International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:7, No:10, 2013

Investigation of Regenerative and Recuperative Burners for Different Sizes of Reheating Furnaces

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***Abstract*—**This research aims to analyze the regenerative burner and the recuperative burner for the different reheating furnaces in the steel industry. The warm air temperatures of the burners are determined to suit with the sizes of the reheating furnaces by considering the air temperature, the fuel cost and the investment cost. The calculations of the payback period and the net present value are studied to compare the burners for the different reheating furnaces. The energy balance is utilized to calculate and compare the energy used in the different sizes of reheating furnaces for each burner. It is found that the warm air temperature is different if the sizes of reheating furnaces are varied. Based on the considerations of the net present value and the payback period, the regenerative burner is suitable for all plants at the same life of the burner. Finally, the sensitivity analysis of all factors has been discussed in this research.

***Keywords*—**Energy Balance, Recuperative Burner, Regenerative Burner, Reheating Furnace.

I. Introduction

At the present time, the fuel cost has increased highly which affected the production cost of the steel. The average energy costs of steel industry are about 15% – 30% of the production costs. It is necessary to find the alternatives to help the steel industry in order to save the energy and use it more efficient. The energy saving can increase the potential of the international competition. The fuel is used in the reheating furnace to heat the billet or the slab in the rolling process. In Thailand, the waste heat is recovered to preheat the combustion air by using the recuperator, the air preheater, the waste heat boiler, the economizer, and the high efficiency burner. The steel industry is currently used the recuperator, which can preheat the temperature of the combustion air up to 300°C and the efficiency of it is about 30%.

The high efficiency burner is the new approach to save the energy used in the reheating furnaces, which have the exhaust gas at high temperature during the burning process of steel. The high efficiency burner is proposed instead of the recuperator and the conventional burner. It can preheat the temperature of the combustion air about 900°C to 1,000°C and the efficiency of it can increase up to 90% with the energy saving of 10% to 20% [1]. The high efficiency burner can classify into 2 types; which are the regenerative burner and the recuperative burner.

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II. Regenerative and Recuperative Burners

The regenerative burners are designed to recover the heat to the inlet air by transferring the heat from the exhaust gas to the inlet air that will be used in the combustion. The regenerative burner has two burners and composes with the regenerator and the reserving valve that used the alumina balls to collect the heat. While the first regenerative burner is firing, the other is exhausting the furnace gases. The exhaust gas is passed through the regenerative burner body and transferred the heat to the alumina balls. Hence, the heat from exhaust gas will be transferred to the inlet air. The reserving valve will set the direction of the air flow that enters into the burner head, which makes the inlet air temperature similar to the operating temperature. According to the above mention, the regenerative burner can save the fuel and make the combustion high efficiency.

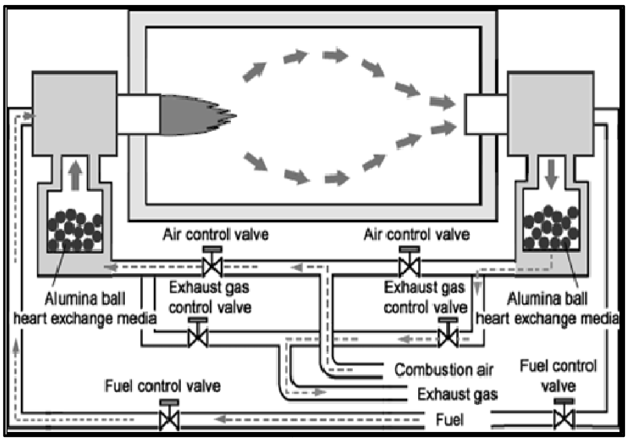

Fig. 1 Principle of regenerative burner system [2]

The structure of the recuperative burner is the same as the radiation heat exchanger tube which heats the inlet air up to the higher temperature about 750°C by recovering the heat from the exhaust gas to the inlet air. Hence, the exchanged heat in the burner can improve the combustion efficiency and save the fuel cost approximately 25% to 30% [3].

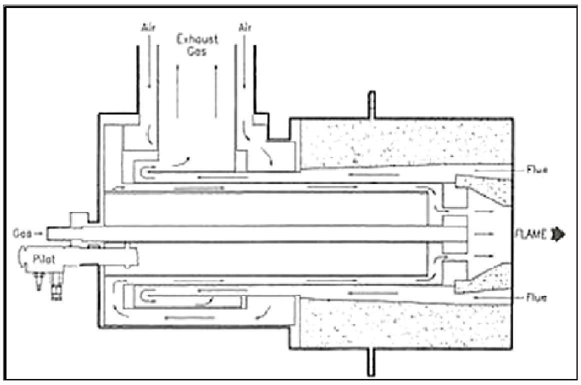

Fig. 2 Principle of recuperative burner system [4]

Fig. 1 shows the regenerative burner principle. The first burner is in the firing mode while the second burner is in the exhausting mode. The first burner is firing with the warm combustion air blowing across its burner as shown in Fig. 1. Meanwhile, the second burner is receiving the hot exhaust gas out from the furnace to its alumina balls in order to keep the heat in the burner as shown in Fig. 1, and hence that exhaust gas will be released. After a period of 30 to 60 seconds, the second burners will be switched to fire while the first burner becomes to receive the hot exhaust gas instead. The firing and receiving mode of burner will run recursively until the reheating furnace is stopped. The highly preheated air temperature makes the combustion process very efficient because the combustion air is not necessary to be heated to the furnace operating temperature [5].

Fig. 2 shows the recuperative burner principle. The temperature of the inlet air is preheated before the combustion in the furnace by the heat exchanging technique. The exhaust gas flows through the burner equipped with a heat exchanger installed inside the burner. The heat from the exhaust gas is exchanged to the inlet air before it flows out from the burn which runs through the area around the outside of the burner and the heat is exchanged inside the burner.

III. Investment Analysis

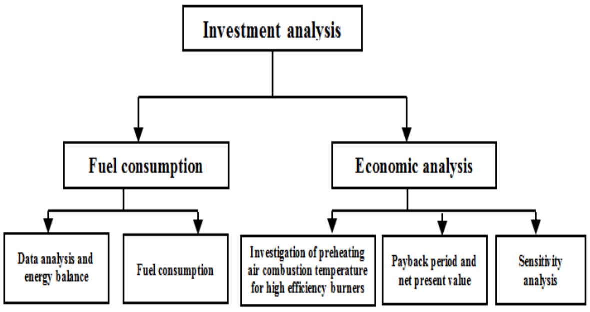

Fig. 3 The investment analysis of regenerative burner and recuperative burner

The investment analysis of the regenerative burner and the recuperative burner is divided in two main parts, which is the calculation of the fuel consumption and the economic analysis as shown in Fig. 3.

The calculations of the fuel consumption have 3 steps. At first, the data is collected and obtained from the different 3 plants in Thailand. Secondly, the energy balance of that data is calculated, and hence the fuel consumption is analyzed finally. For the economic analysis, the net present value (NPV) and the payback period (PB) are utilized to calculate for those plants.

IV. Data Analysis and Energy Balance

The steel industries in Thailand, which used the natural gas in the production, mostly have a capacity of 40 tons/hour to 150 tons/hour. The energy consumption data used in this research is obtained from the 3 plants of the steel industries, which are 40 tons/hour, 70 tons/hour, and 150 tons/hour, respectively. The energy balance theory is utilized to analyze the energy consumption data for those plants.

The energy balance shows the relation between the supplied heat for the thermal equipment (heat input) and the consumed heat (heat output). According to the calculation of the energy balance, the input heat is equal to the output heat for all plants [6] as shown in Table I.

TABLE I
Calculation of Energy Balance

Reheating furnace capacity (ton/hr)	ENERGY BALANCE								
	INPUT (MJ/hr)		OUTPUT (MJ/hr)						Furnace efficiency (%)
	Fuel	Preheat air	Useful Heat Load	Off gas loss	Opening loss	Surface loss	Water cooling loss	Other loss	
40	66,412	8,762	33,228	29,244	239	6,068	1,747	4,648	44.20
70	85,273	15,193	47,405	37,672	252	8,200	3,678	3,259	47.19
150	154,394	36,123	82,840	78,274	3,390	10,758	13,825	1,430	43.48

V. Fuel Consumption of Regenerative and Recuperative Burners

From the energy balance analysis, the rate of fuel consumption is calculated and determined when the regenerative burner and the recuperative burner are run. The data from Table I is utilized to calculate the temperature for each reheating furnace.

The calculation of the heat energy is used for fuel combustion as expressed by;

$$Q_{in} = Q_{out} \tag{1}$$

$$Q_{in} = m_{fuel} LHV \tag{2}$$

when m_{fuel} is the fuel consumption that the preheating air is not used, and *LHV* is the Low Heating Value.

The calculation of the rate of fuel consumption is utilized for the regenerative burner as illustrated by;

$$Q_{in} = Q_{comb,regen} + Q_{air,regen} \quad (3)$$

$$Q_{in} = m_{fuel,regen}LHV + m_{air}\rho_{air}C_{p,a}(T_{air,regen} - T_{sur}) \quad (4)$$

$$m_{fuel,regen} = \frac{Q_{in} - m_{air}\rho_{air}C_{p,a}(T_{air,regen} - T_{sur})}{LHV} \quad (5)$$

when Q_{in} is the heat retained by the fuel from (2), m_{air} is the air flow,ρ_{air} is the air density, $C_{p,a}$ is the specific heat of air, $T_{air,regen}$ is preheating air while using the regenerative burner referring to the burner dealers, and T_{sur} is the ambient temperature.

The calculation of the rate of fuel consumption is used for the recuperative burners as shown below;

$$Q_{in} = Q_{comb,recup} + Q_{air,recup} \quad (6)$$

$$Q_{in} = m_{fuel,recup}LHV + m_{air}\rho_{air}C_{p,a}(T_{air,recup} - T_{sur}) \quad (7)$$

$$m_{fuel,recup} = \frac{Q_{in} - m_{air}\rho_{air}C_{p,a}(T_{air,recup} - T_{sur})}{LHV} \quad (8)$$

when $T_{air,recup}$ is the air preheating when using the recuperative burner referring to the burner dealers. The calculations of fuel consumption of the high-performance burners for 3 plants are shown in Tables II and III. The specifications to preheat the air temperature of the recuperative burner is set in the range from 400°C to 700°C, and the regenerative burners is in the range from 400°C to 1,000°C referring to the burner dealers.

TABLE II
FUEL CONSUMPTION OF RECUPERATIVE BURNERFOR3 PLANTS

Reheating furnace capacity (tons/hr)	Fuel consumption (MMBTU/hr)							
	Existing burner (before)	Preheated air temperature Regenerative burner (°C)						
		400	500	600	700	800	900	1000
40	63.61	60.45	57.28	54.11	50.95	47.78	44.61	41.44
70	81.68	76.19	70.70	65.20	59.71	54.22	48.73	43.24
150	147.89	134.83	121.77	108.72	95.66	82.60	69.55	56.49

TABLE III
FUEL CONSUMPTION OF REGENERATIVEBURNERFOR3 PLANTS

Reheating furnace capacity (tons/hr)	Fuel consumption (MMBTU/hr)				
	Existing burner (before)	Preheated air temperature Recuperative burner (°C)			
		400	500	600	700
40	63.61	60.45	57.28	54.11	50.95
70	81.68	76.19	70.70	65.20	59.71
150	147.89	134.83	121.77	108.72	95.66

VI. INVESTIGATION OF PREHEATING AIR COMBUSTION TEMPERATURE FOR HIGH EFFICIENCY BURNERS

The fuel consumption analysis can be used to explain the relations between the preheating air temperature with the operation cost and the investment costs for the recuperative burner and the regenerative burner. The preheating air temperatures are determined for each burner based on the consideration of minimum total cost of steel per ton. Although the burners are able to reduce the energy cost but they are expensive. The fuel cost can be reduced by increasing the air temperature. The investment cost mainly composes of the maintenance cost. Hence, the investment cost will be increased when the preheating air temperature is high. The decided temperatures of the high efficiency burners are assigned by the lives of the recuperative burners [7] and the regenerative burners [8], which are 10 years and 12 years, respectively. The fuel price is set at 292.10 baths/MMBTU [9].

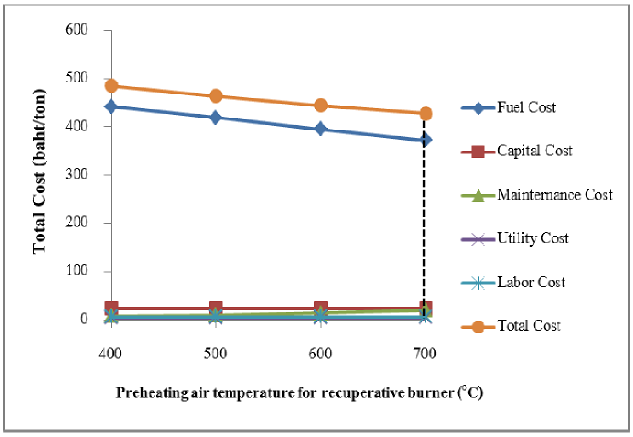

Fig. 4 Relation between the preheating air temperature with the operation cost and the investment cost for the recuperative burner

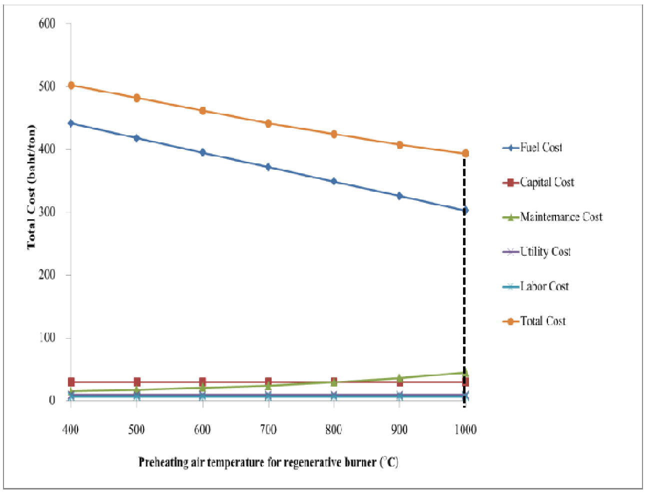

Fig. 5 Relation between the preheating air temperature with the operation and the investment cost for the regenerative burner

Figs. 4 and 5 show the results of the relations between the preheating air temperature with the operation cost and the investment costs of the recuperative and regenerative burners for the steel production at 40 tons/hr. Fig. 4shows the preheating temperature at 700°Cfor the recuperative burner, which gives the minimum total cost of 427.58baht/ton and the reduction of the fuel cost about 19.90%, which cost is 3,697.99baht/ton. For the regenerative burner, the preheating air temperature at 1000°C which can reduce the fuel cost about34.85% at the minimum total cost of 393.29 baht/ton, which cost is 6,475.88baht/ton approximately as shown in Fig. 5.

The maintenance cost is increased when the preheating air temperature increases, especially for the regenerative burner. Since the regenerative burner must be cleaned and the alumina balls must be replaced because of the contaminants from the exhaust gas. The preheating air temperature of the recuperative burner is lower than the one from the regenerative burner. Hence, the recuperative burner has the minimum maintenance cost as compared to the regenerative burner.

TABLE IV
ENERGY SAVING COST AND TOTAL COST OF PROPER PREHEATING AIR TEMPERATURE IN DIFFERENT REHEATING FURNACES

Burner Type	Reheating furnace capacity (tons/hr)	Proper preheating air temperature (°C)	saving energy (%)	saving energy cost (baht/ton)	Total cost (baht/tons)
Recuperative	40	700	19.90	3,697.99	427.58
	70	700	26.90	6,417.44	308.41
	150	700	35.32	15,256.38	314.91
Regenerative	40	1000	34.85	6,475.88	393.29
	70	1000	47.06	11,280.90	261.93
	150	1000	61.80	26,697.94	236.39

The proper preheating air temperatures with the operation cost and the investment cost for the different reheating furnaces are shown in Table IV. For the recuperative burner and the regenerative burner, the proper preheating air temperature, are obtained at 700°C and 1000°C for all reheating furnace, which are the highest temperature. It is concluded that the maintenance cost does not affect the operation cost much. Hence, the suitable the proper preheating air temperatures will be determined based on the most energy saving in each burner.

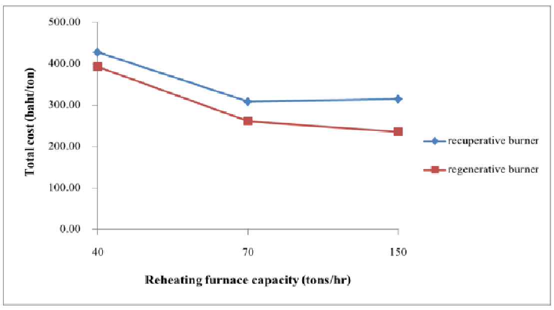

Fig. 6 Illustration of minimum total cost for all reheating furnace capacities

Fig. 6shows the minimum total cost for all reheating furnace capacities. The regenerative burner of the reheating furnace at 150 tons/hr gives the minimum total cost of 236.39baht/ton, which can save the fuel cost about 61.80%as compared to the others at the same preheating air temperature of 1000°C. Since the percentage of the saving energy in the largest reheating furnace can be obtained more than that of the small ones. It is understood that the total cost will be reduced while using the larger reheating furnace.

The life cycles of the regenerative burner and the recuperative burner are not the same. Hence, the suitably high efficiency burner for each plant will be determined based on the criteria of the payback period and the net present value referring to Table V.

VII. PAYBACK PERIOD AND NET PRESENT VALUE

The investment cost consists of the burner cost, the installing cost, and the equipment cost, however the operation cost includes the maintenance cost, the utility cost and the labor cost. The payback period and the net present value (NPV) are calculated by using the data in Table V.

TABLE V
COST INDIFFERENT REHEATING FURNACES

Burner Type	Reheating furnace capacity (tons/hr)	Investment cost (Million baht)	O&M (baht/year)	Net saving cost (baht/year)	Discount rate (%)	Life time
Recup[a]	40	52,800,000	6,791,077	20,099,989.45	8	10
	70	66,900,000	7,458,256	34,853,271.83		
	150	118,900,000	13,462,868	82,867,421.73		
Regen[b]	40	78,000,000	13,195,689	35,174,981.54	8	12
	70	100,000,000	15,544,098	60,993,225.70		
	150	178,500,000	28,460,347	145,017,988.02		

[a]Recup; Recuperative burner, [b]Regen; Regenerative burner

The payback period [10] is used to determine the investment of the high efficiency burners that can be calculated as shown below;

$$\text{Payback Period (year)} = \frac{\text{Investment costs}}{\text{Net saving cost per year}} \quad (9)$$

The net present value is calculated and obtained from the difference between the net value of the energy saving cost, which is received in each year, and the net value of the investment cost that is paid out at the same discount rate though out the project time as shown in (10) [11]:

$$NPV = \sum_{t=1}^{n} \frac{ES_t}{(1+i)^t} - I_o \quad (10)$$

When n is the project time, ES_t is the saving cost energy per year, I_0 is the investment cost, t is the time of cashflow, and i is the discount rate.

It cannot be concluded that the net present value of the regenerative burner is better because the lives of the burners are different 2 years. Hence, they must be compared with equal lives in order to analyze the net present value, which results in 60 years for their lives. A method of comparing projects of unequal lives assumes that each project can be repeated as many times as necessary to reach a common life span; the NPV over this life span are hence compared, and the project with the higher common life NPV is chosen [11].The calculations of the payback period and the net present value are shown in Table VI.

TABLE VI
CALCULATIONS OF PAYBACK PERIOD AND NET PRESENT VALUE

Burner Type	Reheating furnace capacity(tons/hr)	Payback period(yr)	Net present value (baht)
Recuperative	40	2.63	151,380,482.28
	70	1.92	307,968,202.36
	150	1.43	806,305,314.89
Regenerative	40	2.22	307,245,055.16
	70	1.64	590,655,143.34
	150	1.23	1,501,670,888.39

Table VI shows the payback periods and the net present values of 3 plants. It is found that the regenerative burner can save the energy more than the recuperative burner at the preheating air temperature at 1000°C, which is suitable for all reheating furnace capacities based on the consideration of the net present value for the project time of 60 years.

VIII. SENSITIVITY ANALYSIS

The sensitivity analysis is conducted to determine the critical variables on the net present values of the regenerative burner and the recuperative burner for the different reheating furnaces. The factors considered for the sensitivity analysis are the fuel cost (NG), the burner life, the investment cost, the energy saving, and the discount rate.

The fuel cost depends on the price of the natural gas. The variation of it will be affected the net present values. However, it is not useful to consider the sensitivity analysis of the fuel cost because its price has low chance to decrease referring to the prices of it in the past.

For the same reason to the life of the burner, if the burner life decreases, the NPV is not worth as well.

The energy saving will be determined for the preheating air temperature. If it is increased, the NPV will be worth. In fact, it cannot be changed due to the technical constraints of the preheating air temperatures, which are set as the upper bound at 700°C for the recuperative burner, and 1,000°C for the regenerative burner. Hence, it is not necessary to consider the sensitivity of the energy saving.

Generally, the investment cost affects the net present values. However, the energy saving cost is higher than the investment cost in this research. Hence, it is not required to analyze the sensitivity of the investment cost here.

According to the discount rate, it has been changed slightly as shown in the past, which will not affect the net present value. Hence, it is not useful to analyze the sensitivity of the discount rate also.

IX. CONCLUSION

The suitable preheating air temperatures of two burners for 3 plants are investigated for the reheating furnaces in Thailand. It is found that the regenerative burner can save the energy more than the recuperative burner at the preheating air temperature at 1000°C, which is suitable for all reheating furnace capacities based on the considerations of the net present value for the project time of 60 years and the shorter payback periods.

The sensitivity analysis is also discussed for all factors which are not affected the NPV of the project. It is understood that the investment of the high efficiency burner is required to save the energy used in the reheating furnace. Hence, it is an alternative way to install the regenerative burner in the reheating furnace for the steel industry to save the energy cost.

ACKNOWLEDGMENT

This work was supported by Energy Policy and Planning Office, Ministry of Energy, Thailand from June 2011 to May 2012.

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