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Boiler Parametric Study of Thermal Power Plant to Opproach to Low Irreversibility

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Abstract: In this work, in order to reach to low irreversibilities, the energy and exergy have been analyzed in the boiler system of Tabriz power plant. First, it has been done to decrease the irreversibility of system. Second, flow and efficiencies of energy and exergy of the mentioned system have been studied. In the boiler, the energy efficiencies based on lower and higher heating value of fuel are 91.54% and 86.17% respectively. In other hand, the exergy efficiency is 43.98%. Comparing with Rosen and et al., it is demonstrated that, results have a logical agreement with experimental data. Accordingly, the EES used code, have been validated. Furthermore, the gas fired steam power plant efficiency has been increased by the use of irreversibilities reduction and diminution of excess combustion air and/ or the stack-gas temperature. Finally, these have been concluded, overall energy and exergy efficiencies of Tabriz power plant increase 0.497% and 0.46%, respectively when the fraction of excess combustion air decreases from 0.4 to 0.15.Also these efficiencies increase 2.196% nearly when, the stack-gas temperature decreases from 159 to 97 °C.

Keywords: Excess Air, Stack Gas, Exergy Efficiency, Energy Efficiency, Boiler, Tabriz Power Plant

1. Introduction

The leakage in energy supply and pollutant issue requires an improved using of energy sources. Thus, the anfractousity of power plant units has increased implicitly. Plant engineers are increasingly deigning an accuratly high performance. It will be done by thermodynamic calculations of high accuracy. Consequently, the time and cost of thermodynamic calculating during design and optimization have been rised significantly [2]. The most commonly-used analysis for measuring of an energy-conversion process efficiency is the first-law method. Also, by the second laws of thermodynamics, such as exergy (availability, available energy), entropy generation and irreversibility (exergy destruction) the efficiency has been evaluated. Exegetic analysis enriches thermodynamic evaluation of energy conservation, because it provides the tool for a clear difference between energy losses to the environment and internal irreversibilities in the process [3]. In the recent, exergy analysis has imprtant role to reach to the better understanding of the process, to measure sources of inefficiency, to realize quality of energy (or heat) used [2-5]. Exergy is consider as the maximum theoretical useful work (or maximum reversible work) gained by a system interacts with a steady state. Basicly Exergy is saved not conserved as energy but destructed in the system. Exergy destruction is as criteria for irreversibility. Therefore, an exergy analysis is applied to measure exergy destruction. Also it identifies the location, the magnitude and the source of thermodynamic inefficiencies in a thermal system [6].

Boiler efficiency has a significant effect great influence on heating- related energy savings. Thus, it is important to increase the heat transfer to the water and decrease the heat losses in the boiler. Heat can be lost from boilers by different way, including hot flue gas losses, radiation losses and, in the case of steam boilers, blow down losses [7]. For optimizing the operation of a boiler plant, it is necessary to identify where energy loss is likely to occur. A determined amount of energy is lost through flue gases as all the heat produced by the burning fuel cannot be transferred to water or steam in the boiler. Since most of the heat losses from the boiler exit with the flue gas, the recycling of this heat can result in substantial energy saving [8].

In a research, Exergetic analysis of pulp and paper production is presented. An exergy destruction as well as exergy efficiency relation is determined for each section of the system components and the whole system to indicate the largest exergy losses and possibilities of improvement. It is found that the largest exergy losses occurred in the steam plant and soda recovery and these sections are highly exergy inefficient. Further it is observed that with decrease of excess air and preheating of inlet air the exergy efficiency of boilers is increased [9].

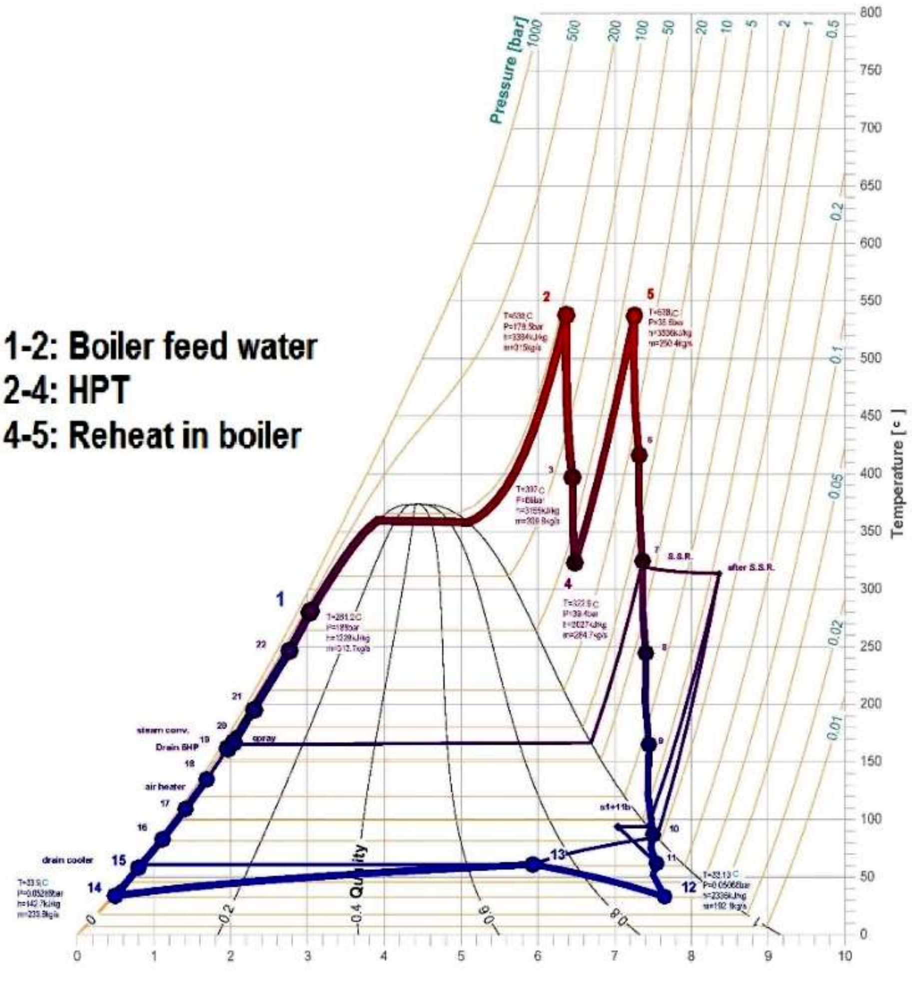
An exergy destruction as well as exergy efficiency relation is determined for each section of pulp and paper production system components and the whole system to indicate the largest exergy losses and possibilities of improvement. It is found that the largest exergy losses occurred in the steam plant and soda recovery and these sections are highly exergy inefficient. Further it is observed that with decrease of excess air and preheating of inlet air the exergy efficiency of boilers is increased [10].

In the other research, the increase in boiler efficiency was obtained by utilizing existing combustion equipment, existing combustion controls system, and a new ZoloBOSS in-furnace laser based combustion measurement system. This optimization improves the boiler efficiency by reducing the O2, improving and balancing the combustion, balancing the temperature and O2 distribution in the boiler and by continuous adaption to varying boiler conditions [11].

This demonstrates that there are huge savings potentials of a boiler energy savings by decreasing its losses. Recently, the technology involved in a boiler can be seen as having reached a plateau, with even marginal increase in efficiency ratherly hard to achieve [12].

Many investigator have helped to the fundamentals and performance of exergy analysis [13-19]. The history of exergy analysis was recently collected [20].

This work aims to identify and assess methods for increasing efficiencies of steam power plants, to provide options for improving their economic and environmental performance. In this study, several measures to improve efficiency, primarily based on exergy analysis, are considered. The modifications considered here, which increase efficiency by reducing the irreversibility rate in the steam generator, are decreasing the fraction of excess combustion air and/or decreasing the stack-gas temperature. The impact of implementing these measures on efficiencies and losses is investigated.



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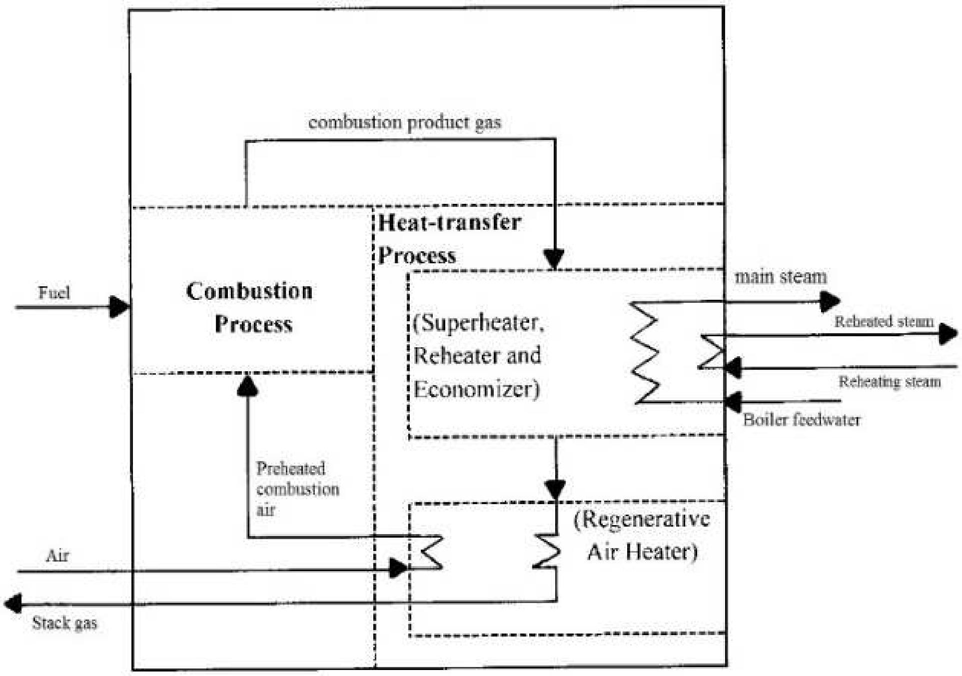

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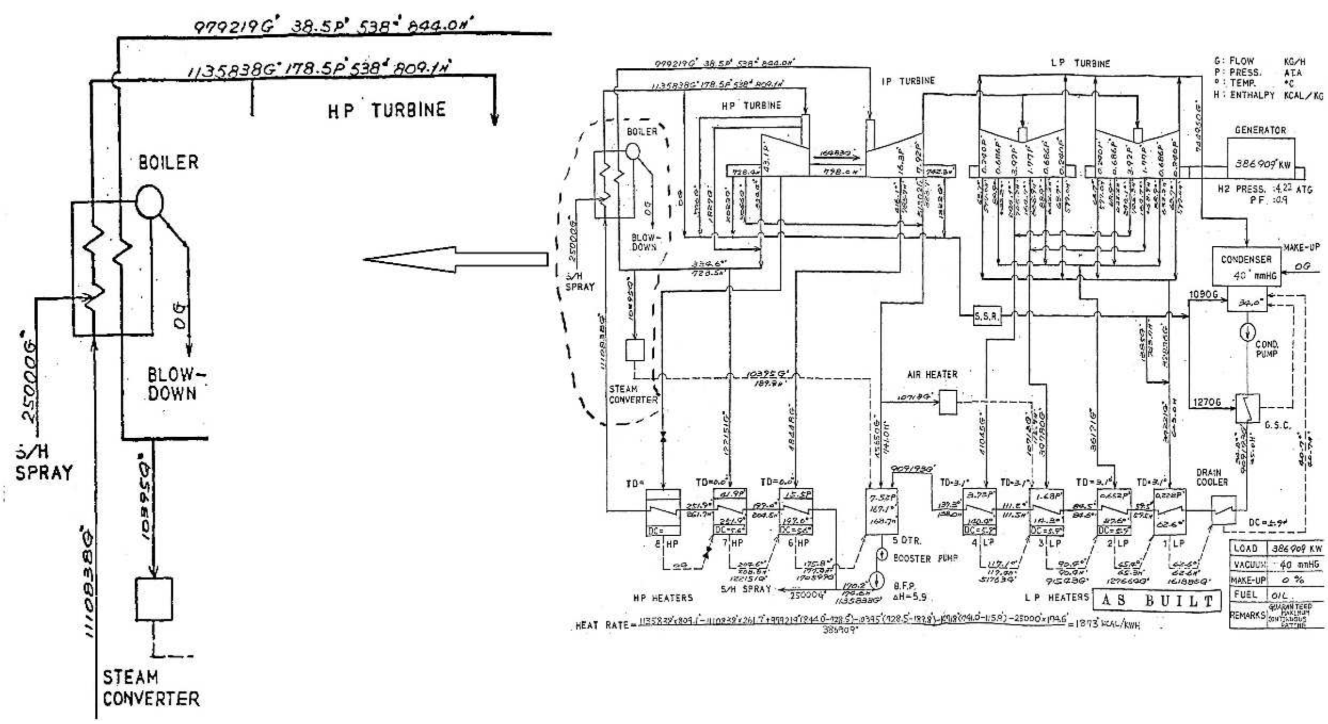

(c)

Figure 1. *(a) State and process data on T-s chart of water, (b) Model of the Boiler and (c) Heat balance diagram for the Tabriz power plant.*

2. Energy and Exergy Analysis

The state and process data on T-s chart of water and The Heat balance diagram for the boiler and power plant is shown in fig. 1 The following thermodynamic analysis of the power plant will consider the balances of mass, energy, entropy and exergy. The variation of kinetic and potential energies will be neglected and steady state flow will be considered. For a steady state process, the mass balance for a control volume system in fig. 1 can be presented as

$$\sum_i \dot{m}_i = \sum_e \dot{m}_e \tag{1}$$

The energy balance for a control volume system is as:

$$\sum_i \dot{E}_i + \dot{Q} = \sum_e \dot{E}_e + \dot{W} \tag{2}$$

The entropy balance for a control volume system is as:

$$\sum_i \dot{S}_i + \sum_i \frac{\dot{Q}_i}{T} + \dot{S}_{gen} = \sum_e \dot{S}_e + \sum_e \frac{\dot{Q}_e}{T} \quad (3)$$

Also, the exergy balance for a control volume system is written as

$$\sum_i Ex_i + \sum_i (1-\frac{T}{T_k})\dot{Q}_k = \sum_e Ex_e + \dot{W} + \dot{I} \quad (4)$$

Where the flue exergy rate is:

$$\dot{Ex} = \dot{m}(Ex) \quad (5)$$

$$\dot{m}(Ex) = \dot{m}(Ex^{tm} + Ex^{ch}) \quad (6)$$

The general form of exergy balance has been exhibited above. With calculating the chemical exergy of gas, the heat input will be included. The heat exergy term in Eq. (4) will be used to calculate the exergy loss associated with heat loss to the surroundings. The specific exergy is given by:

$$Ex^{tm} = (h - h_0) - T_0(s - s_0) \quad (7)$$

3. Methods to Improve Plant Efficiency

In order to improve overall-plant efficiency, some methods are considered here. These methods are as reducing excess combustion air and stack-gas temperature which are selected. It has been done to their potential benefits and application without excessive modifications to existing steam power plants.

4. Effect of Decreasing Excess Combustion Air

One method to reducing the exergy losses in the boiler is reducing of the air fraction in the combustion process. With decreasing of air fraction (while still remaining large enough to promote good fuel combustion), the temperature and the exergy of the combustion product gas increases. The heating of combustion air leads to increasing of product gas in the combustion process.

The plant optimization has been done in this analysis with decreasing the fraction of excess combustion air λ from 0.40 (the base-case value) to 0.15.

Modelling the oil used in the power plant as (CH1.74S0.008) and assuming complete combustion with excess air, the combustion reaction can be expressed as follows:

$$CH_{1.74}S_{0.008} + 1.443(1+\lambda)(O_2 + 3.76N_2) \rightarrow CO_2 + 0.87\,H_2O + 0.008\,SO_2 + 5.425(1+\lambda)\,N_2 + 1.443\lambda\,O_2 \quad (8)$$

Where λ is the fraction of excess combustion air. Then, the air-fuel (AF) ratio can be written as

$$AF = \frac{\dot{m}_a}{\dot{m}_f} = \frac{\dot{n}_a M_a}{\dot{n}_f M_f} = \frac{1.443(1+\lambda)4.76 M_a}{M_f} \quad (9)$$

The chemical energy for the fuel can be written as

$$\text{Input Energy} = \dot{E}_f = \dot{n}_f\,\overline{HHV} \quad (10)$$

Using eqs. (6) and (7) and noting that the thermomechanical exergy of fuel is zero at its assumed input conditions of T_0=19°C and P_0=1atm, the fuel exergy can be written as

$$\dot{Ex}_f = \dot{n}_f\,\overline{Ex}^{ch} \quad (11)$$

The energy flow rate of a gas flow can be written as the sum of the energy flow rates for its constituents:

$$\dot{E} = \sum_i \dot{n}_i\,[\bar{h} - \bar{h}_0]_i \quad (12)$$

The exergy flow rate of a gas flow can be written with eqs. (6) and (7) as

$$\dot{Ex} = \sum_i \dot{n}_i\,[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_i \quad (13)$$

The energy and exergy flow rate of combustion air can be written in terms of the mole flow rate of fuel n_f using eqs. (8), (12) and (13) and noting that the chemical exergy of air is zero, as

$$\dot{E}_a = \dot{n}_f 1.443(1+\lambda)\,[(\bar{h}-\bar{h}_0)_{O_2} + 3.76(\bar{h}-\bar{h}_0)_{N_2}] \quad (14)$$

and

$$\dot{Ex}_a = \dot{n}_f 1.443(1+\lambda)\,\{[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)]_{O_2} + 3.76(\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0))_{N_2}]\} \quad (15)$$

It is useful to determine the hypothetical temperature of combustion gas in the boiler prior to any heat transfer (i.e., the adiabatic combustion temperature) to facilitate the evaluation of its energy and exergy and the breakdown of the boiler irreversibility into portions related to combustion and heat transfer. The energy and exergy flow rates of the products of combustion can be written using eqs. (8), (12) and (13) as

$$\dot{E}_p = \dot{n}_f\,[(\bar{h}-\bar{h}_0)_{CO_2} + 0.87\,(\bar{h}-\bar{h}_0)_{H_2O} + 0.008\,(\bar{h}-\bar{h}_0)_{SO_2} + 5.425(1+\lambda)\,(\bar{h}-\bar{h}_0)_{N_2} + 1.443\lambda\,(\bar{h}-\bar{h}_0)_{H_2}] \quad (16)$$

And

$$\dot{Ex}_p=\dot{n}_f \{[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_{CO_2}+0.87\,[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_{H_2O}$$

$$+0.008\,[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_{SO_2}+5.425(1+\lambda)\,[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_{N_2}+1.443\lambda\,[\bar{h}-\bar{h}_0-T_0(\bar{s}-\bar{s}_0)+Ex^{ch}]_{O_2}\} \quad (17)$$

The adiabatic combustion temperature is determined using the energy balance in eq. (2) with $\dot{Q}=0$ and $\dot{W}=0$:

$$\dot{E}_f+\dot{E}_a=\dot{E}_p \quad (18)$$

Substituting eqs. (10), (14) and (16) into eq. (18) and simplifying yields the following:

$$\overline{HHV}+1.443(1+\lambda)\,[(\bar{h}-\bar{h}_0)_{O_2}+3.76(\bar{h}-\bar{h}_0)_{N_2}]_{T_a}=[(\bar{h}-\bar{h}_0)_{CO_2}+0.87\,(\bar{h}-\bar{h}_0)_{H_2O}$$

$$+0.008\,(\bar{h}-\bar{h}_0)_{SO_2}+5.425(1+\lambda)\,(\bar{h}-\bar{h}_0)_{N_2}+1.443\lambda\,(\bar{h}-\bar{h}_0)_{O_2}]_{T_p} \quad (19)$$

Here T_p is evaluated using an iterative solution technique. Note that the flow rates of energy $\dot{E}_g$ and exergy $\dot{Ex}_g$ for the stack gas can then be evaluated using eqs. (16) and (17) because the composition of stack gas is same as that of the product gas.

An energy balance equation for the boiler can be written as

$$\dot{E}_f-\dot{E}_g=\dot{m}_{fw}(h_{fw,e}-h_{fw,i})+\dot{m}_{re}(h_{re,e}-h_{re,i}) \quad (20)$$

The irreversibility rates in the boiler associated with combustion $\dot{I}_c$ and heat transfer $\dot{I}_{ht}$ can be evaluated as follows:

$$\dot{I}_c=\dot{Ex}_f+\dot{Ex}_a-\dot{Ex}_p \quad (21)$$

$$\dot{I}_{ht}=\dot{Ex}_p+\dot{Ex}_{feed,i}+\dot{Ex}_{re,i}-\dot{Ex}_g-\dot{Ex}_{feed,e}-\dot{Ex}_{re,e}-\dot{Ex}_a \quad (22)$$

Note that the exergy of combustion air at environment conditions is zero and, thus, not shown in eq. (7). The total irreversibility rate for the boiler $\dot{I}_{boiler}$ can then be expressed as

$$\dot{I}_{boiler}=\dot{I}_c+\dot{I}_{ht} \quad (23)$$

And the exergy efficiency Ψ_{boiler} as

$$\Psi_{boiler}=\frac{\dot{Ex}_{net,boiler}}{\dot{Ex}_f} \quad (24)$$

Where $\dot{Ex}_{net,boiler}$ represents the net exergy output rate for the H_2O that flows through the steam generator, i.e.

$$\dot{Ex}_{net,boiler}=(\dot{Ex}_{feed,e}-\dot{Ex}_{feed,i})+(\dot{Ex}_{re,e}-\dot{Ex}_{re,i}) \quad (25)$$

The overall-plant thermal and exergy efficiencies are determined as follows:

$$\eta_{plant}=\frac{\dot{W}_{net}}{\dot{E}_f} \quad (26)$$

$$\Psi_{plant}=\frac{\dot{W}_{net}}{\dot{Ex}_f} \quad (27)$$

The variation with the fraction of excess combustion air λ of the product-gas temperature T_p and the irreversibility rates, are illustrated in Figs. 2 and 3. The variation with λ of the boiler exergy efficiency ψ_{boiler}, the overall-plant efficiencies based on exergy ψ_{plant} and energy η_{plant}, are illustrated in Fig. 5. Consider that, in Figs. 2, 3 and 7, the dotted line shows the estimated behavior of the mentioned parameters between $\lambda=0$ (theoretical combustion air) and the point where calculations are made (i.e., $\lambda=0.15$).

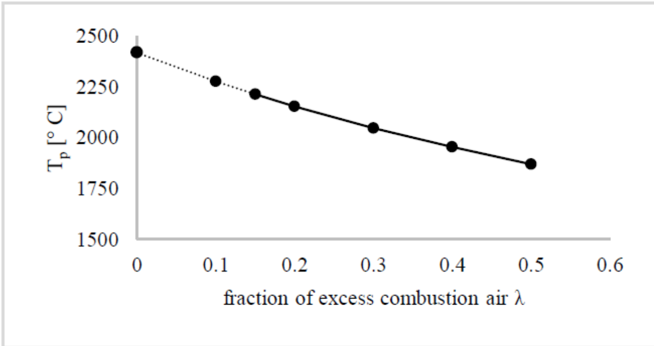

Figure 2. *The variation with fraction of excess combustion air λ of the combustion product-gas temperature T_p.*

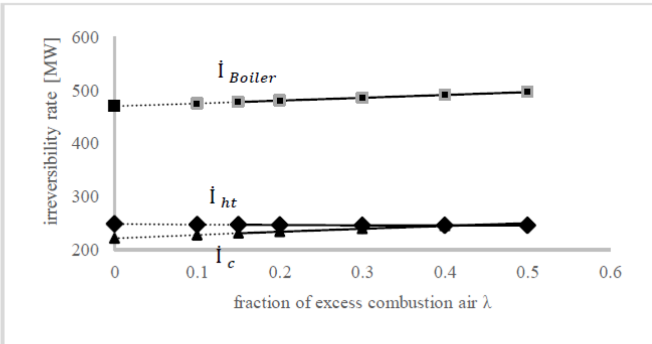

Figure 3. *The variation of irreversibility rates versus fraction of excess combustion air λ.*

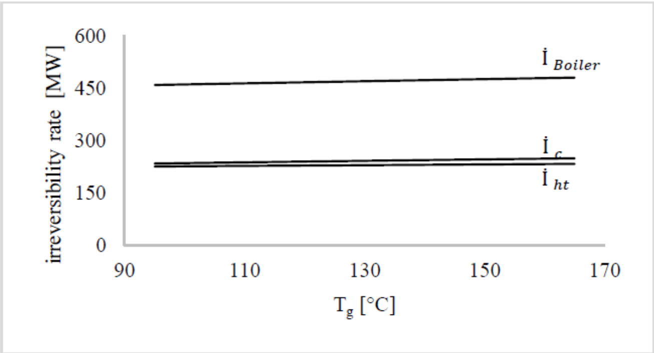

Figure 4. *The variation of irreversibility rates versus stack-gas temperature T_g.*

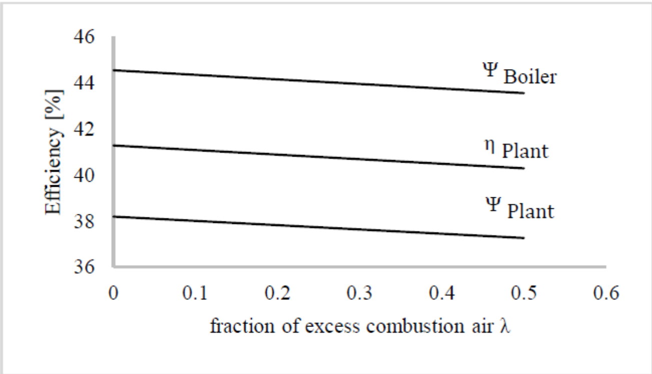

Figure 5. *The variation of efficiency versus fraction of excess combustion air λ.*

Fig. 3 illustrated that with decreasing the fraction of excess combustion (λ), the combustion irreversibility decreases and, inrersely the heat transfer irreversibility increases consequently, the boiler irreversibility which is achieved by the summation of two above irreversibilities increases. It can concluded that with decreasing of λ the temperature of combustion products rises, and it leads to increasing of combustion products increasing. Also, the other conclusion is that, with decreasing of λ, the combustion products temperature increases, it leads to increasing in the difference of the fluid temerature with exhauoted gas totally, with increases of λ, $\dot{I}_{boiler}$ decreases and the consumption of fuel decreases consequently.

According to Fig. 5, with decreasing of λ, the boiler exergt efficiency (Ψ_{boiler}) and the overall plant efficiencies based on exergy Ψ_{plant} and energy ηplant increase. Because, with decreasing of λ, $\dot{I}_{boiler}$ decreases. And it leads to increasing of Ψ_{boiler}.

Also the decreasing of value of λ from 0.4 to 0.15, the energy and exergy efficiencies increase 0.497% and 0.46%, respectively. Forthermore if decreases form 0.4 to 0, two mentioned efficiencies increase 0.796% and 0.736%, respectively.

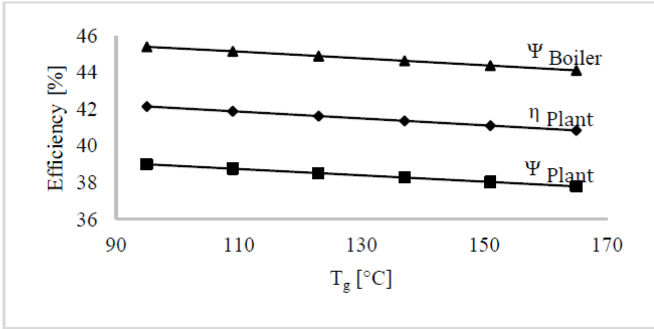

Figure 6. *The variation of efficiency versus stack-gas temperature T_g.*

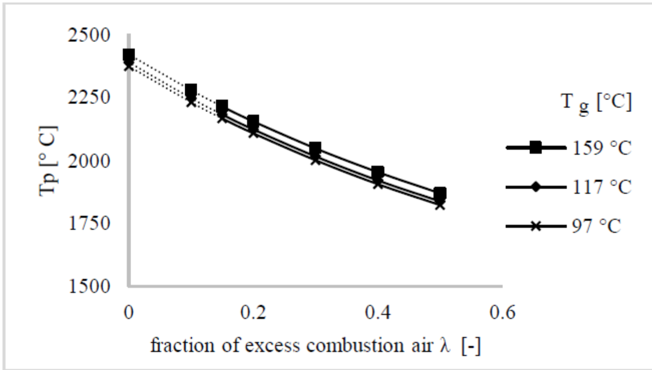

Figure 7. *The variation of the combustion product-gas temperature versus fraction of excess combustion air λ, T_p and stack-gas temperature T_g.*

5. Effect of Decreasing Stack-Gas Temperature

Another method to diminish the irreversibility rate associated with combustion in the steam generator is reducing the stack-gas temperature T_g. When T_g decreases, more heat can be recovered in the regenerative air heater and can be used to rise the combustion-air temperature. Practical considerations provide lower limits for the temperature of the stack gas. By the use of a Teflon coating to safe materials from the corrosive acids (sulphuric and nitric) that condense out of stack gases at lower temperatures permits the stack-gas temperature *Tg* to be decreased by 56–83°C (100–150°F) below the nominal stack-gas temperature of 149°C (300°F) [21,22].

Also, two cases of reduced stack-gas temperature (relative to the base-case value of T_g = 159°C) are considered here: 117°C and 97°C. For each case, the energy recovery rate $\Delta\dot{E}$ from the regenerative air heater increases the energy (and temperature) of the combustion air. The energy flow rate of the preheated combustion air can be written as

$$\dot{E}_a = \Delta\dot{E} + \dot{n}_f 1.443(1+\lambda)\,[(\bar{h}-\bar{h}_0)_{O_2} + 3.76(\bar{h}-\bar{h}_0)_{N_2}] \tag{28}$$

Where the term in square brackets is evaluated at the preheated combustion-air temperature for the base case.

In this work, the preheated combustion-air temperature T_a is evaluated frequently for different amounts of T_g, using eq. (28). Then the combustion product-gas temperature T_p is obtained by eq. (19) and the fuel flow rate (n_f or m_f using eq. (20)). The exergy flow rates of the fuel, $\dot{Ex}_f$ the preheated combustion air, $\dot{Ex}_a$ the combustion product gas $\dot{Ex}_p$ and the stack gas $\dot{Ex}_g$ are determined as described in Section 4. The boiler irreversibilities ($\dot{I}_c$, $\dot{I}_{ht}$ and $\dot{I}_{boiler}$) and exergy efficiency Ψ_{boiler} and the overall-plant exergy efficiency Ψ_{plant} and thermal efficiency η_{plant}, are achived accordingly.

The variation with fraction of excess combustion air λ of stack-gas temperature T_g and several irreversibility rates are demonstrated in Fig. 8. The variation of the exergy efficiency of the boiler and the overall-plant exergy and thermal efficiencies, with stack-gas temperature T_g are demonstrated in Fig. 9.

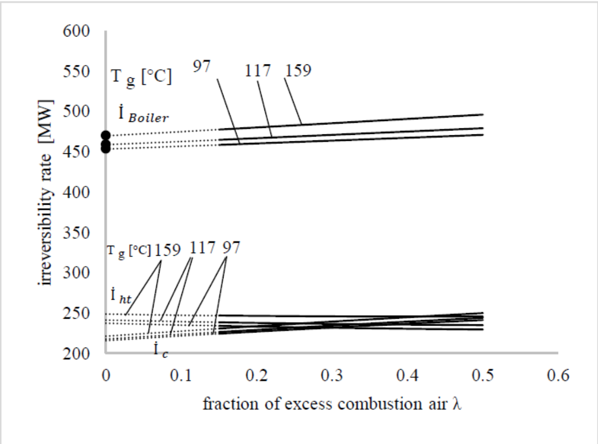

Figure 8. *The variation with fraction of excess combustion air λ of stack-gas temperature T_g and several irreversibility rates.*

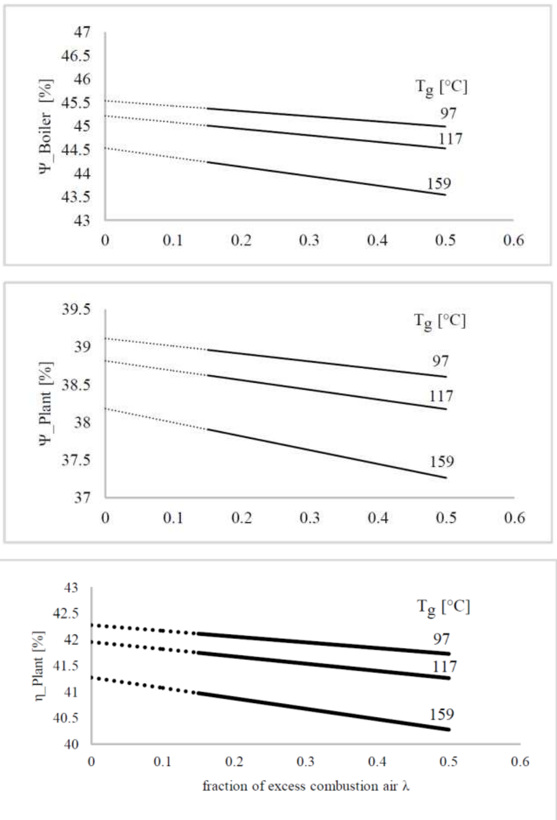

Figure 9. *The variation of the exergy efficiency of the boiler and the overall-plant exergy and thermal efficiencies, with stack-gas temperature T_g.*

According to fig. 8, $\dot{I}_{ht}$ and $\dot{I}_c$ decrease when, the stack-gas temperature (T_g), decreases. The decreasing of $\dot{I}_{ht}$ and $\dot{I}_c$ leads to decreasing of $\dot{I}_{boiler}$ two reasons, can be presented: first, with decrease of T_g, the temperature of pre-heated combustion air rises and the temperature of product gas will be increased consequently. The great value of product gas temperature makes the increasing in the difference between the temperatures of H_2O flow and exhausted gases.

Second, with decreasing in the value of T_g, two impacts can be shown as: significant decreasing in the $\dot{I}_{ht}$ and the slight decreasing in the $\dot{I}_c$. According the Fig. 9 it can be concluded that, with decreasing in the T_g, three parameters (Ψ_{boiler}, η_{plant} and Ψ_{plant}) will be rised.

The decreasing of Ψ_{boiler} leads to decreasing of $\dot{I}_{boiler}$. Also, with decreasing of T_g from 159°C to 97°C, Ψ_{plant} and η_{plant} increase 1.055% and 1.141% respectively.

6. Effect of Varying Excess Air and Stack-Gas Temperature Concurrently

The results of Sections 4 and 5 shows that the plant exergy efficiency can be rised by decreasing either the fraction of excess combustion air λ or the stack-gas temperature T_g. The other developments in plant exergy efficiency that may be achievable by changing λ and T_g concurrently are now analyzed. The parameter values considered are listed in Table 1.

Table 1. *Parameter values considered in investigating the effect of varying λ and T_g simultaneously.*

Parameter	Base-case value	Alternative values
Fraction of excess combustion air, λ	0.4	0.4, 0.3, 0.2, 0.15
Temperature of stack gas, Tg (°C)	159	117, 97

For the alternative values of λ and T_g, the mole flow rate of the fuel $\dot{n}_f$ is determined using eq. (20). The combustion-air temperature T_a, which changes only with T_g, is obtained by eq. (28). Then, the combustion product-gas temperature T_p is determined using eq. (19). Finally, exergy flow rates, such as $\dot{Ex}_f$ and, $\dot{Ex}_a$ are determined as described in Sections 4 and 5.

As λ and T_g are varied, the behaviours are illustrated for the combustion-gas temperature Tp (Fig. 7), several boiler irreversibility rates ($\dot{I}_c$, $\dot{I}_{ht}$ and $\dot{I}_{boiler}$) (fig. 4) and the boiler exergy efficiency Ψ_{boiler} well as the overall-plant exergy Ψ_{plant} and thermal η_{plant} efficiencies (figs. 5 and 6).

The concurrent affection of λ and T_g variation fig. 7. Exhibits the variation of T_p versus λ variation in the several amounts of T_g. fig. 4 shows the irreversiblities variations of boiler versus T_g variation.

According to fig. 8, in the all selected amounts of T_g decreasing of λ and $\dot{I}_{ht}$ increased and, $\dot{I}_c$ decrease inversly. Totally, $\dot{I}_{boiler}$ reduces. It is better to mention, the effect of $\dot{I}_{ht}$ is significantly more than $\dot{I}_c$ on the $\dot{I}_{boiler}$.

Accrding to fig. 9 three parameters of Ψ_{boiler}, η_{plant} and Ψ_{plant} are increased when, both λ and T_g are decreased. With decreasing of λ to 0.15 and T_g to 97°C, the energy and exergy efficiencies increases 1.36% and 1.268% respectively. With decreasing of λ to 0 and T_g to 97°C, the energy and exergy efficiencies increases 1.747% and 1.621% respectively.

7. Conclusions

With decreasing the fraction of excess combustion (λ), the combustion irreversibility decreases and, inrersely the heat transfer irreversibility increases consequently, the boiler irreversibility which is achieved by the summation of two above irreversibilities increases. It can concluded that with decreasing of λ the temperature of combustion products rises, and it leads to increasing of combustion products increasing. Also, the other conclusion is that, with decreasing of λ, the combustion products temperature increases, it leads to increasing in the difference of the fluid temerature with exhauoted gas totally, with increases of λ, $\dot{I}_{boiler}$ decreases and the consumption of fuel decreases consequently.

With decreasing of λ, the boiler exergt efficiency (Ψ_{boiler}) and the overall plant efficiencies based on exergy Ψ_{plant} and energy η_{plant} increase. Because, with decreasing of λ, $\dot{I}_{boiler}$ decreases. And it leads to increasing of Ψ_{boiler}.

Also the decreasing of value of λ from 0.4 to 0.15, the energy and exergy efficiencies increase 0.497% and 0.46%, respectively. Forthermore if decreases form 0.4 to 0, two mentioned efficiencies increase 0.796% and 0.736%, respectively.

$\dot{I}_{ht}$ and $\dot{I}_c$ decrease when, the stack-gas temperature (T_g), decreases. The decreasing of $\dot{I}_{ht}$ and $\dot{I}_c$ leads to decreasing of $\dot{I}_{boiler}$ two reasons, can be presented: first, with decrease of T_g, the temperature of pre-heated combustion air rises and the temperature of product gas will be increased consequently. The great value of product gas temperature makes the increasing in the difference between the temperatures of H_2O flow and exhausted gases.

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The decreasing of Ψ_{boiler} leads to decreasing of $\dot{I}_{boiler}$. Also, with decreasing of T_g from 159°C to 97°C, Ψ_{plant} and η_{plant} increase 1.055% and 1.141% respectively.

The concurrent affection of λ and T_g variation fig7. Exhibits the variation of T_p versus λ variation in the several amounts of T_g. fig. 4 shows the irreversiblities variations of boiler versus T_g variation.

In the all selected amounts of T_g decreasing of λ and $\dot{I}_{ht}$ increased and, $\dot{I}_c$ decrease inversly. Totally, $\dot{I}_{boiler}$ reduces. It is better to mention, the effect of $\dot{I}_{ht}$ is significantly more than $\dot{I}_c$ on the $\dot{I}_{boiler}$.

Three parameters of Ψ_{boiler}, η_{plant} and Ψ_{plant} are increased when, both λ and T_g are decreased. With decreasing of λ to 0.15 and T_g to 97°C, the energy and exergy efficiencies increases 1.36% and 1.268% respectively. With decreasing of λ to 0 and T_g to 97°C, the energy and exergy efficiencies increases 1.747% and 1.621% respectively.

Nomenclature

$\dot{E}x$	Exergy rate [MW]
$\dot{e}x$	specific Exergy rate [$MWkg^{-1}$]
$\dot{E}$	Energy rate [MW]
h	specific enthalpy [Jkg^{-1}]
HHV	High Heat value[$kjkg^{-1}$]
$\dot{I}$	exergy destruction rate
LHV	low Heat value[$kjkg^{-1}$]
$\dot{m}$	mass flow rate [kgs^{-1}]
P	pressure [atm]
$\dot{Q}$	heat transfer rate [MW]
s	specific entropy [Jkg^{-1} K^{-1}] and [$Jkmol^{-1}$ K^{-1}]
T	temperature [°C]
$\dot{W}$	work rate [MW]
$\dot{W}_s$	Isentropic work rate [MW]
Greek symbols	
η	energy efficiency[%]
Ψ	exergy efficiency[%]
Subscripts	
A	air
ch	chemical
c	Combustion
F	fuel
fw	Feed water
g	stack-gas
ht	Heat transfear
In	inlet
Out	outlet
p	Product gas Combustion
re	reheat
th	thermal
0	dead state conditions

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