi, A., & Price, L. (2010). Industrial energy audit guidebook: Guidelines for conducting an energy audit in industrial facilities.

[12] Morvay, Z.K. and Gvozdenac, D.D., (2008). Applied Industrial Energy and Environmental management. John Wiley & Sons Ltd. UK.

[13] U.S.EPA, (2001). Guide to Industrial Assessment for Pollution Prevention and Energy Efficiency.EPA/625/R-99/003.United States Environmental Protection Agency, Office of Research and Development Washington DC.