Boiler Thermodynamic Analysis to Reduction Pollution

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***Abstract*– The most significant energy consumers in energy related industries are boilers and other gas-fired systems. Combustion efficiency term commonly used for boilers and other fired systems and the information on either carbon dioxide (CO2) or oxygen (O2) in the exhaust gas can be used. Efficiency increase and pollutant emission control are the most significant projects of the world. In this paper the incomplete combustion process has solved and the effect of excess air to boiler pollution has considered. The concept of equilibrium constant and molar balance used to find unknown coefficient in combustion products. The conclusion shows there is an optimum for excess air to reduce boiler pollution and increase boiler efficiency. The conclusion also shows to reduce mole fraction of NO, CO2 and CO in a gas fired boiler, the excess must be about 10 percent.**

***Keywords*–** Excess Air, Boiler Efficiency and Pollution (NO, CO, CO_2)

I. INTRODUCTION

Efficiency increase and pollutant emission control are the most significant projects of the world [1]. The pollution from industries could be better handled at the design stages when designers can consider a range of alternative design options at each stage of process design to choose more environmentally friendly options. A significant amount of work has been dedicated to incorporate environmental issues during the early stages of process. As a design objective most identify cost, and consider environment as a design constraint. Even in recent process design books there are no clear guidelines as to how to incorporate environmental issues as a design objective [2]. Excess air ratio is one of the operating variables affecting both thermal and environmental performances of a boiler. As is known, with the diminishing of the excess air ratio, the rate of NOx emissions in the boiler furnace is reduced[3]. Furthermore, the emission of NOx, SOx, polycyclic aromatic hydrocarbons (PAHs), CO, and particles leads to air pollution, acid rain, and health hazards [5,6]. Nevertheless, the demand for fossil fuel continues to rise globally [4]. Therefore, techniques to achieve better combustion efficiency with the least amount of pollutant emissions are necessary, and this goal can be reached through the control of combustion processes or adjustment of the fuels applied [4]. It is an assertion well established by researchers and engineers related to the industrial boiler field that excess air is a control variable affecting thermal efficiency and the operating reliability of boilers [4]. The increase in the value of the excess of air in the furnace leads to a reduction in the adiabatic flame temperature, and probably will prompt an increase in the heat transfer coefficients for all the convective equipment's, causing a reduction in the flue gas temperature. As the excess air ratio goes up, the O2 concentration in the main combustion area also increases, resulting in the rise of the flame temperature in the boiler. This then leads to a drop of the temperature in the boiler radiation area, and eventually affects the boiler efficiency [5, 6]. A boiler should always be supplied with more combustion air than is theoretically required, in order to ensure complete combustion and safe operation. If the air rate is too low, there will be a rapid buildup of carbon monoxide in the flue gas and, in extreme cases, smoke will be produced (i.e., unburned carbon particles) [5]. At the same time, boiler efficiency is very dependent on the excess air rate. Excess air should be kept at the lowest practical level to reduce the quantity of unneeded air that is heated and exhausted at the stack temperature [7, 8].

The amount of excess air (or O2) in the flue gas and the stack temperature rise above the inlet air temperature are significant in defining the efficiency of the combustion process. Excess oxygen (O2) measured in the exhaust stack is the most typical method of controlling the air-to-fuel ratio. Careful attention to furnace operation is required to ensure an optimum level of performance. To accomplish optimal control over avoidable losses, continuous measurement of the excess air is a necessity.

Fossil-fuel-fired steam generators, process fired heaters/furnaces, duct heaters, and separately fired super heaters may benefit from an excess air control program. Specialized process equipment, such as rotary kilns, fired calciners, and so on, can also benefit from an air control program.

Taplin [9] presents more information on combustion efficiency including combustion efficiencies data for natural gas or other fuels. In view of the above mentioned issues, it is necessary to develop an accurate and simple method which is easier than the existing approaches less complicated with fewer computations for predicting the natural gas combustion efficiency as a function of, excess air fraction and stack temperature rise. The results of the proposed predictive tool can be used in follow-up calculations to determine relative operating efficiency and to establish energy conservation benefits for an excess air control program. The paper discusses about the effect of excess air and stack gas temperature on the boiler efficiency and pollution emission (NO, CO, CO2)

II. ANALYSIS

Fig. 1 shows the boiler model for thermodynamic analysis. The process flow diagram for the boiler is shown in Fig. 1. The process parameters for the boiler are shown in Table 1.

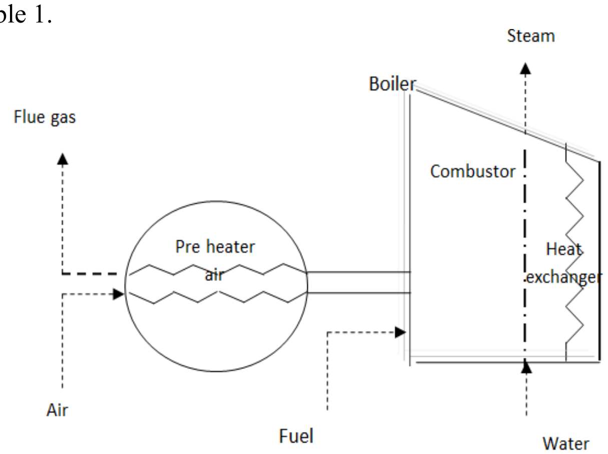

Fig. 1: Schematic diagram of preheater air and boiler

Table 1: Operating values of the power plant

Gas mass flow rate	16.76	kg/s
Gas lower heat value	48500	kJ/kg
Air mass flow rate	320.7	kg/s
Maximum gas temperature in boiler	2000	ºC
Gas exit temperature from boiler	137	ºC
Feed water mass flow rate	1017.5	ton/hr
Feed water pressure	24	Mpa
Feed water inlet temperature	282.5	kg/s
Steam temperature	540	ºC
Extraction steam pressure	4.48	Mpa
Extraction steam temperature	303	ºC
Extraction steam mass flow	255.8	kg/s
Reheated steam temperature	540	ºC
Cooling water mass flow rate	10000	kg/s

III. Modeling ANDSIMULATIONOF BOILER

Fuel of boiler is natural gas including CH_4 ،C_2H_6 ،C_3H_6 ، C_4H_{10} ،ISO-C_4H_{10} ،n-C_4H_{10} ،ISO-C_5H, n-C_5H_{12} ،CO_2 و N_2..The combustion process is incomplete. The concept of equilibrium constant and molar balance has been used to calculate the molar fraction of product. Equation 1 illustrates combustion equation. There are 12 unknown combustion product coefficients. This unknown coefficient has been fined with using molar balance concept (Equation 2-6) and equilibrium constant concept (equation 7-17)

a

(1)

Carbon equilibrium:

$$A+2b+3c+4d+5e=X_1+X_4 \quad (2)$$

Oxygen equilibrium:

$$2f+2X_{12}=2X_1+X_2+X_4+2X_5+X_6+X_8+X_9 \quad (3)$$

Hydrogen equilibrium:

$$4a+6b+8c+10d+12e=2X_2+2X_3+X_4+2X_5+X_8+X_{10} \quad (4)$$

Nitrogen equilibrium:

$$2g+3.76X_{12}N_2=X_6+2X_7 \quad (5)$$

Mole equilibrium:

$$X_{11}=X_1+X_2+X_3+X_4+X_5+X_6+X_8+X_9+X_{10} \quad (6)$$

CO2 constant equilibrium:

$$CO_2 \Leftrightarrow 2CO+O_2 \quad (7)$$

$$K_{CO_2}=\frac{\left(\frac{X_4}{X_{11}}\right)^2\left(\frac{X_5}{X_{11}}\right)}{\left(\frac{X_1}{X_{11}}\right)}\left(\frac{P}{P_0}\right) \quad (8)$$

H_2OConstantequilibrium 1:

$$H_2O =\Leftrightarrow 2H_2+O_2 \quad (9)$$

$$K_{H_2O,1}=\frac{\left(\frac{X_3}{X_{11}}\right)^2\left(\frac{X_5}{X_{11}}\right)}{\left(\frac{X_2}{X_{11}}\right)}\left(\frac{P}{P_0}\right) \quad (10)$$

H_2OConstantequilibrium 2:

$$2H_2O =\Leftrightarrow H_2+2OH \quad (11)$$

$$K_{H_2O,2}=\frac{\left(\frac{X_3}{X_{11}}\right)\left(\frac{X_8}{X_{11}}\right)}{\left(\frac{X_2}{X_{11}}\right)}\left(\frac{P}{P_0}\right) \quad (12)$$

H_2Constantequilibrium:

$$H_2 =\Leftrightarrow 2H \quad (13)$$

$$K_{H_2}=\frac{\left(\frac{X_{10}}{X_{11}}\right)^2}{\left(\frac{X_3}{X_{11}}\right)}\left(\frac{P}{P_0}\right) \quad (14)$$

O2 constant equilibrium:

$$O_2 =\Leftrightarrow 2O \quad (15)$$

$$K_{H_2}=\frac{\left(\frac{X_9}{X_{11}}\right)^2}{\left(\frac{X_5}{X_{11}}\right)}\left(\frac{P}{P_0}\right) \quad (16)$$

CO constant equilibrium:

$$K_{NO}=\frac{\left(\frac{X_6}{X_{11}}\right)^2}{\left(\frac{X_5}{X_{11}}\right)\left(\frac{X_7}{X_{11}}\right)}\left(\frac{P}{P_0}\right)^0 \quad (17)$$

With initial assumption for the product temperature the equilibrium constants has been calculated and by use of these constants the unknown coefficients can be found. The effect of thermodynamic parameter to the boiler efficiency and pollution can be considered with using of these coefficients. EEs software use to solve this unknown coefficient.

IV. RESULT AND DISCUATION

Under perfect or stoichiometric combustion, the correct amounts of fuel and oxygen are chemically combined so that both constituents are totally consumed, with no combustibles or uncombined oxygen remaining in the flue gases. When there is not sufficient air available to complete the combustion process, some of the fuel is left unburned, resulting in inefficiency and undesirable emissions, (i.e., such as carbon monoxide and 'smoke). 'If left unchecked, the buildup of combustibles can lead to a safety hazard and could cause an incident. In actual practice, some amount of excess air 'above and beyond stoichiometric requirements is needed for the complete combustion of the fuel.

The problem is most people do not know how much excess air is actually being used in their boilers 'Since excess air is one of the major factors affecting the stack loss (and therefore boiler efficiency), some information about its magnitude is needed if the stack loss is to be quantified. The reason that excess air is so important is because excess oxygen not consumed during combustion passes through the boiler, absorbs otherwise usable heat, and is carried away in the form of a stack loss. In practical terms, clean efficient combustion is a "balance" between operating as close to stoichiometric as the burner will permit, and providing sufficient excess air to ensure that combustibles are kept at minimum levels under all firing conditions. The theoretical air curves show that oxygen (O_2) or carbon dioxide (CO_2) can be used to determine the excess air.

It is important to note that the measurement of CO_2 alone does not define on which side of stoichiometric the burner is operating Indeed; the burner could be in the fuel rich mode without the operator's knowledge. This ambiguity does not exist in the O_2 - excess air relationship, and is one of the reasons why the measurement of O; is preferred. Fig. 2 shows the combustion products temperature with the amount of excess air. It is illustrate that with increase the execs air the combustion products temperature has decreased. Fig. 3 shows Boiler efficiency with excess air. It is shows Boiler efficiency decreased with increasing in excess air because of rising in boiler irreversibility. However excess air reduces boiler efficiency but needed to have better combustion process to reduce boiler pollution.

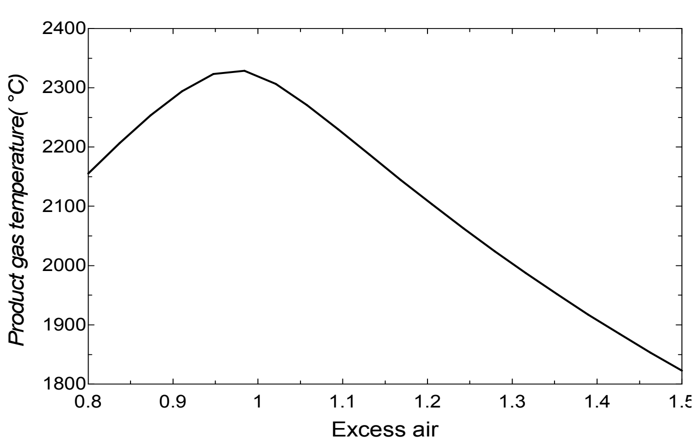

Fig. 2. Combustion gas product temperature vs excess air

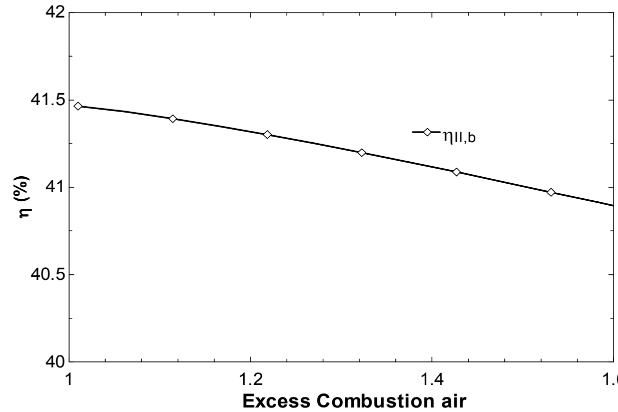

Fig. 3. Boiler efficiency vs excess air

Fig. 4 shows that there is an optimum excess air for reduction mole fraction of NO. Fig. 5 and Fig. 6 illustrate that increasing in excess air reduce the mole fraction of CO and CO2. There are two important factors to find optimum excess air to combustion process: Pollution of environment and boiler efficiency. However increasing in excess air reduces the pollution (NO, CO, CO2) but reduce the boiler efficiency. Finding the optimum excess air to have maximum boiler efficiency and minimum boiler pollution is so important.

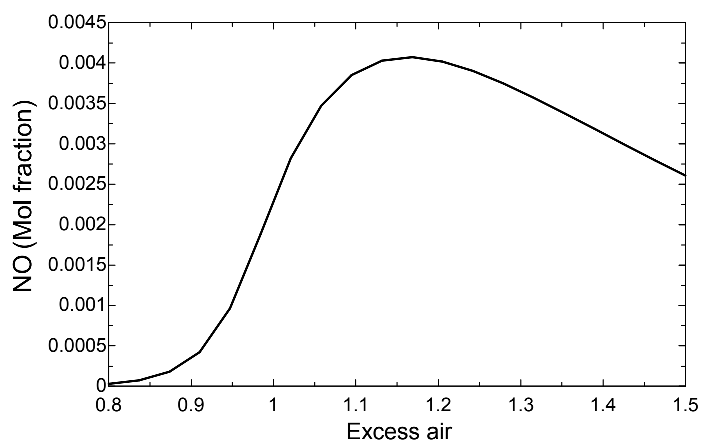

Fig. 4. Mole fraction of NO vs excess air

Fig. 5 shows the mole of fraction of CO2 with excess air. This figure shows that there is an optimum excess air for reduction mole fraction of CO_2. It is indicated from figure that with increasing in excess air the mole fraction of CO2 decreased.

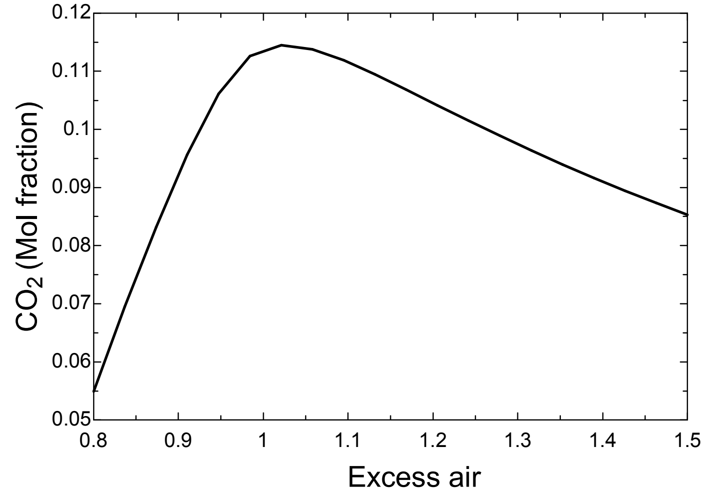

Fig. 5. Mole fraction of CO2 vs. excess air

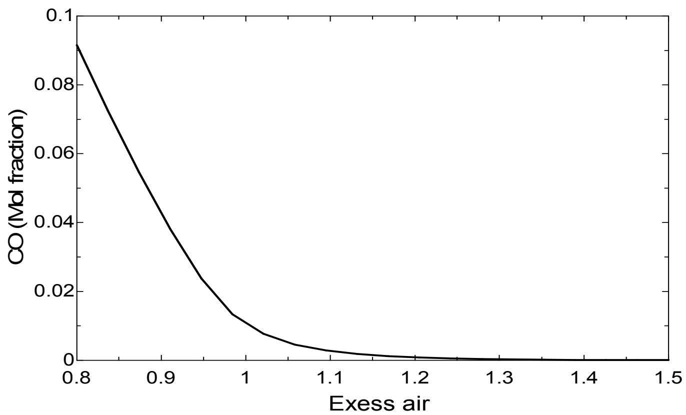

Fig. 6. Mole fraction of CO vs excess air

V. CONCLUSION

Efficiency increase and pollutant emission control are the most significant projects of the world. The present investigation of the changes in steam-generator irreversibility rate and plant efficiency, from decreasing the fraction of excess combustion leads to many useful findings. The results show that decreasing either the fraction of excess combustion air due to increase in boiler efficiency but increase in boiler pollution (NO, CO2 and CO). Calculations show that to have acceptable boiler efficiency with minor pollution in a gas fired boiler the access air must be a boat about 10 present.

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