A Study Of Exergy Analysis for Combustion in Direct Fired Heater (Part I)

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Abstract: Heat transfer plants with organic media have often been able to replace or improve the classic steam–water operation. The possibility of transferring and closely controlling temperature up to $> 300 \, ^\circ C$ has provided the heat transfer media technology with many new fields of application. This growing application of heat transfer plants with liquid heat transfer media other than water has made it necessary to produce complete and accurate engineering database for combustion and its devices to continuous improvement of industrial heating. Heating is an important operation in almost all industrial fields. A large variety of heating techniques is available at the market. Some examples are fuel burning, electrical heating, and so on. The analysis of related combustion process and estimation of the effective coefficients is the first step toward a successful design. The process of combustion fuel and their combustion and combustion devices are considered in this study. Direct fired heater exergy and energy analysis are performed taking into account precise calculation of chemical exergy for products of combustion.

Keywords: Exergy, Energy, Combustion, Thermal System.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>Area $[, m^2]$</td>
</tr>
<tr>
<td>A_Abs</td>
<td>The absolute availability of a system $[-]$</td>
</tr>
<tr>
<td>C_p, c</td>
<td>Specific heat capacity $[, J/kgK]$ or heat capacity $[, J/kg]$</td>
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<tr>
<td>E, E</td>
<td>Specific exergy $[, J/kg]$ or available work $[, J]$</td>
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<tr>
<td>E_f</td>
<td>Fuel exergy $[, kJ/kg]$</td>
</tr>
<tr>
<td>e_ch</td>
<td>Chemical exergy $[, kJ/kg]$</td>
</tr>
<tr>
<td>E/Q</td>
<td>Exergy factor $[, %]$</td>
</tr>
<tr>
<td>H, H</td>
<td>Specific enthalpy $[, J/kg]$ or enthalpy $[, J]$</td>
</tr>
<tr>
<td>m_a</td>
<td>Mass flow rate of air $[, kg/s]$</td>
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<tr>
<td>m_f</td>
<td>Mass flow rate of fuel $[, kg/s]$</td>
</tr>
<tr>
<td>m_e</td>
<td>Mass flow rate of exhaust flue gas $[, kg/s]$</td>
</tr>
<tr>
<td>P</td>
<td>Power $[, kW]$</td>
</tr>
<tr>
<td>P_o</td>
<td>Environment pressure $[, \text{bar}]$</td>
</tr>
<tr>
<td>Q, Q</td>
<td>Specific heat $[, J/kg]$ or heat $[, J]$</td>
</tr>
<tr>
<td>Q, Q</td>
<td>Specific heat $[, J/kg]$ or heat $[, J]$</td>
</tr>
<tr>
<td>R</td>
<td>Molar gas constant $[, J/mol K]$</td>
</tr>
<tr>
<td>S</td>
<td>Distance $[, m]$</td>
</tr>
<tr>
<td>S_o</td>
<td>Entropy of a system at environmental state $[, J/kg]$</td>
</tr>
<tr>
<td>S_1</td>
<td>Specific entropy, of substance I, $[, J/kgK]$</td>
</tr>
<tr>
<td>T</td>
<td>Temperature $[, K]$</td>
</tr>
<tr>
<td>u, U</td>
<td>Specific internal energy $[, J/kg]$ or internal energy $[, J]$</td>
</tr>
<tr>
<td>v, V</td>
<td>Specific volume $[, m^3/kg]$ or volume $[, m^3]$</td>
</tr>
<tr>
<td>σ</td>
<td>Stefan-Boltzmann constant $[, \text{W/m}^2, \text{K}^4]$</td>
</tr>
<tr>
<td>ε</td>
<td>The emissivity $[-]$</td>
</tr>
<tr>
<td>ω</td>
<td>Exergetic efficiency $[-]$</td>
</tr>
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</table>
I. Introduction:

Traditional methods of thermal system analysis are based on the first law of thermodynamics. These methods use an energy balance on the system to determine heat transfer between the system and environment. The first law of thermodynamics introduces the concept of energy conservation, which states that energy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is conserved and can not be destroyed.

1.1 Energy and Exergy:

Exergy is a measure of the quality or grade of energy and it can be destroyed in the thermal system. The second law states that a part of the exergy entering a thermal system with fuel, electricity, flowing streams of matter, and so on is destroyed. In general, energy balances provide no information on the quality or grades of energy crossing the concept of exergy in the analysis of thermal systems. destroyed within the system due to irreversibilities. Thermal system boundary and no information about internal losses. By contrast, the second law of thermodynamics introduces the concept of exergy. Exergy analysis has played a key role in order to evaluate processes by taking into account not only the quantity of energy but also both the quantity and quality of energy. Various definitions have been used to describe the term of exergy. Exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy. Exergy is a measure of the potential of the system or flow to cause change, as a consequence of not being completely stable equilibrium relative to the reference environment. Unlike energy, exergy is not a subject to a conservation law (except for ideal or reversible processes). Rather exergy is consumed or destroyed due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process.

1.2 Theoretical Analysis:

Exergy analysis is a method using the conservation of mass and conversion of energy principles together with the second law of thermodynamics for the analysis, design and improvement of energy and other systems. An exergy balance applied to a process or a whole plant tells us how much of the usable work potential or exergy supplied as the input to the system under consideration, has been consumed by the process. The loss of exergy or irreversibility provides a generally applicable quantitative measure of process inefficiency. In other words, an Exergy analysis is similar to an energy analysis, but it takes into account the quality of the energy as well as the quantity. Since it includes a consideration of entropy, Exergy analysis allows a system to be analyzed more comprehensively by determining where in the system the Exergy is destroyed by internal irreversibilities, and the causes of those irreversibilities.

2. Combustion and Exergy:

The purpose of combustion in industrial applications, for the most part, is to transform chemical energy available in various types of fuels to thermal energy or heat to be used in the processing of gas or liquid streams or solid objects. Typical examples involve the heating of air, water, and steam for use in heating of other processes or equipment, the heating of metals and nonmetallic minerals during production and processing, the heating of organic streams for use in refining and processing, as well as heating of air for space comfort conditioning. For all of these, it is necessary to have a workable method for evaluating the heat that is available from a combustion process. Available heat is the heat accessible for the load (useful output) and to balance all losses other than stack losses. Exergy is a measure of the energy available for useful work in a system. This property is also referred to as Availability. Exergy is a better measure of the work that may be extracted from a system rather than properties such as the internal energy or enthalpy of the system. No device or process can extract a quantity of work greater than the availability of the system without violating the second law of thermodynamics. Thus, the availability of a system also helps to define the upper limit on the efficiency of the device/process. cause and true magnitude of energy resource waste and to determine losses. Such information can be used in the design of new energy-efficient systems and for improving the performance of existing systems.
The method of Exergy analysis presented in this investigation enables us to identify the location, volume. These studies however, were restricted to a particular combustion process and did not strictly quantify the contribution of the various exergy terms. The current study wishes to apply the second law to the combustion process, while relaxing most of the approximations and simplifications made in the past. It is hoped that an inclusive examination of the various parameters will provide a more fundamental and complete understanding of the combustion processes. The current work also aims to incorporate excess air ratio into the study to allow for comparison of the combustion of different equivalent ratios. For more accurate analyses chemical exergy will be calculated in this study. The study of the combustion process analyzed will be in the direct fired heater, used in purpose of heating of heat transfer medium (Mineral Oil MOBILThERM 605), in plant of heating of thermal oil in EGYPTALUM company in Nag-Hammady, Egypt.

4. The Objective of Investigation:

Direct fired heaters are the most common industrial heating facilitates. They are readily employed for a wide range of applications and can be powered on various fuels depending on the local availability. Their many advantages and relative lack of competition has made direct fired heaters one of the preferred devices for converting the chemical energy of fuels into thermal energy. The current work attempts to understand the destruction of exergy (availability) in combustion processes and compare it with the losses of energy, with specific application to direct fired heaters. However, the analysis is not restricted to direct fired heaters and is applicable to all combustion processes.

From the literature review, it is evident that a comprehensive second law examination of combustion processes is lacking. Such a study would provide a more fundamental understanding of combustion processes and help in identifying strategies to reduce the destruction of exergy during combustion processes. Some work has been done towards applying the second law to combustion by Dunbar and Lior [1] (constant pressure combustion) and Daw et al. [2] (constant pressure combustion) and Caton [3] (constant pressure combustion) systems. The current study wishes to apply the second law to the combustion process, while relaxing most of the approximations and simplifications made in the past. It is hoped that an inclusive examination of the various parameters will provide a more fundamental and complete understanding of the combustion processes. The current work also aims to incorporate excess air ratio into the study to allow for comparison of the combustion of different equivalent ratios. For more accurate analyses chemical exergy will be calculated in this study. The study of the combustion process analyzed will be in the direct fired heater, used in purpose of heating of heat transfer medium (Mineral Oil MOBILThERM 605), in plant of heating of thermal oil in EGYPTALUM company in Nag-Hammady, Egypt.

5. Thermal Oil Plant Operation:

Thermal oil system is shows in Fig. 2. The Figure provides an efficient means of supplying indirect heat to one or more process systems. Such systems offer both high temperature and low pressure, making them ideal for a wide variety of process heating application. The heat transfer fluid firstly heated by means of a direct fired heater then circulated through a closed loop systems to the users. Heat from the fluid is transferred to the user and then re-circulated for reheating and the cycle repeated. However, organic media has become more common and often replaces a classic steam-water operation. The heaters are made with coils made of seamless tubes. The thermal fluid is heated during the flow through the tubes. The heat is transferred to the fluid as radiant heat in the combustion chamber, where the inner cylindrical tube coil and a flat tube coil form the chamber wall and the bottom respectively.
Consequently refractory concrete is avoided. The combustion gasses are hereafter cooled in the outer convection part, as the gasses pass the space between the two tube coils. The thermal design ensures a modest volume of the thermal fluid relative to the size of the heater, and allows unlimited thermal expansion due to the high fluid temperature.

The fuel that will be used in this test will be fuel oil No.6 that is named in Egypt and Arab countries as (Mazout); this fuel must be heated before using because it's high viscosity at ambient temperature. Table (1) shows fuel chemical analysis for typical heavy oil No.6 by weight.

Table (1): Fuel chemical analysis for typical heavy oil No.6 by weight

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>H₂</th>
<th>N₂</th>
<th>O₂</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by Weight</td>
<td>87.87</td>
<td>10.33</td>
<td>0.14</td>
<td>0.50</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Almost all industrial liquid fuel burners use atomization to aid vaporization by exposing the large surface area (relative to volume) of millions of droplets in the size range of 100-400 µm. Evaporation then occurs at a rapid rate even if the droplets are not exposed to furnace radiation or hot air due to enhanced mass transfer rates. Rotary-cup atomization delivers the liquid fuel to the center of a fast-spinning cup surrounded by an air stream. Rotational speed and air pressure determine the spray angle. This is still used in some large boilers, but the moving parts near the furnace heat have proved to be too much of a maintenance problem in higher temperature process furnaces and on smaller installations where a strict preventive maintenance program could not be affected.

6. Flue Gas Analysis:

The major constituents in flue gas are CO₂, O₂, N₂ and H₂O. Excess air is determined by measuring the O₂ in the flue gas. Before proceeding with measuring techniques, consider the form of the sample. A flue gas sample may be obtained on a wet or dry basis. When a sample is extracted from the gas stream, the water vapor normally condenses and the sample is considered to be on a dry basis. The sample is usually drawn through water near ambient temperature to ensure that it is dry. The major constituents of a dry sample do not include the water vapor in the flue gas.

When the gas is measured with an in situ analyzer or when precautions are taken to keep the moisture in the sample from condensing, the sample is on a wet basis. The amount of O₂ in the flue gas is significant in defining the status of the combustion process. Its presence always means that more oxygen (excess air) is being introduced than is being used. Assuming complete combustion, low values of O₂ reflect moderate excess air and normal heat losses to the stack, while higher values of O₂ mean needlessly higher stack losses. The quantity of excess O₂ is very significant since it is a nearly exact indication of excess air.

The O₂ is an equally constant indication of excess air when the gas is sampled on a wet or in situ basis because the calculated excess air result is insensitive to variations in moisture for specific types/sources of fuel. The current industry
The standard for heaters operation is continuous monitoring of O\textsubscript{2} in the flue gas with in situ analyzers that measure oxygen on a wet basis. For testing, the preferred instrument is an electronic oxygen analyzer.

The flue gas analyzer unit, which measures (CO\textsubscript{2} SO\textsubscript{2}) and O\textsubscript{2} on a dry volumetric basis, remains a trusted standard for verifying the performance of electronic equipment. The flue gas analyzer uses chemicals to absorb the (CO\textsubscript{2} SO\textsubscript{2}) and O\textsubscript{2}, and the amount of each are determined by the reduction in volume from the original flue gas sample.

7. Temperature Measurements:

Thermal oil inlet, thermal oil outlet, ambient temperature, fuel oil temperature, flue gas temperature and outer surface temperature, all are measured in this study for more accurate calculation. All measurements of temperature included in this investigation will be executed by PT-100 thermocouple (Type K) Fig. 3. Temperature of thermal oil inlet, thermal oil outlet, fuel oil inlet, and flue gas were measured by PT-100 thermocouple. Temperature of outer surface of heater was measured by using device which uses Infrared sensor technology to measure temperature of surfaces without contact.

8. Method of Calculation:

The most commonly used indicator for the efficiency of energy conversion process is the ratio of the output of useful energy to the total energy input. This ratio is called first law efficiency. It is based on a quantitative accounting of energy, which reflects recognition of the first law of thermodynamics and the law of conservation of energy.

It is well known that the second law of thermodynamics defines the availability of energy more restrictively than the first law. Principally, first law is silent on the effectiveness with which availability is concerned. Analysis in terms of the second law of thermodynamics more closely describes the effectiveness with which systems or processes use available energy.

Each calculation of exergy and thus each exergetic analysis imply reference state called ‘dead state’. If a system is in thermal and mechanical equilibrium with the reference environment that is at the environmental temperature T\textsubscript{O} and Pressure P\textsubscript{O}, it is said to be in a thermodynamically dead state or restricted dead state. In general it is taken as T\textsubscript{O} = 298 K and P\textsubscript{O} = 1 atm.

Exergy losses are calculated by making exergy balance for each component of the system. Unlike energy balance where the inflow is equal to outflow (when there is no internal energy generation or consumption), in exergy balance due to reasons of irreversibility, exergy inflow is always greater than the exergy outflow and their difference gives the exergy loss or exergy destruction. Ratio of exergy output to exergy input gives the exergetic efficiency of a system [4].

\[ \omega = \text{Exergetic efficiency} = \frac{\text{Exergy output}}{\text{Exergy input}} \] (1)

Fig. 4. Schematic diagram for the control volume of a test rig.
Exergy calculation (second law of thermodynamics):

The objective of this section is to introduce exergy analysis, a method that uses the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the investigation and analysis of combustion processes and thermal systems. Another term frequently used to identify exergy analysis is availability analysis.

Following usual conventions [5-7], the absolute availability, $A_{\text{Abs}}$, of a system is defined as:

$$A_{\text{Abs}} = U - T_0 S + P_0 V \tag{2}$$

Where $U$, $S$ and $V$ are the internal energy, entropy and volume of the system respectively, while $T_0$ and $P_0$ are the reference temperature and pressure. The work that may be extracted from a system is also limited by the reference conditions. The work that may be extracted from the system is then given by the (thermo-mechanical) availability, $A_{\text{TM}}$, of the system, which is defined as:

$$A_{\text{TM}} = (U - U') - T_0 (S - S') + P_0 (V - V') \tag{3}$$

Where $U'$, $S'$ and $V'$ are the internal energy, entropy and volume of the restricted dead state, respectively.

The restricted dead state is achieved by allowing the system to come to thermo-mechanical equilibrium with the environment, typically the atmosphere. The restricted dead state has the same pressure and temperature as the environment, however, the composition of the restricted dead state is the same as that of the original system and is not necessarily the same as that of the environment. The current work uses this definition of the restricted dead state, in conformance with the standard literature [5-7], with a temperature of 298.15 K and pressure 101.325 kPa for the restricted dead state and the reference conditions. This difference in composition between the restricted dead state and the environment can be exploited to further obtain work from the system. This work, obtained by allowing the restricted dead state to come to chemical equilibrium with the environment, is referred to as the chemical exergy, $A_{\text{Ch}}$, of the system.

$$A_{\text{Ch}} = \sum_{k=1}^{n} N_k \left( \mu_k^0 - \mu_{k,0} \right) \tag{4}$$

Where $N_k$ is the number of moles of the respective species (k) and $\mu_{k,0}$ and $\mu_k^0$ are the chemical potentials of the respective species in the restricted dead state and the environment, respectively. The chemical potentials may further be expressed as:

$$\mu_k = g_k(T_0, P_0) + R T_0 \ln \left( \frac{P_k}{P_0} \right) \tag{5}$$

Where $g_k$ is the Gibbs energy of the $k^{\text{th}}$ species in the mixture, $R$ is the Universal gas constant and $P_k$ is the partial pressure of the $k^{\text{th}}$ species in the mixture. If the restricted dead state and the environment, both had the same constituent species, differing only in their respective compositions, the Gibbs energy term would cancel out, leaving a simpler expression for the chemical availability of the system:

$$A_{\text{Ch} \text{diff}} = R T_0 \sum_{k=1}^{n} N_k \ln \left( \frac{P_k}{P_{k,0}} \right) \tag{15}$$

The difference in concentrations of the various species in the system and the atmosphere may be exploited by first separating the various components in the mixture (using devices such as
semi-permeable membranes) and then allowing them to expand or compress to the atmospheric partial pressures, as the case may be. Work may be gained or lost during this process and this creates an additional potential for work. Since this term may be attributed to the work obtained by allowing the species in the system to diffuse to the atmospheric concentrations, it would be appropriate to refer to this as the “diffusion availability”. It may be noted that diffusion availability of a system can be positive or negative, depending on the concentrations of the various species in the system. The diffusion availability of a system is largely ignored since its contribution is often small relative to the thermo-mechanical availability \( A_{TM} \) of the system. Also, it is not easy to extract the diffusion availability component of the availability since it would require the use of semi-permeable membranes to extract the various species in the mixture before allowing them to diffuse to atmospheric concentrations. It is also evident from the expression for the diffusion availability of a system that it depends on the composition of the environment. The assumed composition of the atmosphere therefore, makes a difference on the diffusion availability of the system. The current work uses a standard wet atmospheric unless otherwise stated.

The availability of a system, \( A_{Total} \), incorporating the various components would then be

\[
A_{Total} = (U - U_0) - T_0(S - S_0) + \sum_{i=1}^{n} N_i (\mu_i^0 - \mu_i)
\]

(1.6)

The above expression for availability is valid for closed systems. For open systems, the flow availability, \( A_{Total, f} \) needs to be considered. This is defined

\[
A_{Total, f} = (H - H_0) - T_0(S - S_0) + \sum_{i=1}^{n} N_i (\mu_i^0 - \mu_i)
\]

(1.7)

Where \( H \) and \( H^0 \) are enthalpies of the system and the restricted dead state respectively.

In general, then, the availability of a system, \( A_{Total} \), may be expressed as a sum of the thermo-mechanical availability and chemical availability.

\[
A_{Total} = A_{TM} + A_{Ch}
\]

(8)

The chemical availability term may further be split into constituents, the reactive availability and diffusive availability as:

\[
A_{Total} = A_{TM} + A_{Reactive} + A_{Diff}
\]

(9)

The importance of developing thermal systems which uses fossil fuel in the process of combustion that make effective use of nonrenewable resources such as oil, natural gas, and coal is apparent. The method of Exergy analysis is particularly suited for furthering the goal of more efficient resource use, since it enables the locations, types, and true magnitudes of waste and loss to be determined. This information can be used to design thermal systems, guide efforts to reduce sources of inefficiency in existing systems, and evaluate system economics.

8.2 Exergy Analysis Formulas

The start point in the Exergy analysis is Exergy balance for a system, Exergy balance in this system can be symbolized as:

\[
E_{in} = E_{oil} + E_{stack} + E_{loss} + E_{Destruction}
\]

(11)

Where, \( E_{in} \) represent chemical exergy involved in fuel oil entering to combustion chamber, also exergy of fuel oil = LHV * 1.04, [5] that means \( E_{in} = 41033*1.04 = 42674.32 \) kJ/kg fuel.

\( E_{oil} \) in above equation represent Exergy flow to thermal fluid, and is calculated here from:

\[
E_{oil} = \text{Exergy flow to thermal fluid} = m \cdot c_p \cdot (T_{out} - T_{in} - T_0) \cdot \ln \left( \frac{T_{out}}{T_0} \right)
\]

(12)

Where, the value 1.04 is factor multiply in lower heating value of fuel to get exergy value contained in fuel. [5].

\( m \) = Thermal fluid mass flow rate kg/hr, \( C_p \) = average specific heat capacity kJ/ (kg.k)

\( T_{out} \) = Thermal fluid outlet temperature Kelvin, \( T_{in} \) = Thermal fluid inlet temperature Kelvin.

\( E_{stack} \) in above equation represents exergy flow to surrounding with flue gas and calculated here from equation:

\[
E_{stack} = h - h_0 - T_0(s - s_0) + e^{ch}
\]

Where, in above eq., \( h \) and \( s \) represent the specific enthalpy and entropy, respectively, at the inlet or
exit under consideration; \( h_0 \) and \( s_0 \) represent the respective values of these properties when evaluated at the dead state. Values of \( h, s, h_0 \) and \( s_0 \) are from standard tables of thermodynamics. Where the underlined term is the thermo-mechanical contribution of exergy in combustion products, \( e^{ch} \) is the chemical contribution evaluated as following:

\[
\bar{e}^{ch} = \bar{R} T_0 \sum_i y_i \ln \left( \frac{x_i}{y_i^0} \right) \quad (14)
\]

Where, \( \bar{R} = \text{Universal Gas Constant} = 8.314 \) kJ/kmol. K and \( y_i \) and \( y_i^0 \) denote, respectively, the mole fraction of component \( i \) in the mixture of combustion products at \( T_0, P_0 \) and in the environment, with assumption that products of combustion are modeled as an ideal gas mixture at all states considered.

\( E_{s,\text{loss}} \) in main equation represents exergy flow to surrounding by radiation from the surface of heater and calculated here from equation:

\[
E_{s,\text{loss}} = (1 - [T_0 / T_{surf}])^* Q_e \quad (15)
\]

Where \( Q_e \) calculate (surface losses) which is quantified macroscopically by a modified form of the Stefan–Boltzmann law equation relation:

\[
Q_e = \varepsilon \sigma A (T_s^4 - T_{0}^4) \quad (16)
\]

\( E_{\text{Destruction}} \) in main equation represents Exergy Destruction inside furnace because irreversibility and are calculated by making Exergy balance for control volume in this study.

9. Results Presentation and Analysis

In this study, exergy analysis was carried out for combustion in direct fired heater. A flue gas sample for 40 runs of restricted heater was taking and input and output streams for each run were studied. Exergy and energy balance for each run was evaluated and theoretical analysis was carried out using these results. These results include a complete energy and Exergy analysis for direct fired heater, therefore energy efficiency, exergetic efficiency; exergy losses, energy losses, irreversibility and exergy destruction within the system (control volume of test rig) are calculated. Excess air ratios at variation of fuel oil flow rate, the following operating condition are tested:

1-Fuel oil flow rate=120 kg/hr, 2-Fuel oil flow rate=144 kg/hr, 3-Fuel oil flow rate=192 kg/hr, 4-Fuel oil flow rate=240 kg/hr, 5-Fuel oil flow rate=279 kg/hr, 6-Fuel oil flow rate=298 kg/hr, 7-Fuel oil flow rate=318 kg/hr, 8-Fuel oil flow rate=336 kg/hr

Figure 5 represents the variation of energy efficiency with excess air at different levels of fuel flow rate. The figure shows that the energy efficiency, for all curves, tends to decrease with the increase of excess air level. A closer look in the figure would show that the high values of energy efficiency are achieved in the range of 8% to 20% of excess air. For all levels of fuel flow rate, the energy efficiency values are limited in the range of 60% to 82%.

Fig. 5. Variation of the energy efficiency with excess air.

Figure 6 shows the variation of exergy efficiency with excess air at different levels of fuel flow rate. It is clear that the trend is the same as it appears in Fig. (5) but with change in values of exergy efficiency and energy efficiency. The Figure shows that the energy efficiency reached a range of 18% to 24% instead of 60% to 82% at the same excess air of the range of 8% to 20%.

Fig. 6. Variation of the exergy efficiency with excess air.
Fig. 6. Variation of the exergy efficiency with excess air.
Figure 7 shows the variation of energy stack losses with the excess air at different level of fuel flow rate. In the Figure, it is clear that general trend for the lines to go to high level of energy which goes to surrounding with flue gases with increase of excess air level, but in range of 8% to 20% excess air stack losses decrease and return to increase again with excess air. Energy stack loss values are limited by the range 10% to 33% for all runs.

Fig. 7. Variation of the energy stack losses with excess air.
Figure 8 shows the variation of exergy stack losses with the excess air at different level of fuel flow rate, it is obvious that the trends of the curves are the same as they appear in Fig. 7; but with changes in value of exergy stack losses than energy stack losses, since energy stack losses vary in range of 10% to 33%, while exergy stack losses vary in range 32% to 73% for all runs.

Figure 9 shows the variation of exergy destruction with the excess air at different level of fuel flow rate. In this Figure, it appears that the exergy destruction within the system under investigation decreases while the excess air level increases for all runs that mean the irreversibility within the system decreases with the increase of excess air levels.

Fig. 8 Variation of the exergy stack losses with the excess air.

Fig. 9. The variation of exergy destruction with variation of excess air.

10. Conclusions
1-The exergitec efficiency is very low comparing the energy efficiency in direct fired heater. The Exergy destruction is in the range of 12% to 60% in direct fired heater.
2- The exergy loss through the flue gas is in the range of 20% to 65% in direct fired heater, and it is in the range of 0.004% to 0.008% for surface emission.
3- The average exergetic efficiency becomes 22% in direct fired heater. According to this analysis the minimum possible exergy losses in a direct fired heater should be within the following limits: Percentage exergy loss through flue gas: 20%, percentage exergy loss through surface emission: 0.005%. With reference to these limits the percentage exergy destruction is 60% and the exergetic efficiency is 22%. This is the maximum
possible exergetic efficiency that can be taken by maintaining the optimum running condition.

4 - As increasing of exergetic efficiency, as the energy efficiency also increased

1. References


