Energy Efficiency Manual for Thailand's Iron & Steel Industries

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Table of Contents

1 GENERAL 3

1.1 OUTLINE AND PURPOSE OF ENERGY EFFICIENCY MANUAL 3
1.2 MODEL STEEL PLANT TO ESTIMATE ENERGY SAVINGS POTENTIAL 4

2 ENERGY SAVING TECHNOLOGIES FOR EAF (ELECTRIC ARC FURNACE) 6

2.1 TECHNOLOGIES FOR OPERATIONAL IMPROVEMENT & SMALL INVESTMENT 6
2.1.1 Good slag foaming with coherent burner 6
2.1.2 Effective use of combustibles in scrap 7
2.1.3 Correlation of record and results of operating pattern 8
2.2 TECHNOLOGIES FOR LARGE SCALE INVESTMENT 10
2.2.1 High temperature continuous scrap preheating EAF 10
2.2.2 Regenerative burner or oxygen burner for ladle heater 10
2.2.3 Scrap pretreatment to reduce charging frequency 11

3 ENERGY SAVING TECHNOLOGIES FOR RHF (REHEATING FURNACE FOR ROLLING) 13

3.1 TECHNOLOGIES FOR OPERATION IMPROVEMENT AND SMALL INVESTMENT 13
3.1.1 Sufficient combustion air temperature 13
3.1.2 Proper air ratio & furnace pressure control 14
3.1.3 Oxygen enrichment for combustion air 15
3.2 TECHNOLOGIES FOR LARGE SCALE INVESTMENT 17
3.2.1 Direct rolling and hot charge 17
3.2.2 Fiber block for insulation 18
3.2.3 Low NOx regenerative burner 18
3.2.4 Air conditioning by absorption type refrigerating 20

4 THERMAL BALANCE MEASUREMENT AND ANALYSIS 21

4.1 EAF THERMAL BALANCE 21
4.2 RHF THERMAL BALANCE 24

1 General

1.1 Outline and purpose of Energy Efficiency Manual

This document explains energy efficient technologies applicable to EAF-based steel plants in Thailand. Most of the technologies in this document are common in ASEAN steel mills. Furthermore, these technologies garnered interest among Thai experts when they were discussed with Japanese experts during the field surveys at Thai steel mills in 2017. This manual also discusses important points related to implementing such technologies. For economic benefits, investment cost, and more detailed and general information, please refer to the Technologies Customized List for AEAN (TCL) made by Japan Iron and Steel Federation (JISF) in 2016.[1]

This manual on energy saving technologies focuses on EAF (Electric Arc Furnace) and RHF (Reheating Furnace for Rolling), as EAFs usually consume around 50% and RHFs consume around 25% of total energy consumption in steel mill. These two facilities have much room for energy efficiency improvement and deserve further study. Technologies included in this manual are categorized as below:

1) Technologies for operational improvement & small investment for EAF
2) Technologies for large scale investment for EAF
3) Technologies for operational improvement & small investment for RHF
4) Technologies for large scale investment for RHF

Table 1 shows a comparison of items in above TCL and the Action Plan of Thailand 2014-2019 made by the Iron and steel Institute of Thailand (ISIT). The 19 technologies highlighted in yellow in the TCL also appear in the Action Plan. But 10 technologies in the Action Plan are not covered in TCL.

[1] The TCL is available for download at http://www.jisf.or.jp/en/activity/climate/Technologies/index.html

Table 1: Energy saving technologies in TCL and ISIT Action Plan

Field	No.	ID	Technology in TCL (by JISF)	No.	Technology introduced in Action Plan of Thailand (2014-2019)
EAF	1	A-1	High temperature continuous scrap preheating EAF	7	Continuous Scrap Feeding
	2	A-2	Medium temperature batch scrap preheating EAF	2	Scrap Preheating
	3	A-3	High efficiency oxy-fuel burner/lancing for EAF (most important)	22	Oxy-Fuel Burner
	4	A-4	Eccentric bottom tapping (EBT) on existing furnace		
	5	A-5	Ultra high-power transformer for EAF		
	6	A-6	Optimizing slag foaming in EAF	6	Slag Foaming
	7	A-7	Optimized power control for EAF (important)	5	Neural Network
	8	A-8	Operation support system with EAF meltdown judgment		
	9	A-9	Low NOx regenerative burner system for ladle preheating	1	Efficient Ladle Preheater
	10	A-10	Oxygen burner system for ladle preheating		
	11	A-11	Waste heat recovery from EAF	29	Waste Heat Recovery
	12	A-12	Energy saving for dedusting system in EAF meltshop		
	13	A-13	Bottom stirring/stirring gas injection		
	14	A-14	Induction Type Tundish Heater [for molten steel]		
	15	A-15	Scrap pretreatment with scrap shear	4	Scrap Management
	16	A-16	Arc furnace with shell rotation drive		
		***	Delaying power-on after 1st scrap charge		
		***	Addition of aluminum dross		
		***	[To be considered in questionnaire for EAF]	8	Ladle – EAF Synchronization
		***	["Efficient Tundish Preheater" is introduced in SOACT]	1	Efficient Tundish Preheater
RHF	25	D-1	Process control for reheating furnace	20	Process Control
				12	Combustion Setting
				15	Air Compressor for Atomize air
	26	D-2	Low NOx Regenerative burner total system for reheating furnace	23	Regenerative Burner
	27	D-3	High temperature recuperator for reheating furnace	10	High Efficiency recuperator
	28	D-4	Fiber block for insulation of reheating furnace	14	Insulation of Furnace
	29	D-5	Air conditioning by absorption type refrigerating by using reheating furnace exhaust gas	29	Waste Heat Recovery
	30	D-6	Induction type billet heater for direct rolling	9	Direct Rolling and Hot Charge
		***		11	Advance Descaling Nozzle
		***		13	Emulsion Fuel
		***	["Oxygen enriched combustion system" is introduced in NEDO Hand book]	16	Oxygen Enrichment
		***		17	Biomass Thermal gasification
		***		18	Roller water cooling bottom furnace
		***		19	Emisspro^{TM}
Common	31	E-1	Inverter drive (VFD; Variable Frequency Drive) for motors	27	VSD–AC, CT, Chiller, Pump
	32	E-2	Energy monitoring and management systems	28	Pump Management
	33	E-3	Management of compressed air delivery pressure optimization	25	Compressed Air Management
		***		21	Cooling Tower
		***	[Boiler technologies are introduced in NEDO Hand book]	24	Boiler

In the last chapter of this manual, thermal balance measurement and analysis for EAF and RHF are explained, which shall contribute to the understanding of the current operating situation and facilitate the quantitative evaluation of energy saving potential.

1.2 Model steel plant to estimate energy savings potential

When estimating the potential energy saving from upgrading to energy efficient technology, the first step is to know the current status of energy consumption and the possible level of energy saving. Also, production capacity should be set to estimate the investment cost. For this reason, the Model Plant configuration is assumed in the TCL. Key assumptions include: 500,000 ton/y of annual steel production, 80 ton conventional type of EAF with 430 kWh/ton electricity consumption, 100 ton/h walking beam RHF with 1,450 MJ/ton of thermal heat consumption, and so on. Table 2 shows the main configuration of the assumed steel plant. These figures are the same as those in TCL.

Table 2: Configuration of model steel plant in ASEAN

<EAF>		<RHF>	
Annual production	: 500,000 ton/y	Type	: Walking beam
Nominal capacity	: 80 ton	Nominal capacity	: 100 ton/h
TTT	: 52 minutes	Heated material	: 130 SQ billet
Iron source	: 100 % scrap	Heating temperature	: 1100 degC
Scrap preheating	: none	Fuel	: Natural gas, 44 MJ/m3N
Scrap charging	: 3 times	Combustion air temp.	: 300 degC
Ladle furnace	: used	Hot charge or direct charge	: none
NG burner	: for scrap melting	Insulation	: brick & plastic
O2 & carbon lance	: only at slag door	O2 enrichment	: none
Electricity cons.	: 430 kWh/ton	Heat cons.	: 1,450 MJ/ton
Oxygen cons.	: 30 m3N/ton		
NG cons.	: 20 m3N/ton		
Coke cons.	: 15 kg/ton		
Product	: mild steel less than 0.2 % C		
Tapping temperature	: 1,620 degC		

2 Energy saving technologies for EAF (Electric Arc Furnace)

2.1 Technologies for operational improvement & small investment

Performance of EAF often depends largely on the operators' skills. Optimal conditions in the furnace are complicated and change quickly, and composition of raw materials (scrap) is difficult to analyse, so operators have to possess sufficient experience to deal with a variety of conditions and should be open-minded about accepting suggestions from outside experts. Before analysing the savings potential associated with installing advanced and expensive facilities, operational improvement and small-scale investment should be considered. Energy consumption of 360 kWh/ton is a reasonable target value for the EAFs of a standard configuration (as described in the previous Chapter).

2.1.1 Good slag foaming with coherent burner

Slag foaming is commonly understood as an essential energy saving practice. Slag foaming during the flat bath operation is very important for reducing electricity consumption. Concept of slag foaming during flat bath depicts the concept of slag foaming.

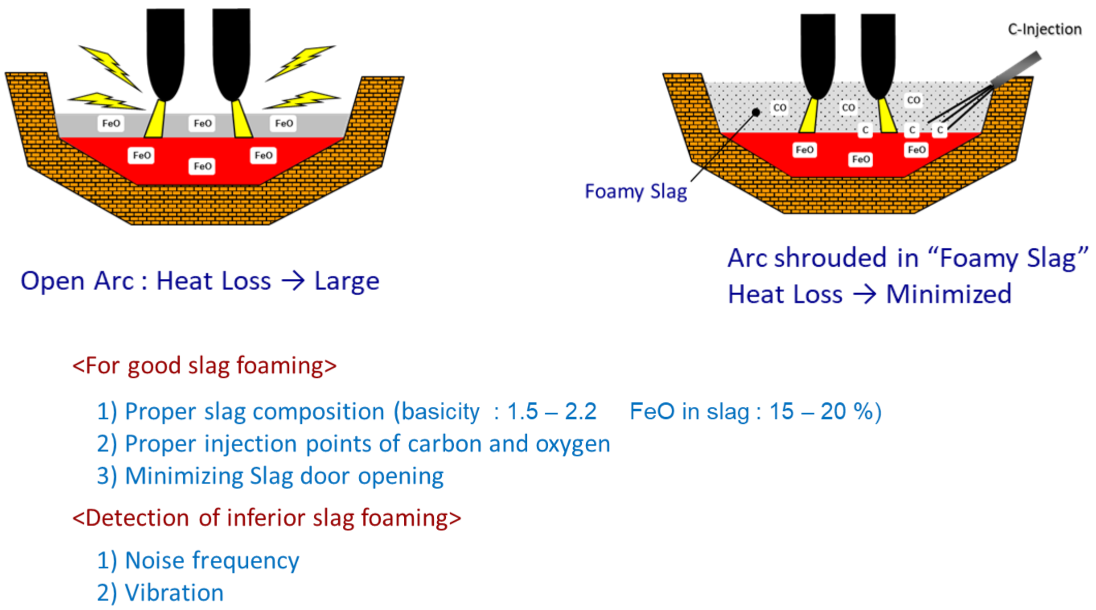


Figure 1: Concept of slag foaming during flat bath

In order to realize good slag foaming, it is essential that the carbon and oxygen is supplied in the proper position relative to the molten slag and steel.

But when furnace size is large, lances from the slag door cannot supply enough materials into the backside of the furnace. One option for solving this problem is the coherent burner. This burner makes a long and sharp oxygen jet. The oxygen jet from the centre hole is restricted to expand by the combustion around the jet, and the combustion is generated by the fuel and oxygen from the peripheral nozzles.

When lances from slag door cannot reach backside area of large furnace, this coherent burner installed on the backside works efficiently.

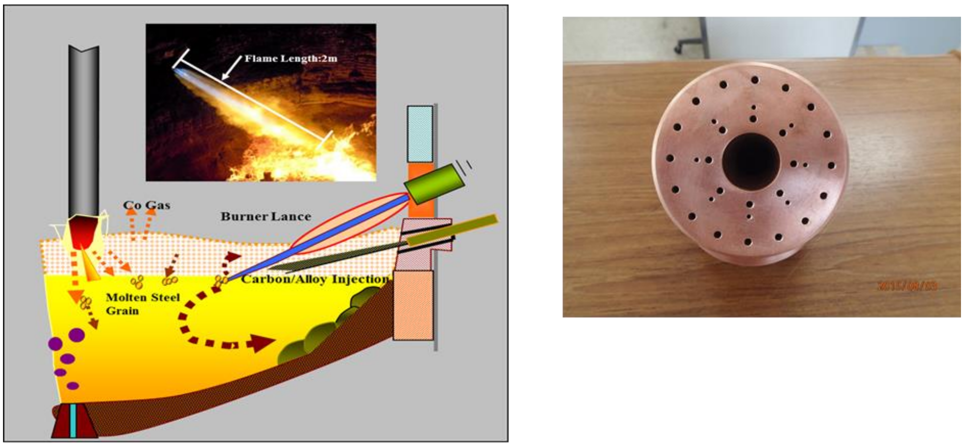


Figure 2: Coherent Burner

When properly used, the coherent burner can reduce electricity consumption and increase productivity. But improperly used, a coherent burner may lead to the increase in natural gas and oxygen and oxidization of Fe (decrease of Fe yield).

Water-cooled lances have recently been used in many steel plants for security and reducing labour, but this equipment requires full opening of slag door which allows air invasion into the furnace, and it is difficult to dip the nozzle into the molten slag. For the purposes of energy efficiency, consumable lances are more effective.

2.1.2 Effective use of combustibles in scrap

Scrap is a kind of industrial waste which often contains combustibles such as oil, rubber, painting, and plastic. When properly used, these materials become a good energy source.

It is widely known that such dirty scrap can reduce electricity consumption. One option for utilizing combustibles in scrap is to, when time allows, supply oxygen into the scrap bottom for 5-10 minutes before arc-power on. Induced air through the slightly opened slag door may work instead of oxygen. Hot heel is necessary as a heat source. Preheated scrap helps energy saving and smooth melting. These activities are expected to contribute to 20 kWh/ton of energy savings.

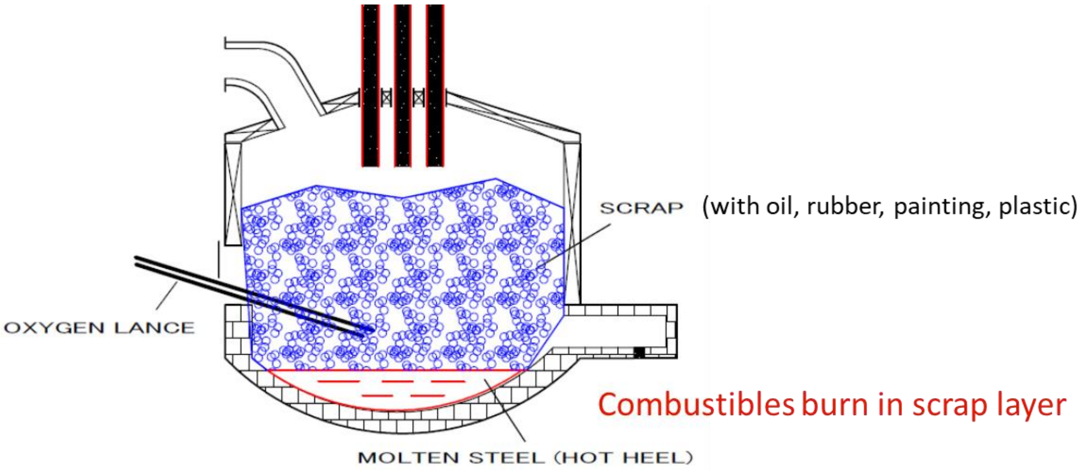


Figure 3: Effective use of combustibles in scrap

2.1.3 Correlation of record and results of operating pattern

When discussing operational improvements, it is always proposed in ASEAN steel mills to focus on understanding the relationship between operational patterns and the results. Many EAF plants are equipped with a data logging system, but an important point is how to effectively use the system for:

1) Proper understanding of physical conditions within the EAF.
2) Timely operational changes when conditions within the EAF change.

Correlation of record and results of operation patternshows the outline of this concept.

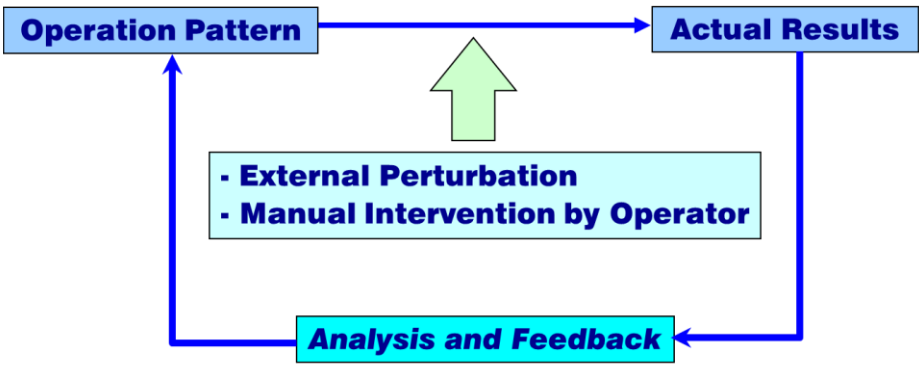


Figure 4: Correlation of record and results of operation pattern

An effective way to visualize the operation pattern is to make a graph of dynamic thermal efficiency. This will be explained in the final Chapter of this manual.

: Visualization of dynamic thermal efficiency is the comparison of two types of operation. EAF-A is a well performing furnace that shows a very short duration of flat bath operation (low efficiency period), whereas EAF-B shows longer period of low efficiency.

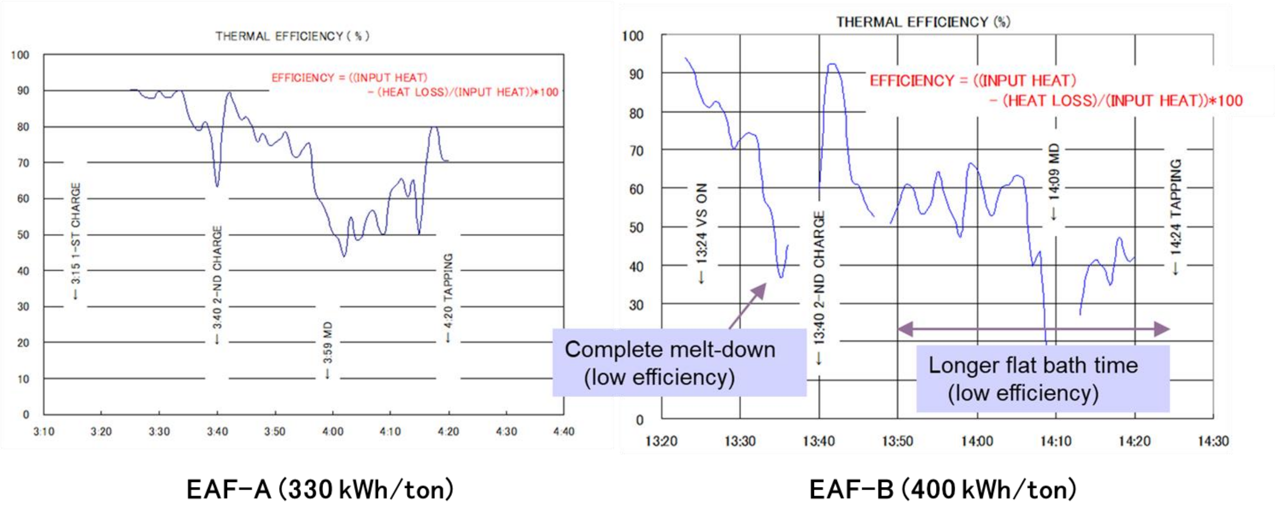


Figure 5: Visualization of dynamic thermal efficiency

2.2 Technologies for large scale investment

2.2.1 High temperature continuous scrap preheating EAF

The most efficient process is to use hot off-gas energy for scrap preheating. One of the processes is what we call ECOARC. : ECOARC processshows the outline of ECOARC process. The preheating shaft is rigidly connected to EAF body and tilts with the EAF as one unit, without a fragile mechanism in the shaft to hold the scrap. Scrap continuously descends, being heated, and melted.

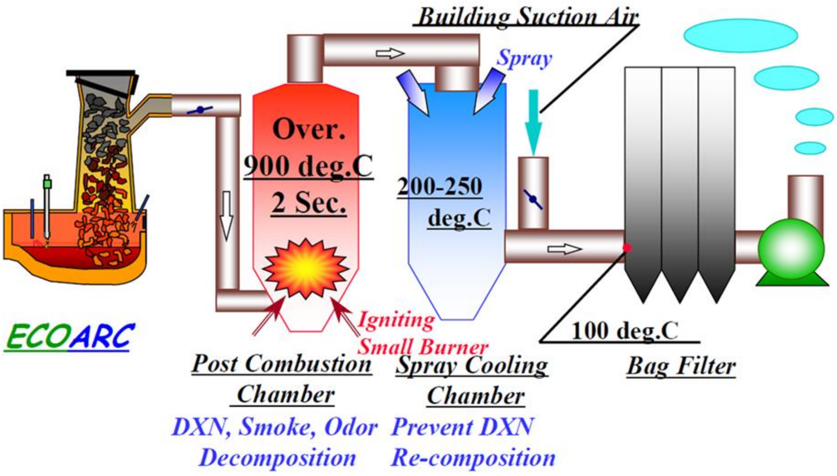


Figure 6: ECOARC process

As air invasion is very minor, off-gas energy is effectively used. Off-gas contains some amount of combustibles such as H2 and CO, which are enough to self-burn without additional fuel. Off-gas temperature rises to higher than 850 °C, a high enough temperature to decompose dioxins. After self-burning, off-gas is rapidly cooled down to 200-250 °C by water-spray to avoid dioxin regeneration, and it is then cooled by dilution air down to 100 °C. Using the ECOARC process is expected to reduce electricity consumption to 280 kWh/ton of steel.

2.2.2 Regenerative burner or oxygen burner for ladle heater

When a regenerative burner or oxygen burner is used for the ladle heater, 40% fuel savings were reported, and in addition, higher brick temperature were realized to save electricity at the EAF and/or ladle furnace (LF) with lower tapping temperature. : Regenerative burner use for ladle heatershows the concept of this system, and : Heat curve and fuel consumption of ladle heatershows the heating curve and fuel consumption of the regenerative burner and conventional burner.

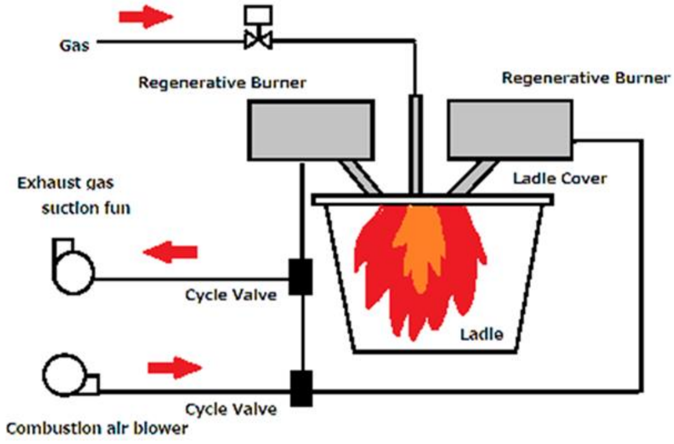


Figure 7: Regenerative burner use for ladle heater

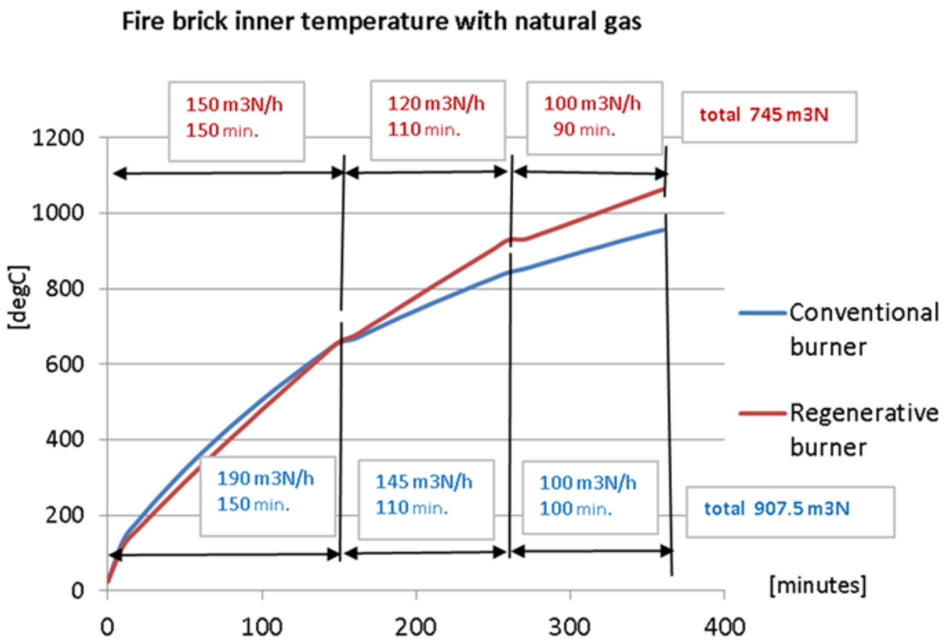


Figure 8: Heat curve and fuel consumption of ladle heater

Thermal energy consumption at ladle heaters in an EAF plant of standard size is reported as 0.45 GJ/ton-steel.

2.2.3 Scrap pretreatment to reduce charging frequency

In some EAF plant, purchased scrap is sometimes directly used without pretreatment. In this case, the density of scrap is low, such as 0.3 - 0.4 ton/m3. Light scrap must be charged many times, which leads to heat loss from the EAF and increased energy consumption. When scrap charging frequency is reduced, 20 kWh/ton energy savings can be expected from reducing the charge frequency by one.

By pretreating scrap using a scrap shearing process, scrap density will be increased to 0.6 ton/m3. Figure 9 shows scrap shear equipment and results. Estimated investment is around 3.8 million US$.

Figure 9: Scrap shear

3 Energy saving technologies for RHF (Reheating Furnace for Rolling)

3.1 Technologies for operation improvement and small investment

In many RHFs in ASEAN countries, the performance of the RHFs has not achieved the design value rendered by furnace suppliers. Before considering large scale investment, the first step is to examine the reasons for such problems. By improving operations and/or making small scale investments explained in this Chapter, the target value of 1200 MJ/ton for 1100 °C (at cold charge) should be challenged.

3.1.1 Sufficient combustion air temperature

The primary means of achieving energy savings for RHF is preheating combustion air. Combustion air temperature is sometimes lower than the design value due to:

1) air invasion into furnace or recuperator inlet
2) lack of recuperator maintenance

Error! Reference source not found. shows the effect of air temperature calculated by the RHF process simulator. Conditions for calculation is assumed as:

<BASE condition>

Furnace inner length	: 21.7 m
Furnace inner width	: 11.2 m
Billet size	: 130 mmSQ x 9.6 m
Inlet billet temp.	: 30 °C
Outlet billet temp.	: 1,100 °C
Production rate	: 100 ton/h
Fuel	: Natural gas
Air ratio	: 1.10 for all zones
Set air temp. at recuperator outlet	: 300 °C

<Calculation results of BASE condition>

Heat consumption	: 1,155 MJ/ton (276 Mcal/ton)

Table 3: Preheated air temperature and heat consumption

Preheated air temperature	Air ratio	Heat consumption	Rate
300 degC	1.10	1,155 MJ/ton	100 %
400 degC	1.10	1,086 MJ/ton	94 %
500 degC	1.10	1,037 MJ/ton	90 %
> 1,000 degC (regenerative burner)	1.10	982 MJ/ton	85 %

When air temperature is raised to 500 °C (advanced case in ASEAN) from 300 °C (normal figures in ASEAN), 10% fuel savings can be expected. And when a regenerative burner is used to raise the air temperature to higher than 1000 °C, 15% fuel savings can be expected.

3.1.2 Proper air ratio & furnace pressure control

In many steel mills, air ratio is controlled by the flow meters for fuel and air. But air ratio may be disturbed by:

1) insufficient fuel composition data and/or
2) lack of flow meter maintenance

Error! Reference source not found. shows the effect of air-ratio fluctuation calculated by the RHF process simulator. The conditions for calculation are the same as those in the former Chapter.

Table 4: Air ration change and heat consumption

Comb. air temp.	Air ratio	Heat consumption	Rate
300 degC	1.10	1,155 MJ/ton	100 %
300 degC	1.15	1,242 MJ/ton	108 %
300 degC	1.20	1,272 MJ/ton	110 %
300 degC	1.25	1,305 MJ/ton	113 %
300 degC	1.30	1,342 MJ/ton	116 %

When the original air ratio 1.10 (design condition) is increased to 1.30, fuel consumption increases by 16%. A simple way to check the air ratio is to measure O2 content in the furnace periodically. Figure 10 shows the relationship between the air ratio and oxygen content in the exhaust gas (combusted gas). Caution in measuring oxygen content is recommended to avoid unnecessary air invasion into the furnace. In some mills, measured oxygen content in off-gas line was 6-8%. This may have happened due to air invasion through the charging port. Too much air invasion lowers the temperatures of the furnace atmosphere and off-gas, and leads to lower preheated air temperature.

Even if the furnace pressure gauge shows positive, air invasion will happen. Actual pressure may be negative in this case, as dynamic pressure caused by atmosphere gas flow generates positive pressure locally. To avoid this phenomenon, the set value of furnace pressure control should be determined by observing actual gas flow at openings, such as hot gas blow-out or cold air invasion.

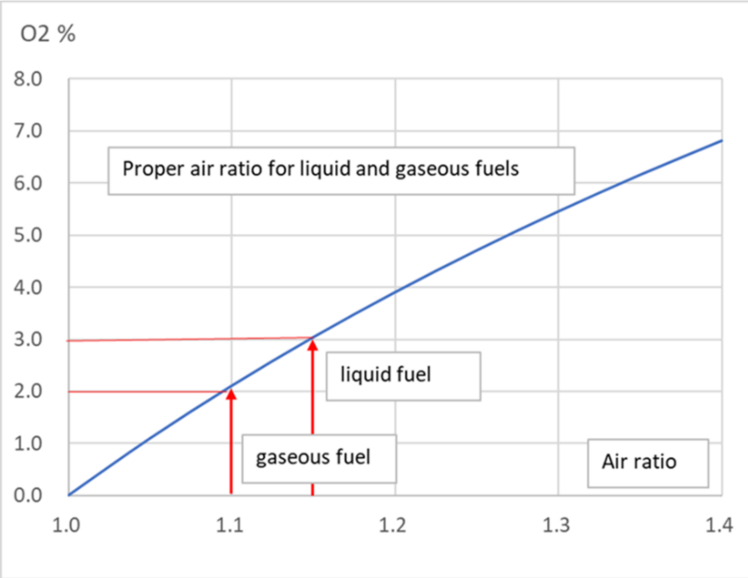


Figure 10: Air ratio and oxygen content in furnace atmosphere gas

3.1.3 Oxygen enrichment for combustion air

Oxygen enrichment contributes to fuel savings with the decrease in off-gas volume. **Error! Reference source not found.** shows the effect of oxygen enrichment calculated by the RHF process simulator. Conditions for the calculation are the same as outlined for Figure 10: Air ratio and oxygen content in furnace atmosphere gas. Purity of enriching oxygen is assumed to be 95%.

Outlet heating temperature	: 1,100 °C (cold charge)
Air ratio	: 1.10 for all zones
Set air temp. at recuperator outlet	: 300 °C
Oxygen purity	: 95% (PSA is assumed.)

When oxygen content in the combustion air is increased from 21% to 24%, 27%, 30%, 33%, and 3 6%, fuel consumption can be decreased as Table 4. The amount of furnace off-gas at 36% enrichment is reduced to nearly half of normal air combustion. Required oxygen of 95% purity becomes 3,720 m3N/h in this case.

Table 5: Effect of oxygen enrichment to heat consumption

O2 in com. air	Heat cons.	Rate	Ex. gas flow rate from furnace	O2 flow rate	Power to produce O2
21 %	1,216 MJ/ton	100 %	38,665 m3N/h	0 m3N/h	0 kWh/ton
24 %	1,149 MJ/ton	94 %	31,555 m3N/h	1,350 m3N/h	2.84 kWh/ton
27 %	1,111 MJ/ton	91 %	27,353 m3N/h	2,174 m3N/h	4.57 kWh/ton
30 %	1,087 MJ/ton	89 %	24,255 m3N/h	2,504 m3N/h	5.26 kWh/ton
33 %	1,069 MJ/ton	88 %	21,869 m3N/h	3,306 m3N/h	6.94 kWh/ton
36 %	1,058 MJ/ton	87 %	19,984 m3N/h	3,720 m3N/h	7.81 kWh/ton

Oxygen enrichment is not commonly used in Japan because of NOx increase in off-gas, however exhaust gas mixing into combustion air to reduce O2 content is sometimes applied.

Cost saving by oxygen enrichment is modelled for a 500,000 ton/y RHF. Assumed energy costs in Thailand are 14.4 US$/GJ and 0.097 US$/kWh (JETRO website 2016). Reduced fuel costs compensated by increased electricity cost for oxygen generation is shown in **Error! Reference source not found.**. This table shows that enrichment to 25-26% affects most effectively. It should be noted that high oxygen content tends to cause high flame temperature and insulation damage.

Table 6: Effect of oxygen enrichment to heat consumption

Assume energy cost in Thailand (JETRO website 2016)
14.4 US$/GJ
0.097 US$/kWh

O2 in com. air	Unit heat cons.	Thermal energy	Fuel cost	Power to produce O2	Electricity cost	Total energy cost	Rate
21 %	1,216 MJ/t	608,000 GJ/y	8.76 mill.US$/y	0 MWh/y	0 mill.US$/y	8.76 mill.US$/y	100.0 %
24 %	1,149 MJ/t	57,5000 GJ/y	8.27 mill.US$/y	1,420 MW/y	0.14 mill.US$/y	8.41 mill.US$/y	96.0 %
27 %	1,111 MJ/t	556,000 GJ/y	8.00 mill.US$/y	2,285 MW/y	0.22 mill.US$/y	8.23 mill.US$/y	93.9 %
30 %	1,087 MJ/t	54,4000 GJ/y	7.83 mill.US$/y	2,630 MWh/y	0.26 mill.US$/y	8.09 mill.US$/y	92.4 %
33 %	1,069 MJ/t	53,5000 GJ/y	7.70 mill.US$/y	3,470 MW/y	0.34 mill.US$/y	8.04 mill.US$/y	91.8 %
36 %	1,058 MJ/t	529,000 GJ/y	7.62 mill.US$/y	3,905 MW/y	0.38 mill.US$/y	8.00 mill.US$/y	91.3 %

3.2 Technologies for large scale investment

3.2.1 Direct rolling and hot charge

Direct rolling or hot charge is a simple but most effective in a hot rolling process. The RHF can be removed when an induction heater is used. An induction heater does not have much heating power, it is only used to compensate the cooling of edges. RHF stopping with the installation of an induction heater can save the fuel by 1.45 GJ/ton, which used to be consumed by standard RHF (see model plant in Chapter 1).

Electric power consumption is estimated as 40 kWh/ton, and the difference between fuel savings and reduced electricity consumption becomes the profit. When rolling mill stops during EAF & CC operation, heated billets shall be returned to EAF to be melted again. Figure 11 shows the example of induction type billet heater. The size is very compact (about 0.8 m x 0.8 m x 6 m, for example) and easy to operate.

Figure 11: Induction heater for billet direct charge

The effect of the hot charge is calculated by using the RHF simulator with the same conditions as the BASE (100 ton/h 1,100 °C) outlined above. Figure 7 shows the results of simulation. When planning the hot charge, the arrangement between CCM yard and rolling mill becomes a barrier. Direct or hot charge should be considered at the initial stage of plant design.

Table 7 Effect of hot charge

Billet charge temp.	Heat cons.	Rate
30 degC	1,155 MJ/ton	100 %
200 degC	1,094 MJ/ton	95 %
400 degC	942 MJ/ton	82 %
600 degC	778 MJ/ton	67 %
800 degC	570 MJ/ton	49 %

3.2.2 Fiber block for insulation

Fiber block has been used in newer furnaces for the roof and side wall. Changing the insulation from brick or plastics to fiber block in existing furnaces should also be implemented.

Fiber block is lighter in weight and has the lower thermal conductivity than conventional materials. It contributes to quick temperature change or heat-up after stopping. Figure 12 shows the configuration of insulation work.

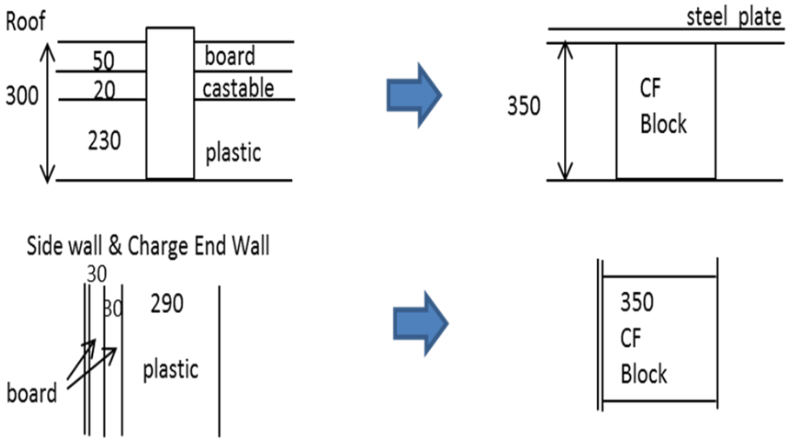
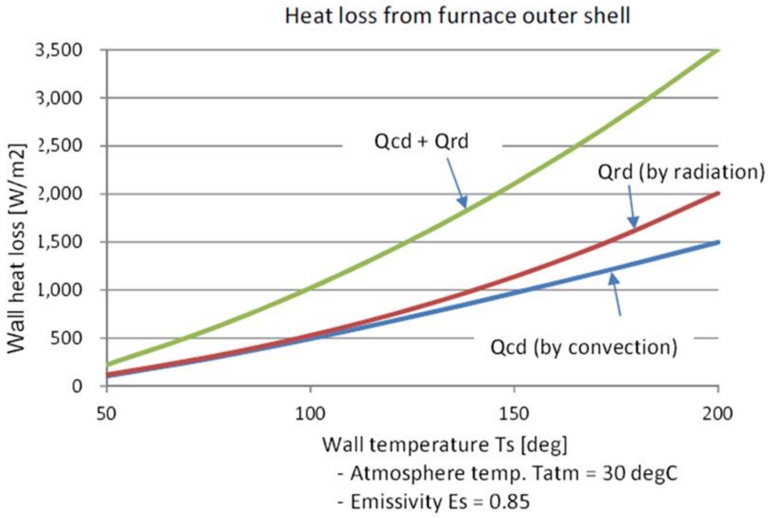


Figure 12: Configuration of brick work and fibre block

Figure 13 shows the heat loss from the furnace outer shell. A standard furnace outer shell temperature of 130 °C can be lowered to around 90 °C, and the estimated reduction in heat loss is 2.7%, which leads to 0.039 GJ/ton reduction in thermal energy.



$$Qs = 2.44 \times (Ts - Tatm)^{1.25} + 5.674/10^{8} \times \varepsilon_s \times ((Ts + 273.15)^{4} - (Tatm + 273.15)^{4}) \quad \text{[W/m2]}$$

(1 [kcal/h·m2] = 0.86 x 1 [W/m2])

Figure 13: Furnace shell temperature and heat loss

3.2.3 Low NOx regenerative burner

Figure 14 is the schematic sketch of regenerative burner system, and Figure 15 shows the concept of low NOx combustion. The low NOx type regenerative burner is characterized as the duel fuel injection. After the furnace temperature is raised high enough (higher than 800 °C), fuel injection points are changed to the peripheral position to hot air jet, and fuel is injected into the global circulation of furnace atmosphere gas, where oxygen content is low. As the oxygen percentage of burning area is low, the flame temperature does not get too high, and NOx generation is restricted.

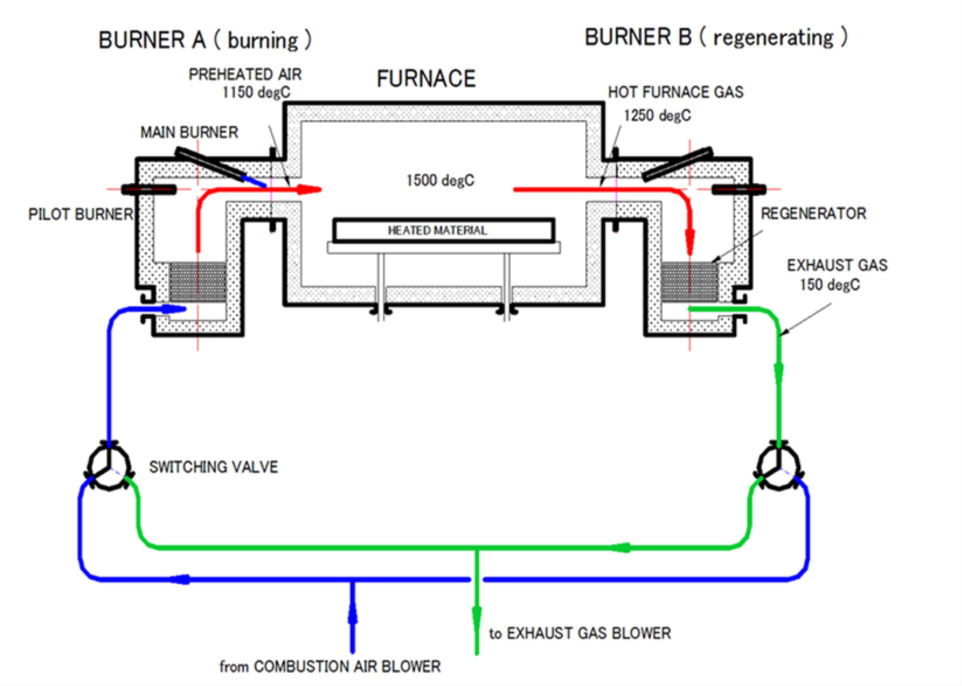


Figure 14: Regenerative combustion system for RHF

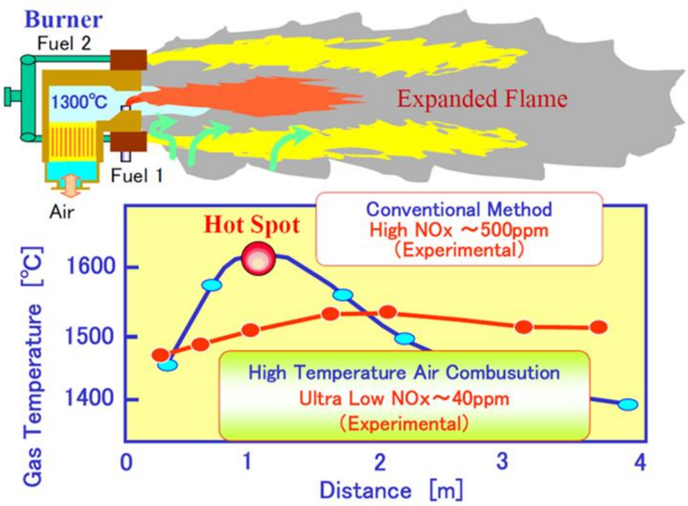


Figure 15: Concept of low NOx combustion of regenerative burner

When a regenerative burner is applied to RHF with 300 °C combustion air, 15% fuel savings can be achieved. Additional advantages of this burner system are:

1) Production increase by same furnace length or
2) Compact furnace size for the same capacity

Figure 16 shows the difference distributions of furnace gas temperatures. When a regenerative burner system is used, the furnace gas temperature in preheating zone drops rapidly, because most of combusted gas is exhausted from burner ports. This means that preheating zone does not work efficiently and can be eliminated. Or when additional burners are installed in the charging side, a capacity increase is realized without reducing efficiency due to the low volume of high temperature off-gas at the charge end.

High sulfur fuel is difficult to use in regenerative burners, as sulfuric acid condenses at the bottom of ceramic layer and catches iron oxide powder, which causes clogging.

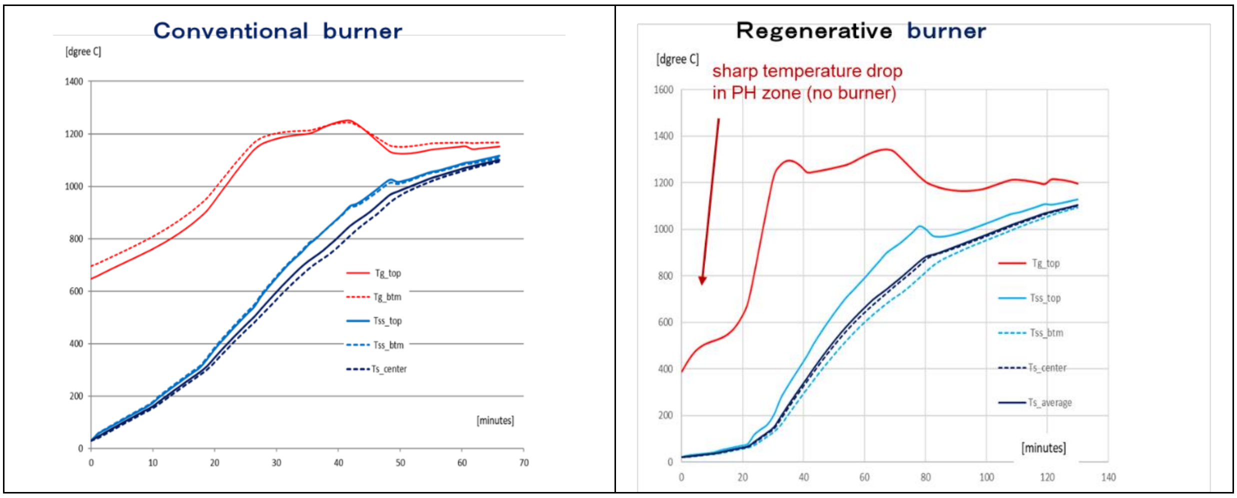


Figure 16: Temperature distribution of furnace atmosphere gas

3.2.4 Air conditioning by absorption type refrigerating

In many RHFs, off-gas temperatures at stack are still high, for example over 400 °C. This thermal energy is used for power generation by using low-boiling compounds, such as the ORC (Organic Rankine Cycle) process. Another option for small sized RHFs is a simple technology for electrical energy saving: absorbing type refrigeration for cold-water generation for air conditioning. Electric power is not generated, but the waste heat is used directly to save air conditioning power which has big demand in ASEAN steel mills.

Figure 17 shows the outline of this process. In this case, 300 °C 20,000 m3N/h hot off-gas from 100 ton/h RHF is applied to regenerate the process liquid, which is used in the absorption chiller. Electricity demand is reduced by approximately 1,370 kW. Considering the operation power of this system, net energy saving becomes 3.0 kWh/ton-steel.

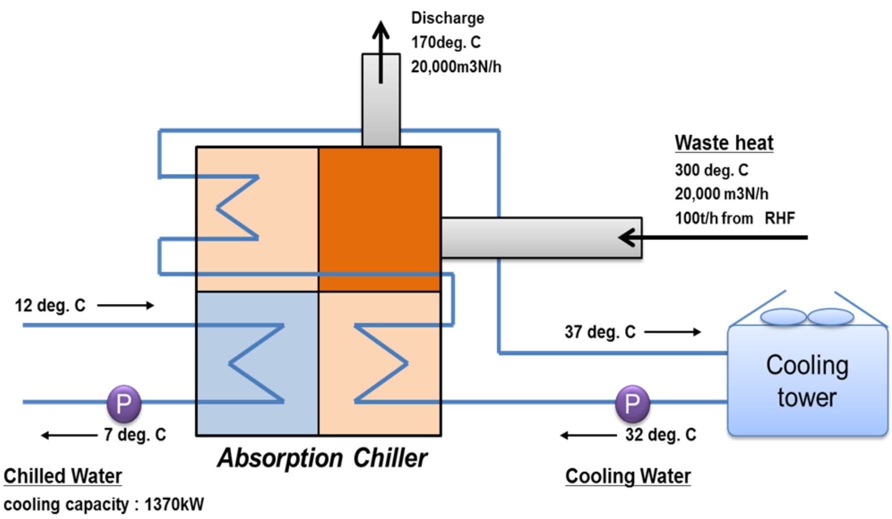


Figure 17: Principle of cooling water generation by absorbing type refrigerating

4 Thermal balance measurement and analysis

The purpose of thermal balance analysis is to:

1) Help understand physical phenomena in the furnace
2) Compare the performance of furnaces
3) Indicate target value for improvement

Thermal balance itself is not the final target, but it helps plant managers understand energy saving opportunities. The processes of EAFs and RHFs are completely different. An EAF uses a batch process with quickly changing conditions, imperfect material data, and is difficult to model by computer simulation. On the contrary, RHF uses a continuous stable process with satisfactory material data, and it is possible to analyse by computer simulation. This Chapter explains the way to measure and analyse the thermal balance of these facilities and how to use the results in a practical way.

4.1 EAF thermal balance

Figure 18 is a sample of an EAF thermal balance presented by one of the EAF suppliers. But this thermal balance averaged across one heating cycle is not enough to fully understand energy saving opportunities. Instead, the concept of dynamic thermal efficiency is proposed to study operation pattern. For this purpose, time-dependent heat input and heat loss should be measured at each minute.

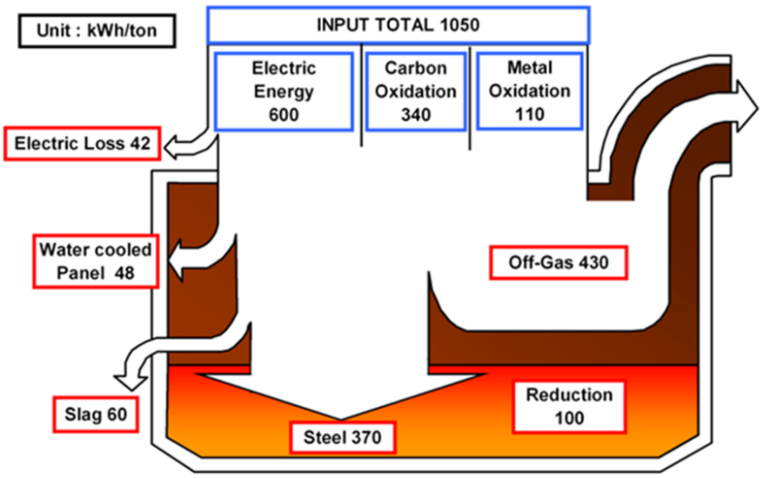


Figure 18: Temperature change of off-gas and cooling water from EAF

Figure 19 shows the temperature change of off-gas (left) and cooling water (right) from EAF. As these graphs show, heat loss and thermal efficiency of the EAF change along with the process proceeding. It is important to pay attention to the heat-loss pattern at each stage (early melting, final melting, refining).

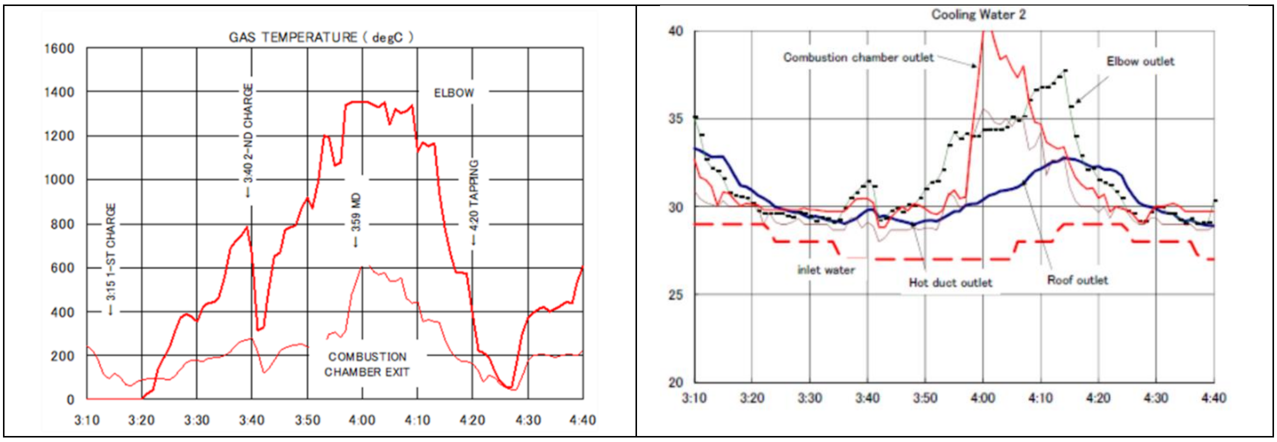


Figure 19: Temperature change of off-gas and cooling water from EAF

Generated heat and heat transfer phenomena in EAF due to the below factors are complicated, and not easy to identify by direct measuring.

- Arc energy
- Combustion of combustibles in scrap
- Combustion of injected carbon
- Combustion of CO (carbon monoxide) from the Bath
- Metal oxidation
- Radiation loss through openings
- Heat transfers among arc, scrap, gas, and wall

To accomplish good EAF performance, it is effective to know the change in thermal efficiency in relation to operational activities. But it is difficult to measure and identify the change of thermal efficiency.

It is difficult to measure the Effective Heat (heat absorbed by material), but relatively easy to know heat loss. Therefore, effective heat can be defined as:

(Heat Input) – (Heat Loss)
Heat Input measuring is easy.
Heat Loss is defined as Cooling Water Loss + Exhaust Gas Loss + Other Loss.

(1) Cooling Water Loss is the sum of the loss of water-cooled panels
(2) Exhaust Gas Loss is the Water Loss at water-cooled duct (and combustion chamber) plus Exhaust Gas loss at water-cooled duct outlet.
(3) Other Loss is the Radiation Loss plus Hot Gas Leakage and others.

By measuring (1), (2), and (3) every minute, variation in thermal efficiency can be calculated. Thermal Efficiency is calculated by ((Heat Input) – (Heat Loss)) / (Heat Input)

Heat Input measuring is easy.
Heat Loss = Cooling Water Loss + Exhaust Gas Loss + Other Loss

(1) Cooling Water Loss : EAF Water-cooled Panel
(2) Exhaust Gas Loss : Cooling Duct Water and Ex. Gas at Duct outlet
(3) Other Loss : Radiation Loss, Hot Gas Leakage, and Others

By measuring (1)(2)(3) every minute, variation of thermal efficiency will be observed.

Thermal Efficiency
= ((Heat Input) – (Heat Loss)) / (Heat Input)

Figure 20 depicts the measuring points of heat loss at every minute. As the off-gas at the water-cooled duct contains much dust, it is difficult to measure the flow rate directly by using Pitot tube. An alternative way is to measure the gas temperatures at the inlet and outlet of water-cooled duct, and to assume the flow rate by the thermal balance with cooling water.

Measuring the flow rate at the secondary in-house dedusting duct is easier, but alternatively, the design value of the flow rate of the dedusting system can be used. Gas composition measuring is desirable, but for handy measuring, default values in Table 8 can be used. The main purpose of these measurements and analysis is to understand the pattern of thermal efficiency change, not to define the absolute values. Note that measuring point of (3) Other Heat Loss should be upstream of the joining point with off-gas from LF or others. Measured data are put into an EXCEL spreadsheet for calculation and visualization.

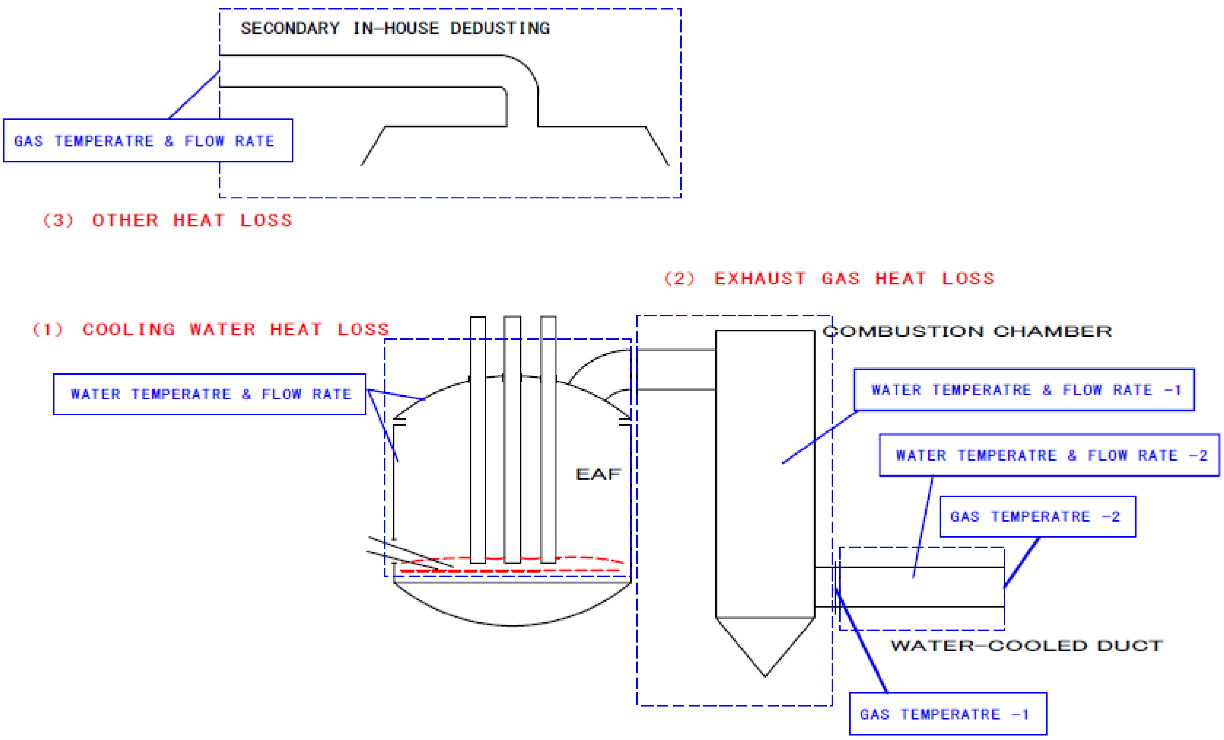


Figure 20: Measuring points of heat loss

Table 8: Default value of gas composition

	Default gas composition at water-cooled duct					
	CO2 (Vol. %)	H2O (Vol. %)	CO (Vol. %)	N2 (Vol. %)	H2 (Vol. %)	O2 (Vol. %)
Melting time	6.0	5.0	0.5	71.5	1.0	16.0
Refining time	8.0	5.0	0.2	73.8	1.0	12.0

	Default gas composition at dedusting collecting duct					
	CO2 (Vol. %)	H2O (Vol. %)	CO (Vol. %)	N2 (Vol. %)	H2 (Vol. %)	O2 (Vol. %)
	0.0	0.0	0.0	79.0	0.0	21.0

Figure 21: Example of spreadsheet and graphis the example of spreadsheet and visualized thermal efficiency. Detailed manual of the thermal efficiency measuring and spreadsheet for calculation have been already transferred to Thai experts.

TIME	INPUT HEAT (Mcal/min)	EFFEC.HEAT (Mcal/min)	EX. GAS LOSS (Mcal/min)	CL.WATER LOSS (Mcal/min)	EFFICIENCY (%)
10:50	439	363	71	5	82.7
10:51	969	866	97	6	89.3
10:52	969	801	161	7	82.6
10:53	969	781	183	5	80.6
10:54	1131	933	187	11	82.5
10:55	1131	890	223	18	78.7
10:56	1131	802	313	16	70.9
10:57	1131	733	382	16	64.8
10:58	700	290	387	23	41.4
10:59	1150	683	449	18	59.4
11:00	1170	634	510	26	54.1
11:01	1170	619	518	34	52.9
11:02	1170	587	543	40	50.2
11:03	1009	452	501	55	44.8
11:04	1170	563	525	82	48.1
11:05	1170	565	500	105	48.3

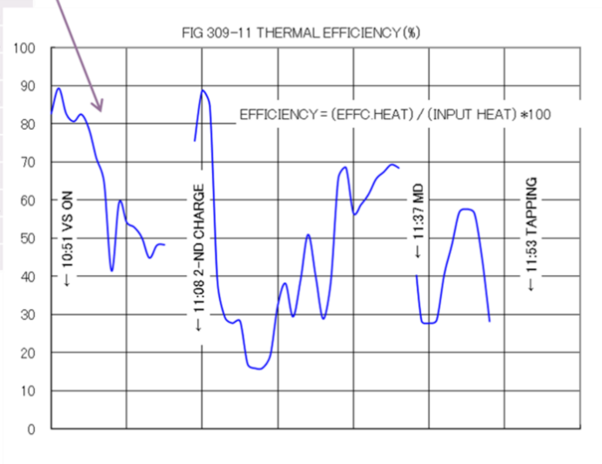


Figure 21: Example of spreadsheet and graph

4.2 RHF thermal balance

The RHF process is continuous and simple, and rather easy to simulate by calculation. The RHF simulator is developed by Japanese team and uses heat transfer formulae and thermal balance calculation. The RHF simulator is used to evaluate the performance of existing RHFs. Calculations of Table 3, Table 4, Table 5, Table 6, and Table 7 are made by using this RHF simulator.

Furnace specification data and some operation data are input to the simulator to reproduce temperature distribution and thermal balance in the computer. Thermal balance and heat transfer among (fuel)/(hot gas)/(wall)/(atmosphere)/(skid)/(steel) are calculated to get temperature distribution and thermal balance. Figure 22: Dividing RHF for calculationshows the longitudinal division of furnace body. The furnace is divided into 10-15 divisions along the furnace length. Temperatures of hot gas, heated material surface, inner and outer walls are assumed as uniform within each division, and then calculations of heat transfer and thermal balance among the elements will be conducted.

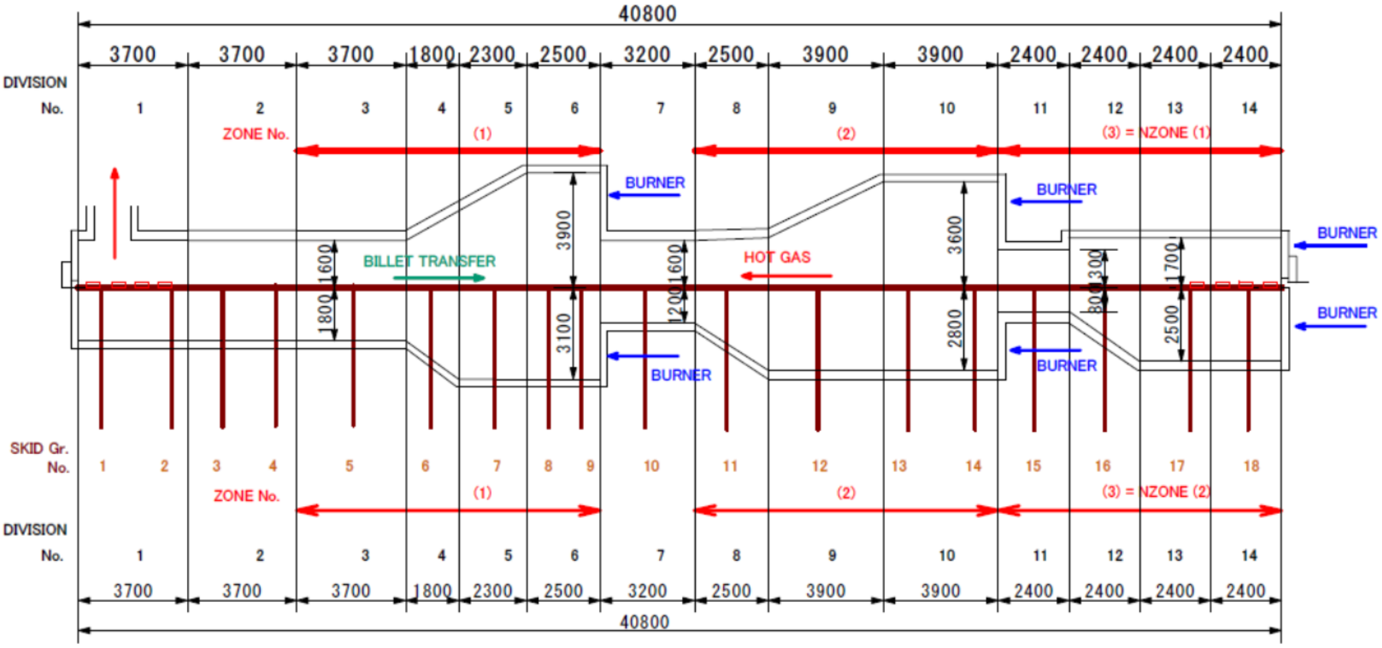


Figure 22: Dividing RHF for calculation

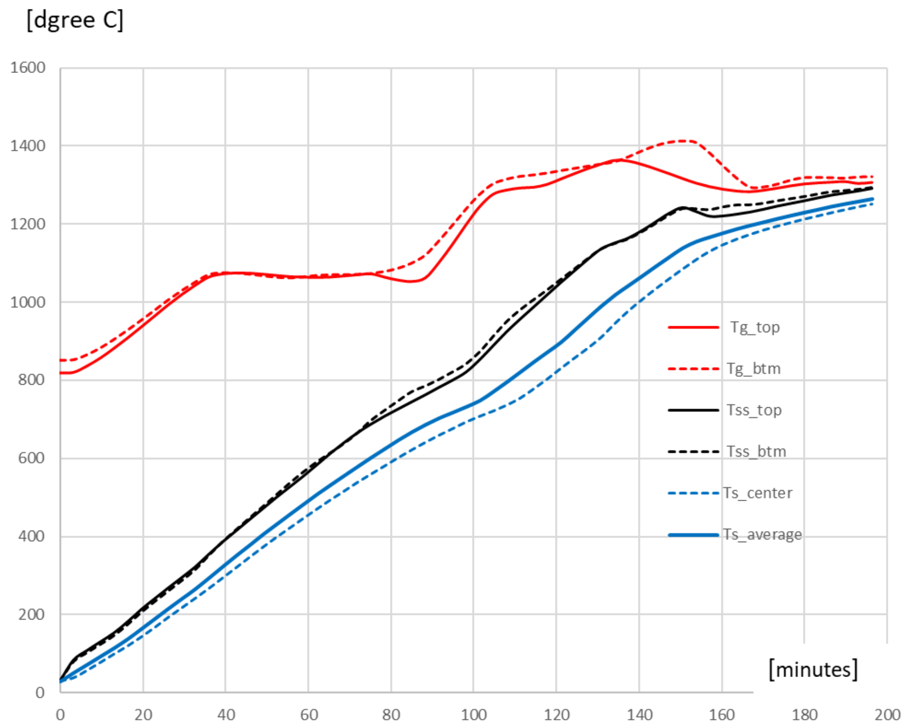


Figure 23: Calculated temperature distribution along the furnace

Table 9 and Table 10 shows the results of calculation and thermal balance.

Table 9: Calculation output

< HEATED MATERIAL >

MATERIAL NAME : 0.06_%_C_rimmed_steel

LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	DENSITY (kg/m3)	THROUGHPUT (ton/h)	OXIDATION LOSS (%)	INLET AVE. TMP.	OUTLET AVE. TMP.	TMP. DIF.
9000.0	1200.0	250.0	7871.	197.8	0.31	30.0	1264.9	43.0

MOVING SPEED CHANGE POSITION	= 40.80 m	FROM INLET
INLET MOVING SPEED	= 0.202 m/min.	(PIECE DIST. : 100.0 mm)
OUTLET MOVING SPEED	= 0.202 m/min.	(PIECE DIST. : 100.0 mm)
RETENTION TIME	= 196.4 min.	(FURNACE LENGTH = 40.800 m)

< ZONE HEAT INPUT, EXHAUST GAS & SCALE LOSS >

ZONE		BN. RATE	HEAT INPUT	AIR RATIO	PH AIR TEMP.	PH GAS TEMP.
TOP	- 1	42.7 %	9800. Mcal/h	1.23	426.2 ˚C	30.0 ˚C
	- 2	54.6 %	12531. Mcal/h	1.06	424.9 ˚C	30.0 ˚C
	- 3	31.5 %	3119. Mcal/h	1.20	401.6 ˚C	30.0 ˚C
BOTTOM	- 1	46.6 %	12163. Mcal/h	1.11	426.5 ˚C	30.0 ˚C
	- 2	61.4 %	16026. Mcal/h	1.04	425.9 ˚C	30.0 ˚C
	- 3	67.8 %	8360. Mcal/h	0.99	421.3 ˚C	30.0 ˚C
		TOTAL	61998. Mcal/h (313.44 Mcal/ton = 1312.3 MJ/ton)			

EX. GAS RECYCL	=	0. % of COMB. AIR.
SET 02 % IN COMBUSTION AIR	=	21.0 %
CONTROLLED FURNACE PRESSURE	=	5.0 Pa

HOT GAS LEAK FROM FURNACE	=	3853. m3N/h	
FURNACE OUTLET EXHAUST GAS	=	76249. m3N/h,	830.4 ˚C
EXHAUST GAS at STACK	=	85694. m3N/h,	421.9 ˚C

Table 10: Thermal balance

< HEAT BALANCE (0˚C BASE, FUEL TOTAL COMBUSTION HEAT = 100 %) >

HEAT INPUT

	Mcal/h	%
HEATED MATERIAL SENSITIVE HEAT	664.6	1.07
SCALE GENERATION HEAT	975.4	1.57
LOQUID FUEL COMBUSTION HEAT	61997.8	100.00
LOQUID FUEL SENSITIVE HEAT	597.7	0.96
COMB. & DIL. AIR SENSITIVE HEAT	799.3	1.29
PURGE STEAM SENSITIVE HEAT	0.0	0.00
(RECUPERATED COMBUSTION AIR HEAT	9680.8	15.61)
TOTAL HEAT INPUT :	65034.8	104.90

HEAT OUTPUT

	Mcal/h	%
HEATED MATERIAL SENSITIVE HEAT	40715.7	65.67
GENERATED SCALE SENSITIVE HEAT	234.1	0.38
EX. GAS SENSITIVE HEAT AT STACK	12332.2	19.89
COMBUSTIBLES IN EX. GAS	0.0	0.00
SKID COOLING WATER HEAT LOSS	8847.5	14.27
FURNACE WALL HEAT LOSS	2047.0	3.30
CHARGE/DISCHARGE DOOR HEAT LOSS	249.4	0.40
HEARTH OPENINGS HEAT LOSS	67.7	0.11
EXHAUST GAS DUCT WALL HEAT LOSS	242.2	0.39
PIPINGS & BURNERS HEAT LOSS	205.5	0.33
FURNACE HOT GAS LEAK HEAT LOSS	1160.5	1.87
OTHER LOSS & CALCULATION ERROR	-1067.0	-1.72
TOTAL HEAT OUTPUT :	65034.8	104.90

(THERMAL EFFICIENCY = 64.60 %)

Once the base calculation is fixed, a study of energy saving opportunities can be conducted by changing many factors, such as air ratio, combustion air temperature, oxygen enrichment, insulation, billet charging temperature, and so on. Case studies shown in this document are made using this RHF Simulator. A detailed manual of the RHF simulator and calculating program have already been transferred to Thai experts.