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Exergetic analysis of a wood fired thermic fluid heater in a rubber industry

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ABSTRACT

This paper presents a framework of thermodynamic, energy and exergy, analyses of industrial Wood fired thermic fluid heater. Mass, energy, and exergy analysis were used to develop a methodology for evaluating thermodynamic properties, energy and exergy input and output resources in industrial wood fired thermic fluid heater. Determined methods make available an analytic procedure for the physical and chemical exergetic analysis of wood fired thermic fluid heater for appropriate applications. The energy and exergy efficiencies obtained for the entire fluid heater was 60.62% and 27.69% at standard reference state temperature of 25 ^{o}C. Chemical exergy of the material streams was considered to offer a more comprehensive detail on energy and exergy resource allocation and losses of the processes in a thermic fluid heater.

Introduction

Thermic fluid heater is a source that is supply heat of temperature from 300^{o}C to high temperatures. This heats the thermic fluid to required temperature and the fluid then passed to process points where heating is required. The heat energy could be extracted from this hot thermic fluid by means of radiation by circulating the fluid around process vessels that need to be heated or by other suitable means and finally recycled to thermic fluid heater. The hot thermic fluid is circulated in a closed circuit by a high temperature circulating pump and the heat is transferred to the process through an appropriate heat exchanger at users end. The combined de-aerator cum expansion tank eliminates any liberated gases and absorbs the thermic fluid expansion during the process. Various operations of fuels are available like oil, gas, wood, coal, rise husk and other agro waste fuels, thereby providing full flexibility and low operational energy coasts.

Therminol® 55 is a unique, synthetic heat transfer fluid designed to provide reliable, consistent heat transfer performance over a long life. This heat transfer fluid is a superior cost-performance alternative to common mineral oil based heat transfer fluids. Therminol 55 fluid is designed for use in non-pressurize/low-pressure, indirect heating systems. It delivers efficient, dependable, uniform process heat with no need for high pressures. The high boiling point of Therminol 55helps reduce the volatility and fluid leakage problems associated with other fluids

Owing to its great significance in today’s industrial world, it is imperative to fully understand how to effectively assess the energy resources utilization and outputs in steam boilers to ensure adequate energy management. The increasing energy demand from emerging economies versus the day-to-day decreasing storages of energy resources, the rising cost of fossil fuels and the considerable environmental impact connected with their exploitation are implications that policy makers cannot disregard. These would consequently result in energy-related problems to become more pronounced in the future [2]. For example, in an industrial country, it was observed that 30-40% of the total energy consumption was as a result of the transportation sector alone [3]. Therefore, the need for effective and efficient energy utilization in production systems cannot be overemphasized.

The impact of thermic fluid heater on the environment, as regards competing for scarce energy resources as diesel, coal, natural gas, etc. for its operation with attended environmental degradation like air pollution, emission of greenhouse gases, which continues to threaten quality of life and the ecosystem calls for closer attention. For a given environment, energy which is convertible into other forms of energy is called useful energy or exergy. Energy which is impossible to convert into other energy forms is called useless energy or anergy[4].Exergy analysis appears to be a significant tool in addressing the impact of energy resource utilization of thermic fluid heater on the environment as raised in past work by Dincer et al. [5] to further the goal of more efficient energy resource utilization of thermic fluid heaters; enabling locations, types, and true magnitudes of wastes and losses to be determined for thermic fluid heaters; revealing whether fluid heaters or not and how much it is possible to design more efficient thermic systems by reducing the inefficiencies in the existing systems; providing a sustainable development for thermic fluid heaters for sustainable supply of energy resources; and distinguishing the high-quality and low-quality energy resources of thermic fluid heaters.

More researchers are increasingly realizing the need to distinguish and determine both the quality and quantity of energy in industrial systems, such as, product manufacture, performance of machines operations, resource control, maintenance, recycling and disposal. Exergy analysis offers a synergy between energy quality and quantity of all processes of material interactions and energy flows of any given system. Exergetic methodology combines the principles of first and second laws of thermodynamics.The first law of thermodynamics which refers to energy analysis does not

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give any information on the degradation, that is, quality of energy that occurs in a process. Therefore, exergy analysis is often used in addition to energy analysis when assessing industrial processes. The second law of thermodynamics which refers to exergy analysis provides both qualitative and quantitative aspects of energy utilization processes [6,7]. Exergy is fundamentally the property of the system, which gives the maximum power that can be distracted from the system when it is brought to a thermodynamic equilibrium state from a reference state [4,8]. Energy and exergy analyses have been used in the assessment of energy utilization in industrial sectors of Saudi Arabia [5] and Turkey [9]. Utlua and Hepbasli [9] elucidated the fact that different approaches have been used by many researchers in the past to carry out their studies. Based on earlier studies, the approaches used to perform the exergy analyses of countries may be grouped into three types, (i) Reistad's, (ii) Wall's and (iii) Scuibba's approach. The first approach considers flows of energy carriers for energy use; while the second one takes into account all types of energy and material flows. The third was introduced to the method of extended-exergy accounting. The methodology used by Utlua and Hepbasli [9] is the Reistad's approach with several minor differences. They applied several balance equations, such as mass balance, energy balance, and exergy balance for a general steady state, steady-flow process, to find the work and heat interactions, the rate of exergy decrease, the rate of irreversibility, and the energy and exergy efficiencies. They stated that exergy is seen as a key component for a sustainable society. Exergy analysis is a powerful tool, which has successfully and effectively been used in the design, simulation and performance evaluation of thermal systems as well as for estimating energy utilization efficiencies of countries or societies. In corroboration, Dinceretal.[5]stated that the potential usefulness of exergy analysis in sectoral energy utilization is substantial and that the role of exergy in energy policy-making activities is crucial. Suresh et al. [10] conducted a study to predict the possible improvement in efficiency obtained with thermal power plants. The study dealt with the comparison of energy and exergy analysis of thermal power plants based on advanced steam parameters in Indian climatic conditions. The study involved coal-based thermal power plants using subcritical, supercritical, and ultra-supercritical steam conditions. The design configurations of 500 MWe unit size were considered. The study encompassed the effect of condenser pressure on plant and exergy efficiency. The effect of high grade coal on performance parameters as compared to typical Indian low grade coal was also studied. The major exergy loss took place in coal combustion followed by the steam generator. Due to condenser pressure limitation, the maximum possible plant efficiency was found to be about 41% for supercritical steam power plant and 44.4% for the ultra-supercritical steam power plant. They therefore concluded that installing coal-based thermal power plants based on advanced steam parameters in India will be a prospective option aiding energy self-sufficiency.

Aoetal.[11] using exergy analysis methodology, proposed that it is not only the coefficient of performance (COP) value of the electric power heat pump set (EPHPS or HP set) that should be considered, but also the exergy loss at the heat exchanger of the HP set to assess the heating efficiency of the HP set and reduce the energy at the heat exchanger of the HP set. The method assessed not only the efficiency of energy quantity, but also the exergy loss of the heat exchanger and the optimum region of the work state at a certain evaporation temperature, and also how to improve the room structure and floor shape in order to heat the room well in a low temperature heating system. They observed that by integrating more components in the methodological process of exergy analysis, the heating efficiency of a set of heat pump (HP) was affected. They concluded that to assess the heating efficiency or to define a better temperature range for the heat exchanger of a HP set, people should not only consider the COP value and the characteristics of the refrigerants only, but also the exergy loss and exergy efficiency at the heat exchanger. It is not perfect to assess an HP set performance with just COP.

Pathmasiri and Attalage [12] carried out an exergy analysis of steam boilers in Sri Lanka. In their study, they discovered that over 80% of steam boilers operating in industries in SriLanka use furnace oil as fuel. Therefore their study was focused mainly on furnace oil fired boilers. Exergy and energy balance for each boiler was evaluated and theoretical analysis was carried out using these results. Key analysis carried out includes the following; variation of exergy efficiency with flue gas temperature and excess air, variation of exergy efficiency with energy efficiency, variation of CO_2 emission with exergy efficiency, variation of cost of steam with exergy efficiency and variation of exergy destruction with excess air and flue gas temperature respectively. The conclusion drawn was that energy analysis can only account for where energy is distributed or lost from systems of interest, while exergy analysis can highlight where energy is used inefficiently. Exergetic efficiency or the rational efficiency is a very useful measure for the thermodynamic quality of a technical process. In the case of steam boilers, exergetic efficiency is always less than the energy efficiency. This was as a result of rapid exergy destruction taking place within the boilers. The exergy destruction takes place due to rapid temperature reduction between combustion products and the steam. They observed that on the average the exergetic efficiency of a steam boiler is three times less than that of the energy efficiency.

This study presents a framework to evaluate thermodynamic properties and performance variables associated with material streams in thermic fluid heater, such as, mass flow rate, temperature, enthalpy, entropy, energy and exergy transfer with chemical, heat and material interactions, efficiencies, and exergetic losses in thermic fluid heater. Chemical exergy which is often left out by some researchers in many analytical processes was considered in this study.

Method

Framework

The framework for the methodology of this study was classified into two major categories as shown in Fig. 1. These include determination of operational variables and performance variables of thermic fluid heater [13,14].

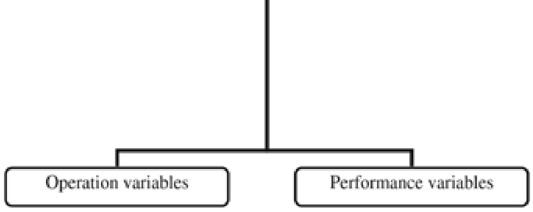

Figure 1. Methodological framework

Operation variables

These are parameters concerned with the functioning of the thermic fluid heaters. They indicate measurable (direct operational variables) and computable (indirect operational variables) properties which describe the generic thermodynamic activities taking place in a thermic fluid heater. Overviews of these properties are outlined in Fig. 2.

(i) Measurable properties

These are usually monitored and recorded directly from inbuilt or attached thermic fluid heater measurement indicators over a specified period of time. An inventory data collection process is normally used to comprehensively collect thermic fluid heater information.

(ii) Computable properties

These properties are those that are not usually read directly from indicators, and as such would have to be computed through the use of appropriate energy tables or charts; thermodynamic formulae, such as conservation of mass and energy, and exergy balance equations.

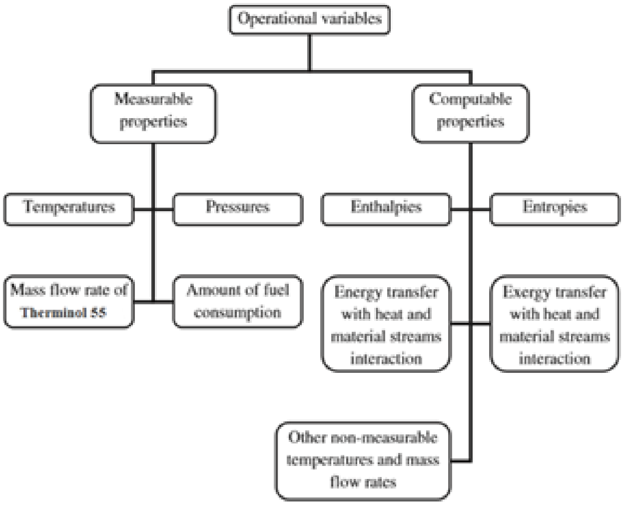

Figure 2. Operation variables

Performance variables

These are parameters concerned with the performance of the thermic fluid heater. Hence, they serve as indices to ascertain and analyze various performance levels of the thermic fluid heaters. They include variations of energy and exergy values and efficiencies of thermic fluid heater in relation with input and output resources; and the magnitudes and types of irreversibility (exergy losses) and the locations they occur in thermic fluid heater. Methods for computing various performance variables are enumerated in the theoretical framework.

Standard environmental reference state

Typical reference state temperature, T_0 and pressure, P_0 of 25 oC (298.15 K) and 101.323 kPa and zero values for the height z_0 and velocity v_0 of the earth surface are used for most analyses. This often involves the use of the natural environment-subsystem model described in Table 1 for the following condensed phases at T_0 and P_0: Water (H_2O), Limestone ($CaCO_3$), and Gypsum ($CaSO_4.2H_2O$). A unique variance between exergy and other thermodynamic properties is that the reference state for exergy is determined by the surroundings. It has been established that the exergy of matter will change if the state of the surroundings changes, even when no changes occur in the system itself [15,16].

Table 1. Composition of a reference-environmental model.

Air constituents	Mole fraction
N_2	0.7565
O_2	0.2035
H_2O	0.0303
Ar	0.0091
CO_2	0.0003
H_2	0.0001

Physical and chemical exergies

The total exergy transfer associated with material streams for a flow process comprises of the physical and chemical exergies [15,17-19]. The flow exergy of a substance is the theoretically obtainable work when the substance is brought into total equilibrium with the local environment. It can be split into chemical exergy and thermo mechanical (physical) flow exergy which is represented by [20]:

$$\varepsilon = \varepsilon^{ph} + \varepsilon^{ch} \tag{1}$$

The specific physical flow exergy is expressed by:

$$\varepsilon^{ph} = h - h_0 - T_0(s - s_{0)} \tag{2}$$

where, h_0=h (T_0, P_0) =enthalpy at reference state; s_0= s(T_0, P_0) = entropy at reference state; and T_0, P_0= reference state temperature and pressure.

Specification of wood

Every fuel has a unique composition and energy content described by its fuel specifications. Knowing the fuel specifications is essential for determining combustion parameters such as combustion efficiency, minimum air requirements, CO_2 concentration and emissions factors [21].

Theoretical framework

During the combustion of hydrocarbon molecules (C_xH_y) are combined with oxygen to produce carbon dioxide (CO_2) and water (H_2O) in an exothermic reaction [22]

Stoichiometric combustion equation.

$$Wood + 10.25Air \rightarrow 50CO_2 + 6.5H_2O + 39.04N_2$$

Actual combustion equation.

$$Wood + 12.3Air \rightarrow 50CO_2 + 6.5H_2O + 2.05O_2 + 46.248N_2$$

The schematic of thermic fluid heater plants

The schematic diagrams shown in Fig. 3 can be used to analyze the mass flow rate, energy and exergy balances and exergetic efficiencies of thermic fluid heater [26, 27]. The schematic diagrams of the combustion and heat exchanging units, respectively, shown in Fig. 3 may be separately analyzed to establish the mass flow rate of the material streams in the thermic fluid heater. Combustion of fuel takes place in the combustion unit of the heater, while the heat carried by the hot flue gas from the combustion unit is used to heat thermic fluid in the heat exchanging unit combustion and heat exchanging units, respectively shown in Fig. 3 may be separately analyzed to establish the mass flow rate of the material streams in the thermic fluid heater.

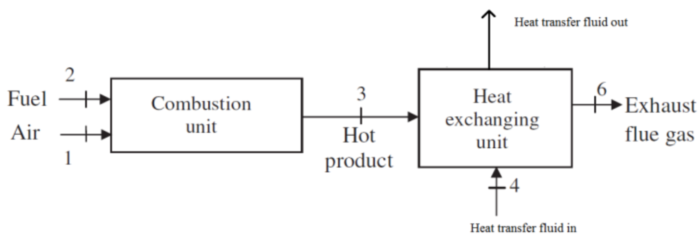

Figure 3. Schematic diagram of combustion and HX unit

Thermodynamic and exergetic analysis determination

An exegetic analysis involves mass, energy and exergy balance for each plant unit, and exergetic efficiency for each of them [28]. The mass, energy and exergy balances at steady state for the material flows in a boiler system with negligible potential and kinetic energy changes can be expressed, respectively, by below equations. [26, 28, 29].

$$\sum \dot{m} = \sum \dot{m}_e \quad (3)$$

$$\dot{Q} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i \quad (4)$$

$$I = \dot{m}_i \varepsilon_i - \sum \dot{m}_e \varepsilon_e \quad (5)$$

Mass balance of material streams

Appropriate mass and energy balance as stated by above stated equation may be applied to a heater system with the evaporation ratio and air fuel ratio an may be used to determine masses of substances of all material streams in the boiler, such as; air(m_a), fuel (m_f), hot products (m_p), thermic fluid (m_t), exhaust flue gases (m_g) respectively.

Hence

$$\dot{m}_a + \dot{m}_f = \dot{m}_p \quad (6)$$

$$\dot{m}_p = \dot{m}_g \quad (7)$$

$$\dot{m}_{t\ in} = \dot{m}_{t\ out} \quad (8)$$

Temperature, enthalpy and entropy of heat transfer fluid

The enthalpy and entropy of heat transfer fluid may be determined at appropriate temperatures, by using enthalpy and entropy table of Therminol 55[30].

Combustion temperatures

From an energy balance analysis of a combustion process, the combustion temperature can be calculated as follows [22].

$$T_c = T_a + \frac{h_r}{[c_p \times (1 + AAF)]} \quad (9)$$

Where, Tc=combustion temperature; Tca=temperature of the combustion air before entering the burner; hr=heat of reaction (hr=LHV, if exhaust gas streams is above 60oC) [31] Cp=specific heat of fuel at ambient temperature of products of combustion. To maintain satisfactory working conditions for personnel around a heater, a cold face temperature or heater room ambient temperature, Tar of 25oC or less is considered satisfactory [31].

Enthalpy and entropy of inlet air

The enthalpy and entropy of inlet air can be evaluated for inlet air temperature, Ta for different heater operation from the ideal gas properties of air tables [30].

Enthalpy of hot products

Applying the energy balance Equation to the combustion unit shown in Fig. 3 and assuming heat was transferred adiabatically[26], the enthalpy of the hot products can be determined using

$$\dot{m}_f h_f + \dot{m}_a h_a = \dot{m}_p h_p \quad (10)$$

Temperature of exhaust flue gases

The steady-state efficiency of combustion is the ratio of the useful heat delivered to the process to the heat content of the fuel [22]. The combustion efficiency is given by

$$T_g = T_c - \frac{HHV \times \eta_{comb}}{(1 + AAF) \times c_p} \quad (11)$$

Enthalpy of exhaust flue gases

Enthalpies of most gases used in combustion calculations can be curve-fitted by the simple second order equation [31]:

$$h = AT^2 + bT + C \quad (12)$$

Where h=enthalpy in Btu/lb ; T=temperature in degrees,^{O}F; a, b and c are coefficients with the following values for T (0-500^{O}F) given as: $a=1.683\times10^{-5}$; b=0.233; and c=-18.03

Above equation can be used to evaluate the enthalpy of the exhaust flue gases. It should be noted that the constants a, b and c are stated only for the quoted temperature range given in ^{o}F.

Entropy of combustion fuel gases

The entropy generated from a source can be expressed as follows [30]:

$$s_{gen} = \frac{q_{source}}{T_{source}} \quad (13)$$

where, s_{gen}=entropy generated from the source, kJ/kgK; q_{source}=heat transfer from a source to a sink, kJ/kg; and T_{source}= temperature of the source, K.

A study of the thermodynamic processes taking place between the combustion and the heat exchanging units shows that: the entropy generated from the combustion unit is the entropy of the combustion fuel gas, s_f, the heat transfer from the combustion unit to the heat exchanging unit equals the energy value of the hot products, h_p and the temperature of the source is the combustion fuel temperature, T_f.

Hence equation can be written as

$$s_f = \frac{h_p}{T_f} \quad (14)$$

Entropy of hot products

The entropy of the hot products can be determined by Eq. (15), where T_p is the temperature of the hot products

$$s_p = \frac{h_p}{T_p} \quad (15)$$

Entropy of exhaust flue gases

The entropy of flue gas can be found by [30]

$$s_g = s_a + c_p \ln \frac{T_g}{T_a} \quad (16)$$

$$At\ T_a = 298K \quad s_a = 1.69528kJ/kgK$$

Chemical exergy of fuels

Complete combustion of a general hydrocarbon with atmospheric air is written as [30, 36]

$$C_xH_y + (x + \frac{y}{4})O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O \quad (17)$$

Where x and y are constant coefficients that characterizes the hydrocarbon and combustion process. Assuming no irreversibility, he molar chemical exergy of reactants and products can be developed as expressed by [19].

$$e^{ch}_{x\ fuel} + (x + \frac{y}{4})e^{ch}_{x\ O_2} \rightarrow -\Delta\bar{g} + xe^{ch}_{x\ CO_2} + \frac{y}{2}e^{ch}_{x\ H_2O} \quad (18)$$

The chemical exergy of fuel can thus obtained by

$$e^{ch}_{x\ fuel} = -\Delta\bar{g} + \bar{R}T_o \ln\left[\frac{n_{O_2}{}^{(x+y/4)}}{n_{CO_2}{}^{x} n_{H_2O}{}^{y/2}}\right] \quad (19)$$

The mole fraction of oxygen (nO2), carbon dioxide (nCO2) and water (nH2O)in a standard environment are given in Table1,where, $\bar{R}$ = 8.3144 kJ/kmolK (molar or universal gas constant)

The standard Gibbs functions of formation of other components are given as follows [36]:

$$\bar{g}_{CO_2} = -394{,}390\ kJ/kmol$$

$$\bar{g}_{H_2O} = -228{,}590\ kJ/kmol$$

The specific chemical exergy was obtained by

$$\varepsilon^{ch} = \frac{e_x{}^{ch}}{M} \quad (20)$$

Where M=molecular mass of chemical substance, kg/kmol

Chemical exergy of air

The chemical exergy of atmospheric air can be determined from the below equation and the mole fractions of the elements in a standard environment presented in Table 1 with their respective chemical exergies given by Ertesvag [20] as presented in Table 2.

$$e_{x\_air}{}^{ch} = \sum \left(n_i e_{x_i}{}^{ch}\right)_{air} \quad (21)$$

The molar mass of air is given as M_{air}=28.96 kg/kmolK [30].

Table 2. chemical exergies of the elements in air.

Components	Chemical Exergies
Nitrogen	0.6681
Oxygen	3.9305
Carbon Dioxide	19.610
Argon	11.640
Water (Gas)	9.474
Water (Liquid)	0.8842
Hydrogen	236.098
Carbon Monoxide	274.87

Analysis of the combustion unit

Applying the energy balance equation to the combustion unit as shown in Fig. 3, the energy input in the combustion unit can be determined by

$$E_{in} = \dot{m}_f h_f + \dot{m}_a h_a \quad (22)$$

Where h_f and h_a are the specific enthalpies of combustion fuel and air.

The combustion efficiency of an adiabatic combustor is usually equal to unity [26], and may be represented by the first law efficiency given by

$$\eta_c = \frac{\dot{m}_p h_p}{\dot{m}_f \times HHV} \quad (23)$$

Where HHV=high or gross heating value of fuel. The combustion unit is assumed to operate in a steady-flow adiabatic process, whereby the change of mass and energy of the control volume is zero. It is also assumed that the kinetic and potential energies are negligible and that there is no work transfer involved. Applying the exergy balance equation to the combustion unit, the exergy destruction in the combustion unit can be determined by

$$\dot{I}_c = \dot{m}_a\left[\varepsilon^{ph}_{a_1} + \varepsilon^{ch}_{a_1}\right] - \dot{m}_p \varepsilon^{ph}_{p_3} + \dot{m}_f\left[\varepsilon^{ph}_{f_2} + \varepsilon^{ch}_{f_2} - \varepsilon^{ch}_{f_3}\right]$$

Where $\varepsilon^{ph}_{a_1}$, $\varepsilon^{ph}_{f_2}$, $\varepsilon^{ph}_{p_3}$ are the specific physical exergies of air and fuel at inlet and that of hot products at exit, while $\varepsilon^{ch}_{a_1}$, $\varepsilon^{ch}_{f_2}$ are the specific chemical exergies of air and the combustion fuel at inlet, and $\varepsilon^{ch}_{f_3}$ is the specific chemical exergy of the combustion fuel at exit. The exergy efficiency of the combustion unit can be determined by

$$\psi_c = \frac{\dot{m}_p \varepsilon_p{}^{ph}}{\dot{m}_f\left[\varepsilon_f{}^{ph} + \varepsilon_f{}^{ch}\right]} \quad (25)$$

Analysis of the heat exchanging unit

Performing an energy balance on the heat exchanging unit as shown in Fig. 3, and noting that $\dot{m}_p = \dot{m}_g$ and $\dot{m}_w = \dot{m}_s$ the heat loss can be determined by

$$Q_{H(loss)} = \dot{m}_p\left(h_p - h_g\right) - \dot{m}_t\left(h_{t\_out} - h_{t\_in}\right)$$

where, h_g, h_s and h_w are the specific enthalpies of exhaust flue gas, steam and feed water.

The first law efficiency of the heat exchanging unit can be determined by [26]

$$\eta_H = \frac{\dot{m}_t\left(h_{t\_out} - h_{t\_in}\right)}{\dot{m}_p\left(h_p - h_g\right)} \quad (27)$$

The exergy destruction in the heat exchanging unit can be determined by

$$\dot{I}_H = \dot{m}_p \varepsilon_p{}^{ph} + \dot{m}_t\left[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}\right] - \dot{m}_t\left[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}\right] - \dot{m}_g\left[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}\right]$$

The exergy efficiency of the heat exchanging unit can be determined by

$$\psi_H = \frac{\dot{m}_t\left[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}\right] - \dot{m}_t\left[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}\right]}{\dot{m}_p \varepsilon_p{}^{ph} - \dot{m}_g\left[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}\right]}$$

Analysis of the entire heater

The overall boiler energy efficiency can be determined by [26]

$$\eta_H = \frac{\dot{m}_t\left(h_{t\_out} - h_{t\_in}\right)}{\dot{m}_f h_f} \quad (30)$$

The overall exergy destruction of the heater was obtained as the sum of exergy destruction in the combustion chamber and the heat exchanger. That is,

$$\dot{I}_B = \dot{I}_C + \dot{I}_H \quad (31)$$

The overall heater exergy efficiency can be determined as the rational efficiency of the entire boiler which is the ratio of the desired exergy output, $\dot{E}_{desired\ output}$ to the exergy used, $\dot{E}_{used}$. The $\dot{E}_{desired\ output}$ was the net exergy for the heating of thermic fluid and $\dot{E}_{used}$ is the net energy input into the system. The exergy efficiency of the boiler can therefore be determined by

$$\psi_B = \frac{\dot{E}_{desired\ output}}{\dot{E}_{used}} \quad (32)$$

$$\psi_B = \frac{\dot{m}_t\left[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}\right] - \dot{m}_t\left[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}\right]}{\dot{m}_f\left[\varepsilon_f{}^{ph} + \varepsilon_f{}^{ch}\right]}$$

Results and discussion

The energy and exergy efficiencies obtained for the entire heater in this study was determined as 60.62% and 27.69% at standard reference state temperature of 25°C (298.15 K). Thermodynamic properties of material streams in the entire heater is found out using equations are given in Table 3.

Table 3. Computed Thermodynamic Properties of material streams in the entire heater

Substances	Mass Flow Rate (kg/s)	Temperature (°C)	Enthalpy (kJ/kg)	Entropy (kJ/kgK)
Air, m_a	0.1353	25	298.18	1.69528
Fuel, m_f	0.011	25	18240	1.358
Hot Products, m_p	0.1463	230	1647.189	3.275
Therminol in m_{t_in}	0.875	160	371.2	0.86
Therminol out m_{t_out}	0.875	220	510.2	1.03
Exhaust flue gas, m_g	0.1463	104.69	79.43	1.933

Table 4. Summary of exergetic parameters of Combustion unit

Exergic Equations	Efficiencies
Energy Input (kJ/s) $E_{in} = \dot{m}_f h_f + \dot{m}_a h_a$	**240.98**
Adiabatic Energy Efficiency (%) $\eta_c = \frac{\dot{m}_p h_p}{\dot{m}_f \times HHV}$	**99.9**
Exergy Destruction (kJ/s) $\dot{I}_c = \dot{m}_a[\varepsilon^{ph}{}_a + \varepsilon_a{}^{ch}] - \dot{m}_p \varepsilon_p{}^{ph} + \dot{m}_f[\varepsilon_f{}^{ph} + \varepsilon_f{}^{ch}]$	**160**
Exergy Efficiency (%) $\psi_c = \frac{\dot{m}_p \varepsilon_p{}^{ph}}{\dot{m}_f[\varepsilon_f{}^{ph} + \varepsilon_f{}^{ch}]}$	**35.18**

The exergy efficiency of combustion unit is 35.18%.From the available energy input 240.98KJ/s, 160KJ/s is lost as waste.

Table 5. Summary of exergetic parameters of Heat exchanging unit

Exergic Equations	Efficiencies
Heat loss (kJ/s) $Q_{H(loss)} = \dot{m}_p(h_p - h_g) - \dot{m}_t(h_{t\_out} - h_{t\_in})$	**107.738**
Energy Efficiency (%) $\eta_H = \frac{\dot{m}_t(h_{t\_out} - h_{t\_in})}{\dot{m}_p(h_p - h_g)}$	**53**
Exergy Destruction (kJ/s) $\dot{I}_H = \dot{m}_p \varepsilon_p{}^{ph} + \dot{m}_t[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}] - \dot{m}_t[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}] - \dot{m}_g[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}]$	**93.66**
Exergy Efficiency (%) $\psi_H = \frac{\dot{m}_t[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}] - \dot{m}_t[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}]}{\dot{m}_p \varepsilon_p{}^{ph} - \dot{m}_g[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}]}$	**45.21**

Table 6. Summary of exergetic parameters of Entire Boiler

Exergic Equations	*Efficiencies*
Heat loss (kJ/s) $Q_{H(loss)} = \dot{m}_p(h_p - h_g) - \dot{m}_t(h_{t\_out} - h_{t\_in})$	**107.738**
Energy Efficiency (%) $\eta_H = \frac{\dot{m}_t(h_{t\_out} - h_{t\_in})}{\dot{m}_p(h_p - h_g)}$	**53**
Exergy Destruction (kJ/s) $\dot{I}_H = \dot{m}_p \varepsilon_p{}^{ph} + \dot{m}_t[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}] - \dot{m}_t[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}] - \dot{m}_g[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}]$	**93.66**
Exergy Efficiency (%) $\psi_H = \frac{\dot{m}_t[\varepsilon^{ph}{}_{t_{out}} + \varepsilon_{t_{out}}{}^{ch}] - \dot{m}_t[\varepsilon_{t\_in}{}^{ph} + \varepsilon_{t\_in}{}^{ch}]}{\dot{m}_p \varepsilon_p{}^{ph} - \dot{m}_g[\varepsilon^{ph}{}_g + \varepsilon_g{}^{ch}]}$	**45.21**

Conclusion

Overall heater Exergetic Efficiency is found to be 28%. Total irreversibility is 254kJ/s and overall first law efficiency is found to be 61%.

Suggestion for improving the performance of the thermic fluid heater is

•The flue gas can be used for preheating air and wood , by improving the exergy efficiency.

•Introduce Nano fluid to increase heat transfer rate.

•Replace the ineffective insulation.

•The performance of existing heat transfer fluid pump is very poor.

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