*Research Article*

# A Study of Specific Energy Consumption in Reheating Furnace Using Regenerative Burners Combined with Recuperator

Kanit Manatura[1*] and Mingsak Tangtrakul[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand*
[2]*Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand*
[*]*Corresponding author. E-mail address: kanitman@hotmail.com, fengknm@ku.ac.th*

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**Abstract**

The steel industry is one of high energy consumption industries. In order to mill steel bar into steel rod, the steel bar is heated to 1,100 - 1,250 ˚C. The objective of this work is to investigate energy utilization in reheating furnace using regenerative burners combined with recuperator. The furnace capacity is 30 tonne per hour, pusher type and the natural gas is used as fuel. Billet sizes 120 x 120 x 4000 mm are used for reheating. Waste heat recovery in recuperator system can preheat combustion air to 300 ˚C due to material temperature limitations. In order that preheating combustion air temperature near furnace temperature so regenerative burner system provides for substituting that it can preheat combustion air up to 1000 ˚C. The results from measurements and energy balance analysis indicate that the regenerative burners combined with recuperator system consume energy approximately 43% less than the case study of conventional recuperative system

***Key Words***: Energy consumption; Reheating furnace; Regenerative burners; Recuperator; Energy balance

## Introduction

At the present time, the cost of fuel using as an energy source has constantly increased due to limiting of natural resource. Each of countries around the world has realized on its higher cost because it is one of the main capital costs of production, makes their products more expensive and consequently can not compete in market. One of the industries that use a lot of heat is the steel industry. The steel industry is mainly basic in development of destination industries in which are principal industry of each country, such as construction, automotive and electric appliance industries. The reheating furnace use fuel for heating billets or slabs for rolling process. In Thailand, have waste heat recovery in preheating combustion air by recuperator. The most of combustion air can be preheated the maximum temperature of 300 ˚C when the temperature efficiency only is 30%. The application of regenerative burner technology instead of conventional burner and recuperator are able to preheat combustion air nearly 1,000 ˚C and the temperature efficiency up to 90%. These can save energy of 10-20% (O'Connor et al., 2006) compare with conventional recuperator system in reheating process. Generally, the regenerative burner consists of regenerators such as alumina, ceramic ball or honeycomb as regenerative media. The principle of regenerative burner using the regenerator that recovers the heat from the flue gas and use it to increase the temperature of combustion air. Normally, regenerative burner is suitable for installation in furnace capacity 500 kW at least. The problems of low capacity furnace are area for installation and high cost in installation that affect to in late payback period. However, regenerative burners have been developing for applying in low capacity furnace that can save energy more than 35% (Wuenning, 2008).

## Methodology

### Reheating Furnace Description

A capacity of the reheating furnace is 30 tonne/hour, pusher type. It consists of 3 zones: preheating zone, heating zone and soaking zone. The heating zone equipped with 3 pairs of regenerative burner, capacity of each pair is 2326 kW, the switching time is 30 s. The soaking zone equipped with 4 ordinary burners, capacity of each burner is 872 kW. Size of Billet is 120mm x 120mm x 4000mm used for reheating, each piece weighs 444 kg. The diagram of the reheating furnace system is shown as Figure 1

### Compositions and properties of fuel

The natural gas is used as fuel in this research for combustion. Mixtures of natural gas varied with resource. In this research, Compositions are shown in volumetric percentage of natural gas from Ratchaburi gas station,Thailand (Table 1).

**Table 1** Natural gas components (PTT, 2002)

| COMPONENTS | PERCENT BY VOLUME |
|---|---|
| $CH_4$ | 72.6 |
| $C_2H_6$ | 3.5 |
| $C_3H_8$ | 1.1 |
| $C_4H_{10}$ | 0.4 |
| $C_5H_{12}$ | 0.2 |
| $C_6H_{14}$ | 0.1 |
| $CO_2$ | 6.1 |
| $N_2$ | 16 |

The higher heating value of the heat of combustion calculated by assuming that all of the water in products has condensed to liquid is always used in calculation. However, in practical events the flue gas temperature from combustion has valued in high level around 500-800 °C effect on water vapor in flue gas is still prior condition. Moreover, it does not have latent heat value from condition transferring. Therefore, the heating value have been used in calculation should be the lower heating value (Table 2).

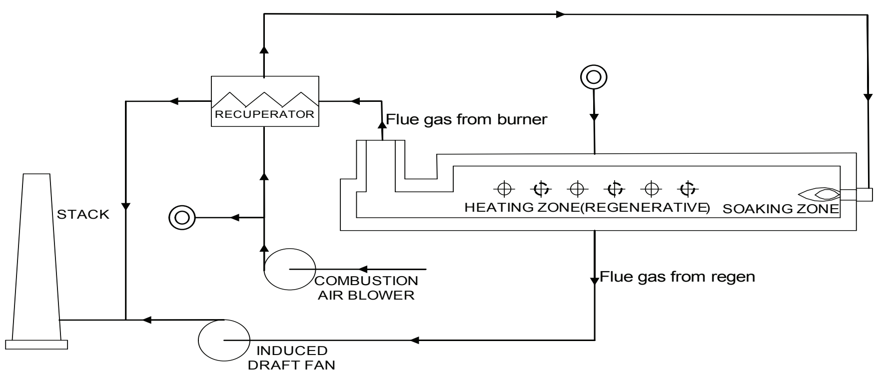


**Figure 1** Diagram of the reheating furnace

**Table 2** Properties of natural gas (PTT, 2002)

| PROPERTIES | VALUE | UNIT |
|---|---|---|
| Molecular weight | 20.7 | kg/kmol |
| Specific gravity | 0.7 | - |
| Higher heating value | 31.7 | $MJ/Nm^3$ |
| Lower heating value | 26.4 | $MJ/Nm^3$ |

**Analysis of air-fuel ratio in combustion**

The hydrocarbon such as the natural gas, the stoichiometric combustion equation can be expressed as (Turns, 2006)

$$(0.726CH_4 + 0.035C_2H_6 + 0.011C_3H_8 + 0.005C_4H_{10} + 0.001C_5H_{12} + 0.001C_6H_{14} + 0.061CO_2 + 0.16N_2) + a_{th}(O_2+3.76N_2) \rightarrow 0.858CO_2 + 0.061CO_2 + 1.64H_2O + a_{th}(3.76N_2) + 0.16N_2 \quad (1)$$

where $a_{th}$ is the stoichiometry ratio of oxygen mole per natural gas mole, the number atoms on the L.H.S of the equation must exactly balance the number on the R.H.S because the combustion process does not create or destroy atoms. Solving equations for oxygen mole getting, $a_{th} = 1.68\ kmol_{O_2}/kmol_{fuel}$

Stoichiometric Air-Fuel ratio ($AF_{stoic}$) is necessary to achieve complete combustion of the fuel and no more. It can be written as

$$AF_{stoic} = \dot{m}_{air}/\dot{m}_{fuel} = 16.96\ kg_{air}/kg_{fuel} \quad (2)$$

In practical situations, more than the stoichiometric quantity the excess of oxidizer required for completely in combustion so Eq. (1) can be rewritten as

$$(0.726CH_4 + 0.035C_2H_6 + 0.011C_3H_8 + 0.004C_4H_{10} + 0.002C_5H_{12} + 0.001C_6H_{14} + 0.061CO_2 + 0.16N_2) + ma_{th}(O_2+3.76N_2) \rightarrow 0.858CO_2 + 0.061CO_2 + 1.64 H_2O + (m-1)\,a_{th}O_2 + ma_{th}(3.76N_2) + 0.16N_2 \quad (3)$$

Where m is the correction factor of excess air

From above equations, found by oxygen mole in excess air in products (flue gas) are equal to $(m-1)a_{th}O_2$. In practice, the flue gas analyzer is used to measure it. The results from the measure are showed in percentage of dry-basis, water vapor and humidity in flue gas is blown off before the apparatus analysis. The remaining gases are then expressed as a percentage (by volume) of the total dry gas constituents - in this case $CO_2$, $O_2$, $N_2$. Therefore, percentage of oxygen from measurement can be adapted to correction factor of excess air as

$$\frac{\%O_2}{100} = \frac{(m-1)a_{th}}{0.858 + 0.061 + (m-1)a_{th} + 3.76ma_{th} + 0.16} \quad (4)$$

Eq. (4) is arranged in the form of m as

$$m = \frac{1.68 - 0.6\left(\frac{\%O_2}{100}\right)}{1.68 - 8\left(\frac{\%O_2}{100}\right)} \quad (5)$$

When knows value of m from Eq. (5) so the Actual Air-Fuel ratio, $AF_{actual}$ is

$$AF_{actual} = m.AF_{stoic} \quad (6)$$

**The methodology and analysis of energy balance in reheating furnace**

Analysis of energy balance is divided to mass and energy (heat) balance. The conservation of mass and energy are applied in this research; if there is no mass/heat accumulation what goes into process (reheating) must come out in continuous operation by giving the reheating furnace is control volume. A steady state, thermal equilibrium is considered in type of continuous steel reheating furnace. Energy balance analysis point out in energy consumption, furnace efficiency, SEC (specific energy consumption) and other performance parameters.

**Mass balance of the reheating furnace**

Given the reheating furnace is valuable in negative pressure during operation. The mass flow rate into and out from reheating furnace can be expressed as Eq. (7) and the details of mass balance (Cengel and Boles, 2007) are shown as Table 3 and Table 4, respectively.

**Table 3** Mass flow rate into the reheating furnace

| INPUT | Formula | kg/s | % |
|---|---|---|---|
| 1) Fuel flow rate into regenerative burner | $\dot{m}_{fuel,regen} = \rho_{fuel}\dot{\forall}_{fuel,regen}$ | 0.2 | 2.3 |
| 2) Combustion air flow rate into regenerative burner | $\dot{m}_{air,regen} = AF_{actual} \times \dot{m}_{fuel,regen}$ | 3.8 | 53.4 |
| 3) Fuel flow rate into ordinary burner | $\dot{m}_{fuel,burner} = \rho_{fuel}\dot{\forall}_{fuel,burner}$ | 0.1 | 1.8 |
| 4) Preheated air flow rate into ordinary burner | $\dot{m}_{preheatair,burner} = AF_{actual} \times \dot{m}_{fuel,burner}$ | 3.1 | 42.5 |
| Total mass input | | 7.2 | 100 |

**Table 4** Mass flow rate out from the reheating furnace

| OUTPUT | Formula | kg/s | % |
|---|---|---|---|
| 1) Flue gas flow rate from regenerative burner to stack | $\dot{m}_{flue,stack} = \dot{m}_{fuel,regen} + \dot{m}_{air,regen}$ | 4.0 | 55.7 |
| 2) Flue gas flow rate from the reheating furnace to recuperator | $\dot{m}_{flue,recup} = \dot{m}_{fuel,burner} + \dot{m}_{preheatair,burner}$ | 3.2 | 44.3 |
| Total mass output | | 7.2 | 100 |

From above tables, it is clear for applying diagram of mass balance of a reheating furnace as Figure 2

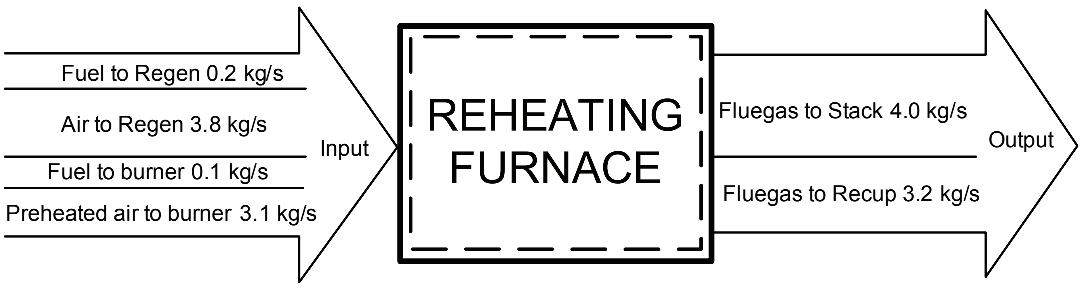


**Figure 2** Mass balance diagram for reheating furnace

Figure 2 shows mass balance diagram leads to know about that the mass flow rate of fuel flow rate in regenerative burner system which is twice to burner system according to the law of conservation of mass.

**Energy balance of the reheating furnace**

The energy balance (Cengel and Boles, 2007) are consist of heat input and heat output of the case study shown in Table 5

**Table 5** Energy balance of reheating furnace

| Heat input | Heat output |
|---|---|
| 1) Combustion from fuel at regenerative burners<br>2) Combustion from fuel at ordinary burner<br>3) Preheated air by recuperator<br>4) Sensible heat of air inlet<br>5) Sensible heat of scale formation | 1) Sensible heat into billet<br>2) Sensible heat of flue gas from regenerative burners<br>3) Sensible heat of flue gas of ordinary burner<br>4) Heat loss in wall<br>5) Heat loss from opening<br>6) Sensible heat into scale<br>7) Other loss |

Assigned to temperature ($T_0$) and pressure ($P_0$) are 25 ˚C and 1 atm, respectively as references in calculation.

**Furnace efficiency**

The efficiency of the reheating furnace is the ratio of the sensible heat of billet ($\dot{Q}_{billet}$) to the heat of combustion in regenerative burner combined with recuperator ($\dot{Q}_{comb}$) is defined as

$$\eta_{furnace} = \frac{\dot{Q}_{billet}}{\dot{Q}_{comb}} \times 100\% \qquad (7)$$

**The Specific Energy Consumption (SEC)**

The Specific Energy Consumption (SEC) is defined as total of energy consumption to total of quantity material processed. In this case study, the reheating furnace using regenerative burner combined with recuperator is control volume studied. The unit of SEC is MJ/ton in this case study.

$$SEC = \frac{\text{Quantity of Energy Consumption}}{\text{Quantity of material processed}} \times 100\% \qquad (8)$$

From calculation the SEC of this case study is 1042 MJ/ton or equal to 26.2 litre/ton of fuel oil, 28 $Nm^3$/ton of natural gas.

**Results and Discussion**

**Data measurement**

Measurement results of the reheating furnace are tabulated in Table 6 below.

**Table 6** Measurement results of the reheating furnace

| Measured parameter | Unit | Values (After) | Values (Before) |
|---|---|---|---|
| Average fuel consumption at regenerative burners | $m^3/s$ | 0.192 | - |
| Average % oxygen in flue gas of regenerative burners | % | 5.93 | - |
| Preheat air temperature from regenerator | ˚C | 931.77 | - |
| Flue gases temperature into regenerator | ˚C | 1003.7 | - |
| Flue gases temperature from regenerator to stack | ˚C | 145.79 | - |
| Average fuel consumption at ordinary burner | $m^3/s$ | 0.15 | 0.0002 |
| Average % oxygen in flue gas of ordinary burner | % | 6.2 | 15 |
| Preheat air temperature by recuperator into reheating furnace | ˚C | 262.57 | 68.05 |
| Flue gas temperature into recuperator | ˚C | 625.63 | 716.4 |
| Quantity of produced billet | kg/s | 8.64 | 5.65 |
| Billet temperature inlet to reheating furnace | ˚C | 39.08 | 34.12 |
| Billet temperature outlet from reheating furnace | ˚C | 1035.38 | 928.2 |
| Average furnace wall temperature | ˚C | 105.1 | 300.1 |
| Temperature in reheating furnace | ˚C | 1085.23 | 716.4 |

The Sankey Diagram of energy balance in case study is presented in Figure 3.

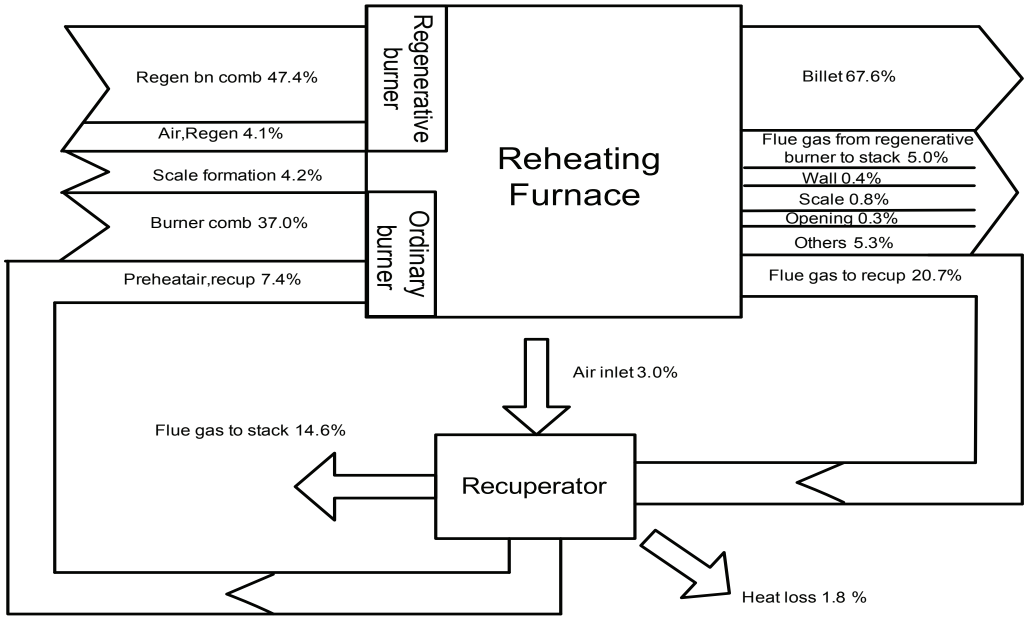


**Figure 3** Sankey Diagram of the reheating furnace

From Sankey diagram in Figure 3, shown by the total heat input into the case study are consist of sensible heat from combustion of regenerative burners by 5055 kW (47.4%), sensible heat from combustion of ordinary burner by 3948.7 kW (37.0%), sensible heat from preheated air at recuperator by 784.9 kW (7.4%), sensible heat of fresh air into regenerative burner by 439 kW (4.1%), sensible heat from scale formation by 445.9 kW (4.2%).

Moreover, the total heat output are composed of sensible heat into billet, sensible heat of flue gas from regenerative burners, sensible heat of flue gas from the reheating furnace to recuperator, heat loss in wall, heat loss from opening, heat loss into scale and other loss by 7213.3 kW (67.6%), 528.8 kW (5.0%), 2210.7 kW (20.7%), 42.8 kW (0.4%), 28.5 kW (0.3%), 83.2 kW (0.8%) and 566.3 kW (5.3%), respectively.

**Conclusion**

In energy balance analysis, the Specific Energy Consumption (SEC) of the reheating furnace using regenerative burners combined with recuperator (furnace capacity = 30 tonne/hr) is 1042 MJ/ton. Moreover, the furnace efficiency of this case study is 80.1% when compare with the reheating furnace using only recuperator (former furnace capacity = 15 tonne/hr). The case study designates in sensible heat of flue gas from regenerative burner which goes down by 25% or 1/4 of sensible heat of flue gas from the reheating furnace to recuperator. The energy saving found by 43.3% of this case study, comparing to the reheating furnace using only recuperator and shows significantly of efficiency in regenerative burner performance.

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