Performance Improvement of Biomass Fired Thermic Fluid Heaters Used in Sri Lanka

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Abstract – *The best industrial heating solution depends on the type of application. Heaters are used in different applications in many industrial settings. Industries such as plastic, food, oil, gas and the chemical industry all use industrial heaters (oil, gas, electric, and biomass) in various processes. Electric heaters are good enough for small applications due to high cost of the electricity. Sometimes it is used as stand-alone units where the equipment cannot be installed close to the main heat source. Steam boilers too are used in Sri Lanka for many heating applications. Hot fluid heaters are also used, but not as much as steam boilers. Moreover, biomass is widely used in Sri Lankan industry for heating requirements due to high furnace oil prices. Many people use a water heater instead of a boiler for radiant floor heating because of less cost. A thermic fluid system is similar in nature to the hot water boiler system and this fluid can be heated up to 300 ^{0}C under low pressure. Thermic fluid heater is a unit in which a liquid phase heat transfer medium is indirectly heated and circulated to one or more heat energy users within a closed loop system.*

This paper discusses about the performance enhancement of the biomass fired thermic fluid heater installed in a company located in Malwana, Sri Lanka. This company mainly manufactures rubber gloves which does not require high pressure but require high temperature. Low efficiency, high energy consumption and high stack temperature are the main problems of the plant. This study showed that by optimizing the plant parameters, the total heat loss can be reduced from 58% to 25%, hence the overall efficiency of the plant can be increased from 42% to 70%. Results were verified by using Engineering Equation Solver (EES) software.

Keywords: *Thermic fluid heaters, Boilers, Biomass*

Nomenclature

M - mass of fuel burnt (kg/h)
C - Calorific value of saw dust (kCal/kg)
$\dot{v}$ - Volume flow rate (m^3/h)
$\Delta\theta$ - Thermic fluid inlet and outlet temperature difference (^{0}C)

c - Specific heat (kCal/kg^{0}C)
ρ - Density of the thermic fluid (kg/m^3)
k - Heat transfer efficiency factor (W/m^{2}K)

1 INTRODUCTION

The share of biomass consumption in the total energy demand is 45.4% in 2017, whereas the share of petroleum was 43.1% (Sri Lanka Energy Balance, 2017). Boilers are mainly used in Sri Lanka for heating requirements in the industry. Biomass are mostly used in boilers and it is estimated that the biomass usage in industrial sector is 75.8% in 2016 while 78.4% in 2017 (Sri Lanka Energy Balance, 2017).

Fuelwood are the most common forms of biomass (Abeywardhena, 2005). There are other heating methods such as hot fluid heaters, but the usage is less compared to boilers. Use of steam for heating applications are essential for some applications like steaming rice in the process of parboiling, heating, and pressurizing of tyre moulds in tyre manufacturing process.

Thermic fluid heater is industrial heating equipment, used where only heat transfers are desired instead of pressure. A thermic fluid is circulated in the entire system for heat transfers to the desired processes. The heaters are used in curing ovens, tank heating, autoclaves, calendar mills, die-mould heating, building heating systems. Thermic fluid heaters are also used for curing of rubber gloves or as heat exchangers which is not required high pressure but need higher temperature. Usage of biomass fired thermic fluid heaters are rapidly growing in the industry. Though thermic fluid heaters considered as high-tech or easily adoptable, the installations are limited due to lack of awareness, minimal guidance and also jurisdictions are low for regulating thermic fluid systems [Omer, 2008].

Use of suitable heating source for an application in industrial context is vital as it gives huge economic benefits. Nowadays the thermic fluid heaters become emerging technology for heating solutions for industrial application in Sri Lanka because of its advantages over steam boilers. Main advantages of the thermic fluid heaters are less operational and low maintenance cost. High temperature under low pressure is another advantage over steam boiler because of higher safety related accident reported with steam boilers.

Thermic fluid heaters are in two forms based on the primary energy source, namely furnace oil and biomass. Biomass fired thermic fluid are less popular because of higher fuel price. Still there is abundance of biomass available and considered as sustainable energy source in Sri Lanka (Rathnasiri, 2008). Therefore, this research is focused on the performance enhancement of 3MkCal/h thermic fluid heater and the method of analysis adopted can be replicated to any thermic fluid heater, which is categorized under thermic fluid heaters. In addition, it is also aimed to provide recommendations for poor plant efficiency, higher consumption of biomass and higher stack temperatures that are identified as the main problematic issues of the plant. Therefore, identifying drawbacks of the existing system and conducting a theoretical study for optimizing the system performance by using thermic fluid were the main objective of this research.

1.1 Biomass Fired Thermic Fluid Heater

Thermal fluid heater (TFH) is a unit which uses the indirect heating, in which a liquid phase heat transfer medium is heated and circulated to one or more heat energy users within a closed loop system. The common heat transfer media are thermic oil, glycol, and water (Devraja et al, 2019) . Nevertheless for common thermic fluid heaters (TFH), the working fluid is thermic oil. The process of the thermic fluid system is similar to the hot water boiler system. This fluid can be heated up to 300 ^{0}C under low pressure which is beneficial for processing of the system.

There are many advantages of having thermic fluid heating system over steam boiler. In thermic fluid heating systems, there are no corrosion in pipes and fittings as there is no water circuit in TFH. This system has simple piping circuit with free from blow down/steam traps and no water treatment required. Furthermore high temperature under low pressure, less maintenance, less operating cost, no fluid losses and hence no fluid make-up required, heating and cooling with a single fluid, new additions are easy to incorporate are the wealth of using thermic fluid heating systems (Wadkinson, 2012).

Steam is an excellent medium for energy transfer, but it is much expensive to use due to the cost associated with operation, maintenance in the today's context (Wanson, 2008). The water treatment activities, frequent inspection and blow downing are required during operation of a boiler. In addition to that, the maintenance of steam traps and valves, frequent tube cleaning and inspection cause the higher operational and maintenance cost. Thermic fluid heater provides less cost during operation and maintenance comparing to the steam boilers. For smooth operation of the system the performance can be further enhanced with periodic cleaning of the coil unit and general preventive activities such as greasing.

Basically, the installation cost is almost same for an equivalent capacity biomass fired boiler and a thermic fluid heater excluding pre and feed water treatment facilities of a boiler. Piping circuit installation cost for steam boiler is higher due to stainless material used for piping. Additionally, a thermic fluid heater piping circuit is required for thermic oil filling-up which cost substantial amount of initial cost.

The risk associated with the steam boiler hazards is one of the main aspects on research alternatives. The most common boiler hazards that lead to accidents are low water levels, excessive pressure, and a failure to purge combustible gases from the firebox before ignition. These hazards can cause serious boiler accidents like explosions or fire. In addition to boiler accidents the economic loss which has raised increasing concern to take measures against awareness of installation and operation of boilers (Prinyankara & Medagedara, 2016; Bierl, 2017). No such explosions can take place in TFHs since it is operating below 2 bar pressure. Therefore, lower safety risk is one of the biggest advantages that thermic fluid heater has over steam boiler.

1.2 Main Features and Operation of Biomass Fired Thermic Fluid Heater

The operational system of vertical biomass fired thermic fluid heater (Thermax 2013) is shown in figure 01. Normally the combustion chamber of the furnace is designed to get the required amount of heat capacity of the heater. Heat transfer happens through both convection and radiation. The number of heat exchangers depend on the requirement of the heat capacity of the plant. Fuel used in thermic fluid heaters are furnace oil, gas, coal or biomass such as wood chip (WC), saw dust (SD), briquettes or pellets. Biomass is widely used in Sri Lanka due to relatively higher furnace oil prices. But the preparation of the fuel is required when using biomass like wood chip or saw dust. Moisture is a critical factor,

because increase in moisture from 0% to 40% may decrease the heating value by about 66% as some literature reveals.
Thermic fluid heater is also provided with forced draft fan, induced draft fan to control the air draft inside the combustion chamber. An Air pre-heater is used for air pre-preparation for combustion with the help of flue gas. When the combustion process is over this flue gas is expelled through the smokestack. In the thermic fluid heater, the flue gas is passed through air pre-heater, water pre-heater, pollution control unit before it is expelled to the environment. Forced draft fan and induced draft fan are controlled in such a way that negative pressure is kept inside the combustion chamber all the time. Therefore, this achieves good combustion as this allows fuel to mix with air rather than resting at the bed.

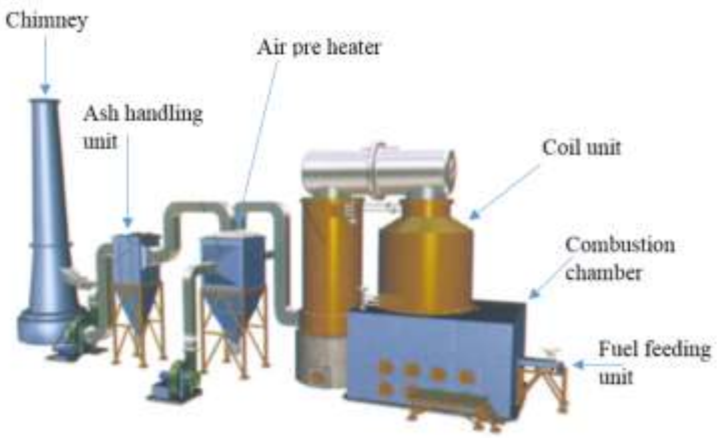

Fig. 01: Vertical biomass fired thermic fluid heater (Thermax, 2013)

As figure 01 shows the coil unit absorbs the heat from flue gas and delivers to the heat exchangers located at heat demand points through the piping circuit where heat is used for effective use. (Sigma Thermal, 2016). Piping circuit is a closed system and therefore there is no fluid losses. But it is opened to the atmosphere at the expansion tank to cater to the fluid volume variations during temperature increment.

1.3 Performance Parameters of Thermic Fluid Heaters (TFH)

Attributes of the performance of a thermic fluid heater are outlined as fuel consumption combustion performance, heat transfer performance and flue gas handling. Fuel consumption is a main design parameter for TFH as it mainly depends on the limitations of the fuel limit to attain the required heat. In the case of biomass, fuel consumption depends on the size of the fuel particles, moisture level, fuel damper adjustment, air draft pattern and absence of debris in the fuel.

The level of the quality of the fuel and air handling are the determinant factors for combustion performance. Combustion efficiency will be lower when using fuel which has higher moisture level, bigger size chips and presence of foreign particles. In addition, combustion efficiency will be lowered if the air flow is not uniformly spread throughout the combustion chamber. Improper combustion not only reduces efficiency but also increases fuel consumption and environment pollution.

Heat received by the thermic oil depends on the quality of the thermic oil, oil flow rate and the temperature difference ($\Delta\theta$) in fluid inlet and outlet pipes. The characteristics of the pipe and its material are also affected by the heat transfer rate.

1.4 Optimizing the Heat Transfer Performance of TFH

Performance optimizing is referred to as running of TFH within designed limits. Therefore, identification of accurate heater efficiency and opportunities for efficiency improvement are estimated for thermic fluid plant as well. Performance of the plant is characterized by its efficiency level. For the calculation of boiler/heater efficiency, direct and indirect methods can be used.

1.4.1 Direct Method

This is a common method of calculating boiler/or heater efficiency. It is the percentage ratio of heat received by the working fluid to the heat supplied by the fuel.

$$\text{Efficiency } (\eta) = \frac{\text{Heat received by the working fluid x 100\%}}{\text{Heat supplied by the fuel (SD)}} \quad \text{--------------------(i)}$$

1.4.1.1 Heat Supplied by the Fuel (Saw dust)

Heat supplied $= M * C$ ----------------------(ii)

Where M – mass of fuel burnt (kg/h)
C – Calorific value of saw dust (kCal/kg)

1.4.1.2 Heat Received by the Working Fluid (Thermic fluid)

Heat received $= \dot{v} * \Delta\theta * c * \rho * k$ ----------------------(iii)

Where
$\dot{v}$ - Volume flowrate (m^3/hr)
$\Delta\theta$ - Thermic fluid inlet and outlet temperature difference (^0C)
c - Specific heat (kCal/kg^{0}C)
ρ - Density of the thermic fluid (kg/m^3)
k - Heat transfer efficiency factor

1.4.2 Indirect Method

This is also known as the heat loss method. The efficiency can be calculated by subtracting the heat loss fractions from 100 as follows:

η = = 100 - (i + ii + iii + iv + v + vi + vii)

Where the principle losses are,

i. Dry flue gas
ii. Evaporation of water formed due to H_2 in fuel
iii. Evaporation of moisture in fuel

iv. Moisture present in combustion air
v. Unburnt fuel in fly ash
vi. Unburnt fuel in bottom ash
vii. Radiation and other unaccounted losses

The governing standards with regards to the indirect method are the British Standard, BS 845:1987 and the USA Standard ASME PTC41Power Test Code Steam Generating Units.

1.4.3 Calculation of principle losses

Principal losses depend on theoretical air requirement, percentage of excess air and actual mass of air supplied/kg of fuel. Once those have been estimated, heat losses can be estimated to obtain the heater efficiency.

Theoretical air requirement = [(11.43 x C) + {34.5 x (H_2 – O_2/8)} + (4.32 x S)]/100 kg/kg of fuel -----------------(iv)

Percentage of excess air supplied (EA) $= \frac{O_2\%}{21-O_2\%} X\ 100$ --------------------------------(v)

Actual air supplied (AAS) per kg of fuel = {1 + EA/100} x theoretical air --------(vi)

1.4.5 Heat losses

(i) Percentage heat loss due to dry flue gas $= \frac{M\ X\ C_p\ X\ (T_f - T_a)}{GCV\ of\ fuel}$ x 100 ------------(vii)

C_p = Specific heat of flue gas = 0.23 kcal/kg ˚C
M = Mass of dry flue gas in kg/kg of fuel
M = Combustion products from fuel: CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/water vapour in the flue gas should not be considered)

M = Total mass of flue gas = mass of actual air supplied + mass of fuel supplied

(ii) Percentage heat loss due to evaporation of water formed due to H_2 in fuel

Heat loss due to evaporation of water formed $\% = \frac{9\ X\ h_z\{584 + C_p(T_f - T_a)\}}{GCV\ of\ fuel}\ x\ 100$ --- (viii)
Where, h_2 = kg of H_2 in 1 kg of fuel
C_p = Specific heat of superheated steam (0.45 kcal/kg ˚C)

(iii) Heat loss due to moisture present in air % heat loss due to moisture present

in air $= \frac{M\ X\ \{\ 584 + C_p\ (T_f - T_a)}{GCV\ of\ fuel}\ x\ 100$ ------------(ix)

Where, M = kg of moisture in 1kg of fuel
Cp= Specific heat of superheated steam (0.45 kcal/kg) ˚C
* 584 is the latent heat corresponding to the partial pressure of water vapour.

2.0 METHODOLOGY

The performance enhancement of the biomass fired thermic fluid heater was considered in this study. The selected industry mainly manufactures rubber gloves which the process does not require high pressure but high temperature. The selected plant with biomass fired thermic fluid heaters plant was designed to run over 70% efficiency, when less than 30% moisture is present in the biomass fuel. As the biomass fuel saw dust and wood chips were used. The actual overall efficiency of the plant was recorded while mapping of the temperature at various points of the plant.

2.1 System Performance

Existing system was investigated meticulously to identify the drawbacks. Data archived in log form is referred for over 3 years. Some outliers were removed, and rational data was taken for the calculations. Flue gas test and moisture test were carried out at the site. With the available data Fuel used for the existing system was investigated. Further, saw dust consumption, moisture percentage of biomass, heat delivered by the fuel and heat absorbed by the system and heat losses were calculated. Efficiency was estimated using direct method and heat loss method.

To propose the improvement of system performance a deep analysis of the entire system was carried out. Few areas of the existing system such as removing excess moisture in fuel, reducing high heat loss through the stack (waste heat), reducing the percentage of excess air supply and the flue gas temperature were critically evaluated. Based on the findings of investigations, a new system was designed to overcome the identified drawbacks of the existing system.

In addition, the hourly capacity of the plant calorific value of saw dust biomass used as the fuel, hourly requirement of saw dust biomass the plant heat usage and working pressure of the plant were measured. Recovery system of waste heat, unrecovered heat discharged through the stack and flue gas temperature were also measured.

2.2 Fuel Consumption and Combustion Performance

Since the fuel consumption was varied with the demand of the final product, demand was set out with the plant utilization, waste heat, climate condition and the fuel quality. Average value was taken scrutinizing the all governing factors.

Combustion of the fuel was taken place at the combustion chamber. Air was drawn from the bottom of the grate bar bed. Saw dust was spread into the chamber by the fuel feeder. FD and ID fans were operated such that 2 bar negative pressure was kept inside the combustion chamber. This was allowed the flue gas to escape through the stack whilst transferring heat to the coil unit

2.3 Verification of the performance of proposed system

Engineering equation solver or EES software was used for the verification of the results of the proposed system. EES can be used to find out the maximization of a given function. Hence it was helpful to determine whether the proposed system is running at its optimum efficiency or not.

Governing equation for the overall efficiency of the plant were compared with the existing performance.

The overall efficiency was given as,
η = 100 – [Dry flue gas + Evaporation of water formed due to H_2 in fuel + Evaporation of moisture in fuel + Other uncountable losses]

3.0 RESULTS AND DISCUSSION

3.1 Plant performance

The performance enhancement of the biomass fired thermic fluid heater was considered in this study. The selected industry mainly manufactures rubber gloves which the process does not require high pressure but high temperature. The plant was designed to run over 70% efficiency when biomass fuel with less than 30% moisture is present. Saw dust and wood chips were used as the biomass fuel. However, the actual overall efficiency of the plant was below 50%.

Existing system consists of pump, combustion chamber with coil unit, FD fan, air pre heater, water pre heater, pollution control unit and ID fan. Mapping of the temperature at various points of the plant is shown in figure 02.

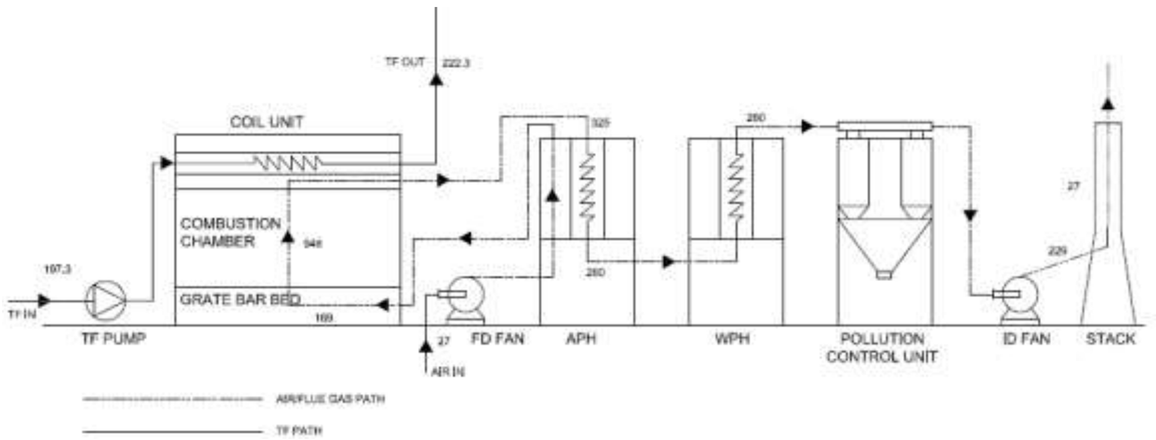

Fig. 2. Existing temperature mapping of the system

The capacity of the plant is 3million kCal/hr (12552 MJ/hr) while saw dust biomass with calorific value 2700 kCal/kg is used as the fuel. Saw dust biomass requirement is about 1.7 ton/hr with the plant heat usage is around 2.3 million kCal/hr whereas working pressure of the plant is 4 bar.

The plant is composed of a water preheater (WPH), to recover the waste heat of 0.25 million kCal/hr. This was included to generate hot water either for direct use in the manufacturing process or to run vapour absorption chiller. But unrecovered heat is discharged through the stack and flue gas temperature is above the acceptable range of 240-250 ^{0}C.

3.2 Parameters of the Existing Thermic Fluid Heating System

Quality of the thermic oil, oil flow rate and the temperature difference ($\Delta\theta$) in fluid inlet and outlet pipes and its material are fixed for a given heater and cannot be altered to increase the efficiency of the heater. The calculated efficiency of the current system was 47% from the direct calculation method and 42% from the indirect calculation method with all the losses (Table 2). The current excess air supply to the system is 180% and total heat loss is 58% as shown in table 1.

Table 1. Performance parameters of the existing system

Description	Existing set-up
Heat supplied	3,375,000 kCal/kg
Heat received	1,589,185 kCal/kg
Efficiency (direct method)	47%
Efficiency (In-direct method)	42%
Excess air supplied	180%
Total heat loss	58%
Heat loss due to moisture present	10%
Heat loss due to dry flue gas	30%
Heat loss due to H_2O formed by H_2 in fuel	15%

3.3 Drawbacks of the Existing System

Saw dust was used in this system as the biomass fuel, which was having 40% moisture content. The system preferred fuel biomass with less than 30%. However, the feeding biomass fuel was 10% higher moisture than which is preferred. Too less moisture increases fuel carry over to flue gas. Further, 10% of the heat generated is lost to evaporate the moisture present in the fuel. Efficiency of the plant is 42% whereas design efficiency is 70%. It was identified 30% of the heat is lost to the environment. In addition, no proper air circulation has occurred as grate bar bed is blocked due to saw dust particles itself. Excess air supply is 180% which is way above the preferred limit of 60%. Moreover, temperature of the air leaving the chimney is 229 ^{0}C, where design limit is 180 ^{0}C.

3.4 Proposed System for Improvement

After a thorough analysis, the few problematic areas were identified for improvements. Removing excess moisture in fuel, reducing high heat loss through the stack (waste heat), reducing the percentage of excess air supply and reducing flue gas out temperature are the focused areas to improve the performances. Accordingly, a new system was designed as shown in Fig. 3.

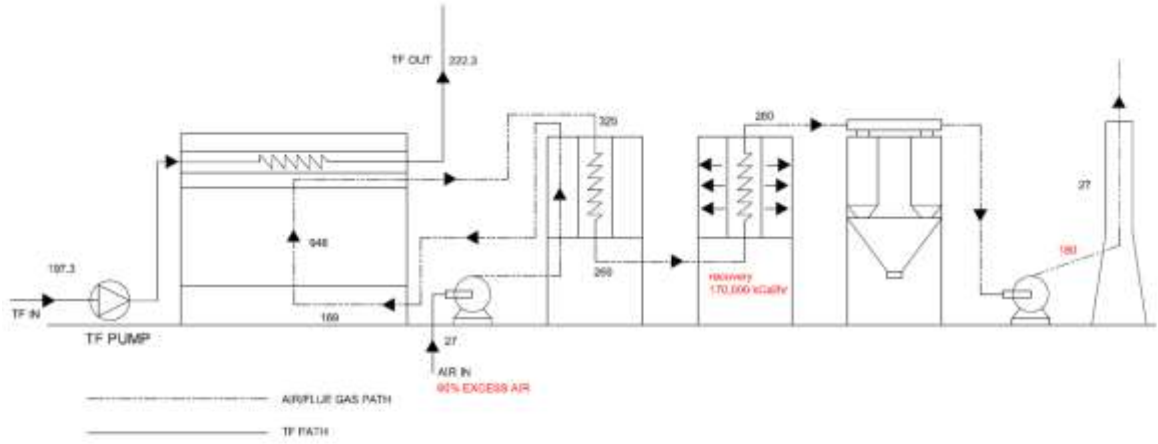

Fig. 3: Proposed Mapping of the System with Temperature Mapping

3.5 Theoretical Analysis

Proposed system suggested to recover the waste heat of 170,000 kCal/hr heat through functioning of WPH. WPH inlet and outlet is to be maintained at 260 ^{0}C and 180 ^{0}C respectively. Pre prepared saw dust is available in briquette form with 10% moisture was used for the new system. In addition to WPH is provided to recover the excess heat of the flue gas.

Performance of the new system is worked out by using indirect method and for the preferred parameters. Comparison of existing vs proposed system parameters are shown in Table 2.

Table 2. Comparison of existing vs proposed system parameters

Description	Existing set-up	New system
Heat supplied	3,375,000 kCal/kg	3,325,500 kCal/hr
Heat received	1,589,185 kCal/kg	1,589,185 kCal/kg
Efficiency (direct method)	47%	75 % (Designed 70%)
Efficiency (In-direct method)	42%	
Excess air supplied	180%	61.50%
Total heat loss %	58%	25%
Heat loss % due to moisture present	10%	2%
Heat loss % due to dry flue gas	30%	10%
Heat loss % due to H_2O formed by H_2 in fuel	15%	10%
Saw dust consumption	1250 kg	800 kg (40% moisture)
Moisture content of the fuel	40%	40% and dried to 10%

3.6 Verification of the System Using EES Software

Engineering Equation Solver (EES) software is used for the verification of the results of the proposed system. EES can be used to find out the maximization of a given function. Hence it is helpful to determine whether the proposed system is running at its optimum efficiency or not.
Governing equation for the overall efficiency of the plant is

η = 100 – [Dry flue gas + Evaporation of water formed due to H_2 in fuel + Evaporation of moisture in fuel + Other uncountable losses]
Substituting from equation (vii), (viii), (ix) and values for fixed parameters.

$$\eta = 100 - \left[\frac{M1\ X\ 0.23\ X\ (T_f - 27)}{GCV\ of\ fuel}\ \% + \frac{9\ X\ 6.68\{584 + 0.45(T_f - 27)\}}{GCV\ of\ fuel}\ \% + \frac{M3\ X\ \{584 + 0.45\ (T_f - 27)}{GCV\ of\ fuel}\ \% + 3\right]$$

It is assumed here that dried saw dust up to 10% moisture is used for the operation. Research work is suggested a way to dry up the saw dust. GCV of fuel is 3800 kCal/kg and M_3 = 10%.

By using EES graph of efficiency vs O_2 % when stack exhaust temperature is 180 ^{0}C, obtained as shown in Fig. 4.

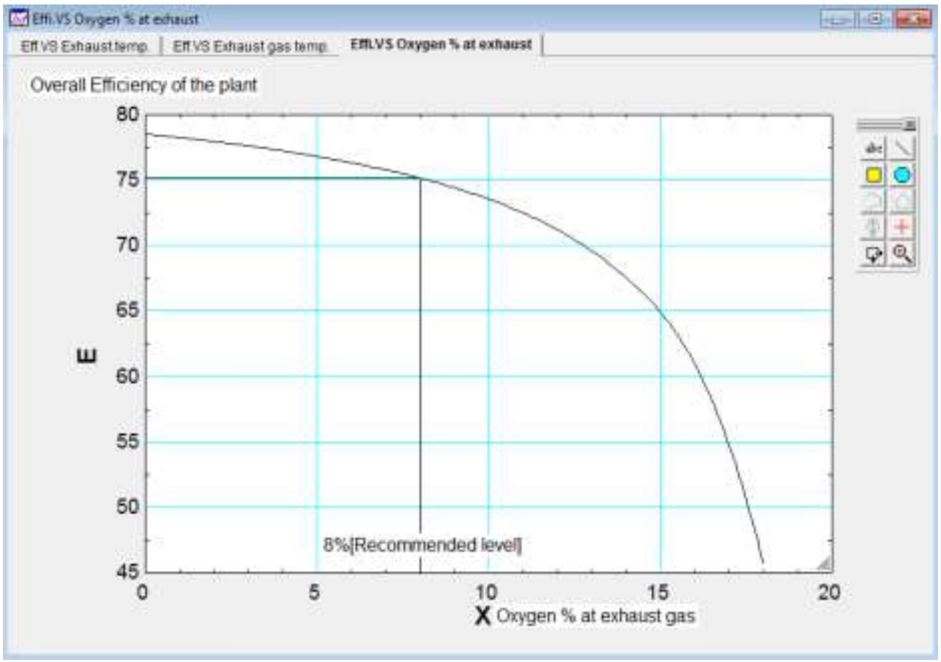

Fig. 4 EES –Overall efficiency of the plant vs oxygen% of exhaust gas

Therefore, it can be concluded that the system is optimized and yielded 75% (Fig. 4) of overall plant efficiency when excess O_2 supply is kept at the range 8%. This can be performed through the adjustment of the ID fan damper. Further, exhaust gas temperature is kept at 180 ^{0}C. This temperature can be regulated when water preheater is operational. Flow rate of the WPH secondary circuit is throttled while monitoring the exhaust gas temperature is settled at 180 ^{0}C. It was assumed here that dried saw dust up to 10%

moisture is used for the operation. WPH secondary circuit and drier design is enclosed in the research to meet the requirement.

4.0 CONCLUSION

Optimizing of thermic fluid heaters are important to reduce fuel consumption through complete combustion. Proper flue gas handling systems help to better use of waste heat for useful work and performance enhancement of the thermic fluid heater.

According to the proposed system, efficiency of the plant can be increased from 42% to 70%, total heat loss can be decreased to 58% to 25% and consumption of the saw dust also can be reduced from 1250kg to 800 kg per month. The analytical results obtained by the indirect method was validated by EE software and the overall efficiency was found as 77%.

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