12-5 Current Condition and Problems with Energy

12-5-1 Energy Management and Conservation

Consumption of electric power, oxygen gas and fuel oil -- all representing different types of energy -- is measured by instruments installed at the control pulpit; and daily, weekly, monthly and annual reports are prepared for management review together with other operation parameters by computer processing. IDC has organized, since the beginning of 1994, an Energy Saving Committee consisting of experts of the production and maintenance sections. The organization chart of the Energy Saving Committee is shown in Figure 12-6. Concerning energy saving, this committee examines and evaluates proposals by the workers, and reports the results of such evaluations to the top management. Daily operation results are reported and discussed in the morning meeting every day, represented by section managers including the Personnel Affairs Section, chaired by Mr. Eldem, Maintenance and Utilities Director.

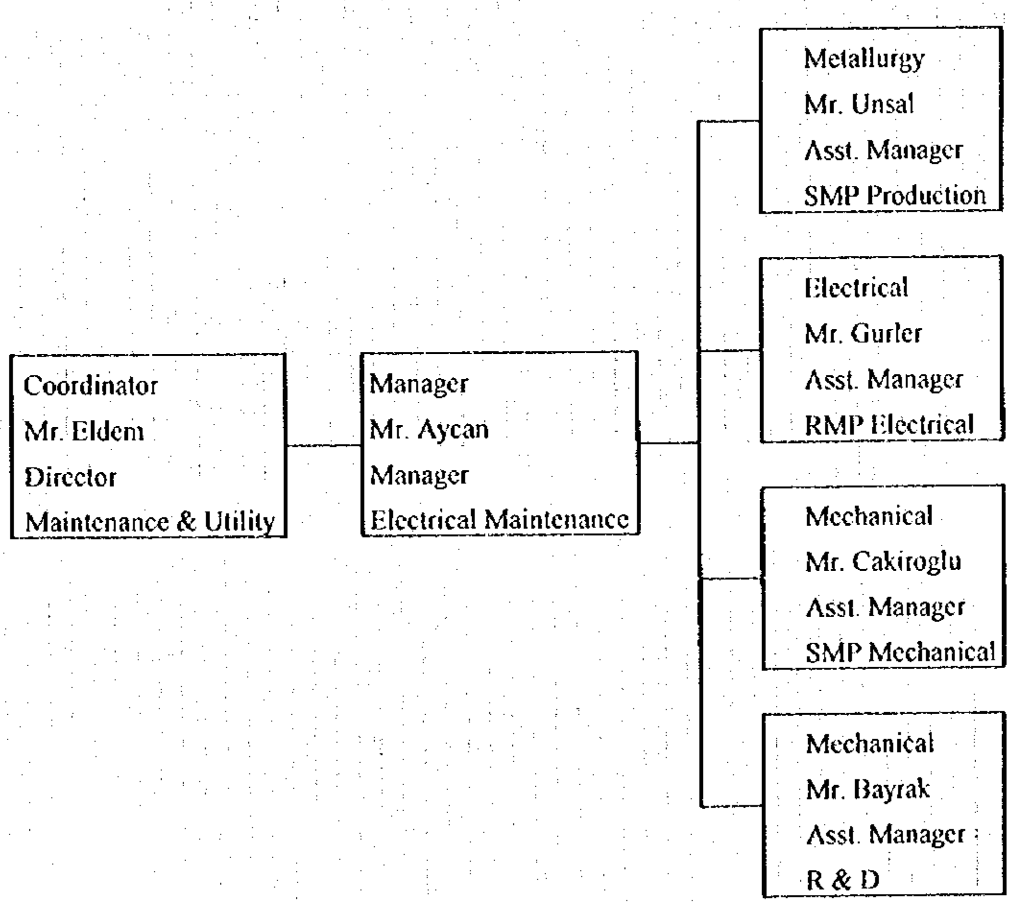

Figure 12-6 Organization Chart of Energy Saving Committee

12-5-2 Results and Plan for Rationalization of Energy Use

The following measures for energy saving are taken.

1. Scrap preheating utilizing exhaust gas from the EAF: Saves about 20 kWh per ton, compared with operation without scrap preheating.
2. Preheating of combustion air to the ladle using its own exhaust gas is being tested.
3. Hot charge of billets to the reheating furnace: About 10 kilograms of fuel is saved per ton of product compared with cold charge.
4. The exhaust heat from the reheating furnace is used to preheat the combustion air to the reheating furnace, produce hot water and steam for heating the buildings, and preheat fuel oil.

In addition to the above measures, IDC has employed the following state-of-the-art technologies. This contributes to energy saving.

1. Use of large capacity transformer for EAF
2. Application of high power and long arc operation to the EAF, resulting in reducing melting time, or short tap-to-tap time.
3. Use of oxy-fuel burners in the EAF makes it possible to reduce melting time and ensures uniform temperature distribution, or elimination of cold spots.
4. Foamy slag operation is applied to the EAF to use the arc heat more efficiently and to prevent radiation of heat from damaging the furnace wall enveloping the arcs.
5. The EBT system (slag-free tapping) of the EAF results in shorter tapping intervals and heat loss.
6. The ladle furnace (LF) contributes to increasing production of steel by relieving the EAF of the refining load. The EAF is operated for the sole purpose of melting scrap and the LF for refining the heat.
7. Slit rolling contributes to increasing production and saving energy.
8. Application of frequency converters to controlling the speed of large motors.

As shown in Table 12-9, IDC has been improving productivity by expansion of the capacities of the relevant pieces of equipment and by adopting state-of-the-art technologies. IDC furthermore plans to improve productivity. Tap-to-tap time has been remarkably improved from 80 to between 52 and 55 minutes; this will be further reduced to 45 minutes in the near future.

Consequently, electric power consumption has also been reduced from 490 to 420 kWh per ton. This is expected to be further reduced to 360 kWh per ton.

Table 12-10 shows some examples of electric power consumption in Japan. These figures range from 330 to 510 kWh per ton. In light of these figures, IDC will certainly achieve electric power consumption of 360 kWh per ton.

Table 12-9 Improvement of SMP Operation

	Design basis ('87)	'93 - '95	Future
Specifications of EAF			
Capacity (tons/heat)	60	70	80
Shell diameter (meters)	5.3	5.5	5.5
Transformer (MVA)	45	72	72
Operation Parameters			
Tap-to-tap time (minutes)	80	50 - 55	45 -50
Electric power (kWh/ton)	490	405- 430	360
Oxygen gas (Nm^3/ton)	23	30 -35	45
Electrode (kg/ton)	3.5	1.6 - 2.3	1.5
Refractories (kg/ton)	20	10	8
Burnt lime (kg/ton)		30	25
Steel yield (%)		89	92
Technologies	1. UHP transformer 2. Scrap preheating 3. Water cooled wall and roof 4. Spray water cooled electrodes 5. Oxy-fuel burners 6. Oxy-lancing 7. Foamy slag practice 8. Long arc practice 9. EBT (slag free tapping) 10. Ladle furnace 11. Sequence casting 12. Mold level control		1. Additional oxy-fuel/oxy-carbon burner 2. Scrap upgrading 3. Ca-Si injection 4. Electromagnetic stirring 5. Ladle shrouding 6. Increased oxygen injection 7. EAF bottom blowing 8. SPH improving

Source: IDC

Table 12-10 Example of Electric Power Consumption in Japan

Company	Furnace	Nominal capacity (t)	Inner diameter (m)	Transformer (MVA)	Burner (Y/N)	SPH (Y/N)	Heat/day	Actual Ton/ht	Power consumption (kWh/t)	Oxygen consumption (Nm3/t)	Electrode consumption (kg/t)
KO	1	100	6.4	35	7	N	7	109.4	432.5	8.5	3.4
	2	20	4	7.5	N	N	11	17.7	513.5	29.2	4.6
	3	20	4	12.5	2	Y	14	21.6	345.1	17.3	4
KA	1	60	5.8	41	1	N	21	73.5	397.1	33.1	2.1
GO	1	100	6.7	60	3	N	22	126.2	363.6	33.6	2
	2	70	6.3	50	2	Y	31	60.3	383.2	30.1	2
	3	70	5.8	35	3	T	25	74.4	410.7	27.9	2
AS	1	60	5.7	45	N	Y	24	57.5	342.5	32.8	1.8
TY	1	200	8	70	10	N	19	170	341	36.4	1.3
TO	1	140	7	60	3	N	21	132.6	380.4	24.3	1.9
	2	140	7	60	3	N	21	132.2	378.2	22.1	1.9
	3	150	8	140	N	N	22	215.8	379.9	30.6	1.6
	4	60	5.2	27.5	3	N	22	62.8	337.1	40.9	1.8
	5	60	5.2	27.5	5	N	22	62.9	341.2	39.1	1.5
	6	130	7	100	N	Y	28	119.4	325	27	0.9
TOA	1	110	7	58	4	Y	26	124.5	400.2	30.6	1.6
	2	70	5.8	30	3	N	19	77.2	410.6	31.4	2.1
	3	70	5.8	30	3	N	18	77.4	405	30.7	2.4
	4	50	5.1	22	3	Y	30	43.8	440.1	20.1	2.6
	5	150	7	55	4	Y	28	133.6	353.3	21.5	1.7
TOP	1	30	4.6	15	N	N	17	31.7	472	25.1	4.5
	2	30	4.6	15	N	N	17	31.8	433.3	25.2	-
	3	120	6.5	56	7	Y	19	136.4	329.1	25.1	1.6
NI	1	25	4	8.5	2	Y	10	20.1	446.9	39.7	4.4

12-6 Current Condition and Problems with Facilities

12-6-1 Major Energy Consuming Facilities

Major energy consuming facilities are as follows:

1. Electric arc furnace: 630,000 tons per year of molten steel

Electric power consumption: 408 kWh per ton, 257,000 MWh per year

Oxygen consumption: 32 Nm^3 per ton, 20,000,000 Nm^3 per year

Fuel oil consumption: 5 kilograms per ton, 3,200 kilograms per year

2. Ladle furnace: 630,000 tons per year of molten steel

   Electric power consumption: 35 kWh per ton, 22,000 MWh per year

3. Rolling mill: 510,000 tons per year of rebar

   Electric power consumption: 80 kWh per ton, 41,000 MWh per year

4. Reheating furnace: 510,000 tons per year of rebar

   Fuel oil consumption: 25 kilograms per ton, 12,800 kilograms per year

12-6-2 Identification of the Current Problems

(1) Problem with Major Energy Consuming Facilities

As mentioned in section 12-5-2, IDC has also been improving productivity and energy saving by expansion of the capacities and introduction of state-of-the art technologies. IDC has achieved superb operation results, of which the following are particularly outstanding:

1. Electric power consumption of the electric arc furnace (400 to 420 kWh/ton-MS)

   Table 12-10 indicates that there is some room to further reduce electric power consumption.

2. Utilization of the scrap preheater

   Use of scrap preheater is limited; half the exhaust gas is used and the equipment capacity, time available and equipment configuration limit the preheating to 70 percent of the scrap.

3. Hot charge

   Application is limited; Application is limited only to low temperature billets due to metallurgical problems.

(2) Problems in Energy Consumption Already Recognized, Items Requested for Auditing

IDC has envisaged reduction of electric power consumption for the electric arc furnace from 420 kWh/ton-MS to 360 kWh/ton-MS. Expansion of the scrap preheater is now under study as one of the means to achieve this objective.

To set a definite target for energy saving and confirm the results of energy saving efforts, it is important to determine the heat balance of the arc furnace operation regarding it as an integral system. Determination of the exact heat balance involves enormous amounts of measurement and calculation. Nevertheless, IDC finds it necessary to determine the heat balance of the electric arc furnace.

(3) Major Items and Points of Factory Audit

The study team understands IDC's objective and agrees with IDC that determination of the heat balance is the cornerstone for promotion of energy saving. Consequently, major items for audit concern development of a heat balance of the arc furnace.

12-7 Method and Procedure of Energy Audit

12-7-1 General

As a basis for total energy control, determination of the energy balance is important. When the energy balance sheet are properly prepared, energy efficiency of an individual plant can be obtained. This enables one to compare his plants with those of other companies and helps identify their problems.

A properly prepared balance gives the entire picture of consumption of energy and comparison with other companies. The daily management of energy can be done more easily by smaller-scaled measurement, or measurements that can be made by existing on-line instruments may be enough.

The measurement of energy flow of an entire minimill plant is very difficult, and a great deal of work is required. Even measurement done only once or twice requires a project organization: many pieces of equipment and many experts, to be mobilized under well-planned preparation.

Generally, input energy flows are not very difficult to measure but output flows are. Even when they are measured, accuracy cannot easily be obtained within 20 percent. Determination of a heat balance requires a great deal of work, time, and precaution for possible dangers.

(1) Premises of the Analysis

The entire minimill plant is a rather complicated system, the main equipment being the EAF (Electric Arc Furnace). Related pieces of equipment include: an LF (Ladle Furnace) and auxiliary systems (pumps, heat-exchangers, dust collectors, etc.). To determine the energy balance of the entire system is really difficult; and as matter of fact the energy balance alone is not enough to understand the state of energy consumption of the EAF; therefore, a measurement plan was developed not only for the EAF but for surrounding pieces of equipment.

The EAF alone required a great deal of preparation: equipment and personnel. IDC and the study team seriously considered and prepared for equipment and personal allocation.

The preparation IDC had to make was not limited to the measurement project and the above mentioned equipment and personnel. IDC had to do some preparation work on site, on the equipment, and other necessary work (analysis, weighing, etc.).

(2) Formulation of Detailed Plan

1) Facilities, Studied and Purpose of the Audit

(a) Facilities

Ideally, the energy balance should be determined for the entire IDC factory. As already mentioned above and as the block flow diagram of Figure 12-7 below shows, the EAF itself has many inputs and outputs and hence required very elaborate work.

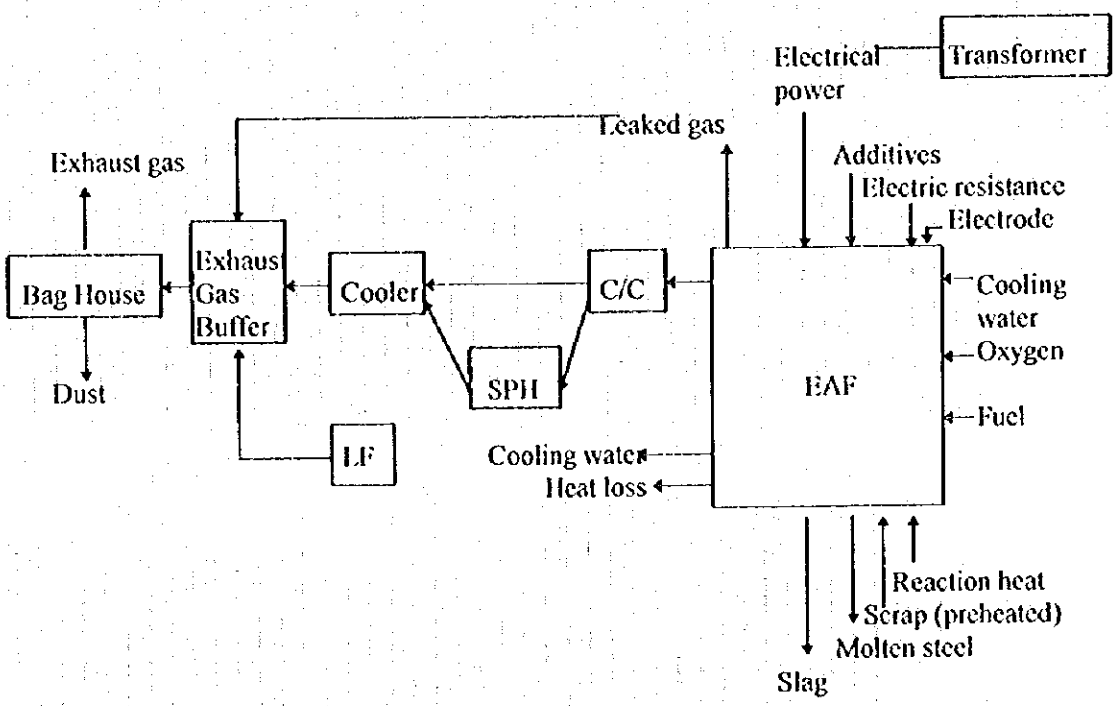

Figure 12-7 Block Diagram of Heat Inputs to and Heat Outputs from EAF

The EAF itself is a reactor: raw materials (scrap and pig iron) and additives melt at high temperatures accompanied by generation and absorption of heat.

(b) Purpose of the Audit

IDC has already attained energy efficiencies of relatively high levels. The following purposes of the audit were tailored to the conditions of IDC:

1. Confirmation of energy consumption levels and comparison with international levels
2. Management's grasp of the entire picture and basis for policy making
3. Enhancement of employees' morale by being exposed to the positive attitude of management
4. Acquisition of measuring skills throughout the whole company

12-7-2 Measuring Items, Method and Frequency

The basic measurements are limited to the EAF and its immediately neighboring equipment, as mentioned above and energy balance should be determined as clearly, simply and easily as possible for the sake of making the difficulties with measurement easier.

(1) Measurement and Estimation Items

The measurement for heat balance of the EAF was done on both inputs and outputs of energy in the following five categories:

1. Measurement by existing instruments: by IDC
   1) Consumption of electric power
   2) Consumption of raw materials (scrap and pig iron)
   3) Consumption of fuel oil and oxygen gas for each of 4 furnace burners and 1 door burner (4 furnace/1 door burners) and oxygen gas for 2 lancings
   4) Composition of molten steel
   5) Composition of slag
   6) Consumption of additives (burnt lime and carbon injection)
   7) Temperature of molten steel
   8) Flow rate of cooling water for furnace
   9) Inlet temperature of cooling water for furnace
   10) Power-on-to-power-off time
2. Measurement by newly prepared instruments: by JICA study team
   1) Temperature of scrap
   2) Temperature, CO/CO_2, and O_2 of the exhaust gas at C/C inlet
   3) Temperature, static pressure, flow rate, CO/CO_2, and O_2 of the exhaust gas at C/C

inlet

4) Outlet temperature of cooling water for furnace
5) Temperature of the roof, shell and bottom of furnace
6) Surrounding conditions

3. Analysis: by IDC
   1) Calorie of fuel
   2) Composition of injected carbon
   3) Composition of additives (burnt lime and carbon injection)
   4) Composition of scrap
4. Calculation/estimation from existing data: by IDC/the study team
   1) Weight and temperature of hot heel --- estimation by experience
   2) Electrode consumption ---statistic estimation
   3) N_2 of the exhaust gas at C/C inlet and outlet ---calculation
   4) Weight of output (molten steel)---statistic estimation
   5) Weight and temperature of slag---calculation and estimation
   6) Surface area of the roof, shell and bottom of furnace---IDC data
5. Analogy: by IDC/the study team
   1) Heat loss at the secondary conductors and transformer

These works were done in close cooperation between IDC and the study team.

(2) Measuring Methods

The original basic plan was proposed by the study team. Through repeated discussions and cooperation between IDC and the study team, the plan was modified and finalized to fit the actual situations. The proposed methods for measurement and analysis were based on NKK's experience which is commensurate with JIS (the Japanese Industrial Standards) including the processing of data after the measurement.

The plan for analysis and measurement for energy audit is summarized in Table 12-11. Figures 12-8 and 12-9 are the flow diagram around EAF and layout around EAF, respectively.

The measurements were done in the following method.

1. Continuous measurement
   1) Consumption of electric power
   2) Temperature, CO/CO_2 and O_2 of exhaust gas at C/C inlet

3) Temperature, static pressure, flow rate, CO/CO_2 and O_2 of exhaust gas at C/C outlet

4) Outlet temperature of cooling water for furnace

5) Temperature of shell and bottom of furnace

2. Total amount/integration

1) Consumption of raw materials (scrap and pig iron)

2) Consumption of fuel oil and oxygen gas for each of 4 furnace /1 door burners and oxygen 2 lancings oxygen gas for two lances

3) Consumption of additives (burnt lime and carbon injection)

3. Instantaneous value

1) Temperature of molten steel

2) Flow rate of cooling water for furnace

3) Inlet temperature of cooling water for furnace

4) Power-on-to-power-off time

5) Temperature of raw materials (scrap and pig iron)

6) Surrounding conditions

4. Analysis values

1) Composition of molten steel

2) Composition of slag

3) Composition of additives (burnt lime and carbon injection)

4) Composition of scrap and pig iron

5) Temperature of roof of EAF

6) Calorie of fuel oil

(3) Measuring Manual of Exhaust Gas, Temperature of Cooling Water and Temperature of Furnace Body

Details are shown in Appendix-1.

Table 12-11 Plan of Analysis and Measurement for Energy Audit (IDC) 1/3

Major Items of Energy Audit	Methods of Analysis and Measurement: Subject Items and points	Measurement or Estimate	Equipment of Analysis and Measurement: Required Equipment	Factory	EIE	JICA	Local Labo	Additional	Personnel Allocation: JICA	EIE	Factory	Remarks: Measuring Interval	Measuring Points
Electric Arc Furnace	**(Heat input)**												
	1. O_2, for two lances										A		
	1) Time (hr-min)	M	Clock	x								Start & Finish	Control room
	2) Consumption (Nm^3)	M	Integrator	x								Integration	Control room
	2. O_2, for each of 4 furnaces/1 door burners										B		
	1) Time (hr-min)	M	Clock	x								Start & Finish	Control room
	2) Consumption (Nm^3)	M	Integrator	x								Integration	Control room
	3. Oil, for each of 4 furnaces/1 door burners										B		
	1) Time (hr-min)												
	2) Consumption (kg)	M	Clock	x								Start & Finish	Control room
	3) Calorie (kcal)	M	Integrator	x								Integration	Control room
		E	(Standard)	-								Heat	-
	4. Carbon injection										A		
	1) Time (hr-min)	M	Clock	x								Start & Finish	Control room
	2) Consumption (kg)	M	(Calculation)	x								Heat	-
	3) Composition (%)	E	(Standard)	-								-	
	5. Additives, each										A		
	1) Time (hr-min)	M	Clock	x								Start & Finnish	Control room
	2) Consumption (kg)	M	Weigher	x								Heat	Heat report
	3) Composition (%)	E	(Standard)	-								Heat	-
	6. Scrap (Scrap bucket)										C		
	1) Consumption (kg)	M	Weigher	x		-					-	Each charge	Heat report
	2) Composition (%)	E	(Standard)	x		-					-	-	-
	3) Temperature (°C)	M	Thermocouple	-		x						Before charge	Scrap bucket
	7. Hot heel												
	1) Weight (kg)	E	(Estimation)									-	-
	2) Composition (%)	M	Analyzer	x								Heat	Heat report
	3) Temperature (°C)	E	(Estimation)									-	-
	8. Electric power										E		
	1) Time (hr-min)	M	Clock	x								Start & Finish	Control room
	1) Consumption (kWh)	M	kWh meter	x								Every 1 min. & integration	Control room
	9. Electrode												
	1) Consumption (kg)	E	(Standard)	-								Heat	-
	10. Slag												
	1) Weight (t/heat)	E	(Calculation)	-								Heat	Heat record
	2) Composition (%)	M	Analyzer	x								Champion heats	heat record

Table 12-11 Detailed Plan of Analysis and Measurement for Energy Audit (IDC) 2/3

Major Items of Energy Audit	Methods of Analysis and Measurement											Remarks	
	Subject Items and points	Measurement or Estimate	Equipment of Analysis and Measurement						Personnel Allocation				
			Required Equipment	Factory	EIE	JICA	Local Labo	Additional	JICA	EIE	Factory	Measuring Interval	Measuring Points
Electric Arc Furnace	**(Heat output)**												
	1. Exhaust gas, C/C inlet								A.B,	A,B,C	D		
	1) Time (hr-min)	M	Automatic meter			x			C			Continuously	C/C inlet
	2) Temperature (°C)	M	Thermocouple			x						Continuously	C/C inlet
	3) CO/CO_2 in gas (%)	M	Automatic meter			x						Continuously	C/C inlet
	4) O_2 in gas (%)	M	Automatic meter			x						Continuously	C/C inlet
	5) N_2 in gas (%)	E	(Calculation)			-						Continuously	C/C inlet
	2. Exhaust gas, C/C outlet								A.B.C	A.B.C.	D		
	1) Time (hr-min)	M	Automatic meter			x						Continuously	C/Coutlet
	2) Temperature (°C)	M	Thrmocouple			x						Continuously	C/Coutlet
	3) Static pressure (mmH_2O)	M	Digital manometer			x						Continuously	C/Coutlet
	4) Flow rate (Nm^3/min)	M	Pitot' tube			x						Continuously	C/Coutlet
	5) CO/CO_2 in gas (%)	M	Automatic meter			x						Continuously	C/Coutlet
	6) O_2 in gas (%)	M	Automatic meter			x						Continuously	C/Coutlet
	7) N_2 in gas (%)	E	(Calculation)			-						Continuously	C/Coutlet
	3. Cooling water								C		F		
	1) Time (hr-min)	M	Clock	x		-						One time a heat	Control room
	2) Flow rate (m^3/min)	M	Magnetic flow meter	x		-						One time a heat	Control room
	3) Temperature, inlet (°C)	M	Thermocouple	x		-						One time a heat	Inlet
	4) Temperature, outlet (°C)	E	Thermometer	-		x						Continuously	Outlet
	4. Furnace body								D				
	1) Time (hr-min)	M	Clock	-		x						Continuously	Heat report
	2) Temperature of 12 points of wall (°C)	M	Thermocouple	-		x						Continuously	Heat report
	3) Temperature of 4 points of bottom (°C)	M	Thermocouple	-		x						Continuously	Heat report
	4) Temperature of roof (°C)	E	(Standard)	-		x						One time during test	-
	5. Molten steel including hot heel												
	1) Temperature (°C)	M	Thermocouple	x								Heat	Heat report
	2) Weight (kg)	E	(Calculation)	-								Heat	Heat report
	3) Composition (%)	M	Analyzer	x								Heat	-
	6. Slag												
	1) Temperature (°C)	E	(Estimation)	-		-						Heat	Heat report
	2) Weight (kg)	E	(Calculation)	-		-						Heat	Heat report

Table 12-11 Detailed Plan of Analysis and Measurement for Energy Audit (IDC) 3/3

Major Items of Energy Audit	Methods of Analysis and Measurement: Subject Items and points	Measurement or Estimate	Equipment of Analysis and Measurement: Required Equipment	Factory	EIE	JICA	Local Lab	Additional	Personnel Allocation: JICA	EIE	Factory	Remarks: Measuring Interval	Measuring Points
Electric Arc Furnace	**(Others)**												
	1. Operation results								E	D	G		
	2. Surrounding condition								D				
	1) Weather					x							
	2) Atmospheric pressure (hpa)					x						Start of heat operation	Around EAF
	3) Outdoor temperature (°C)					x						Start of heat operation	Outside
	4) Indoor temperature (°C)					x						Start of heat operation	Around EAF
	5) Humidity (%)					x						Start of heat operation	Around EAF

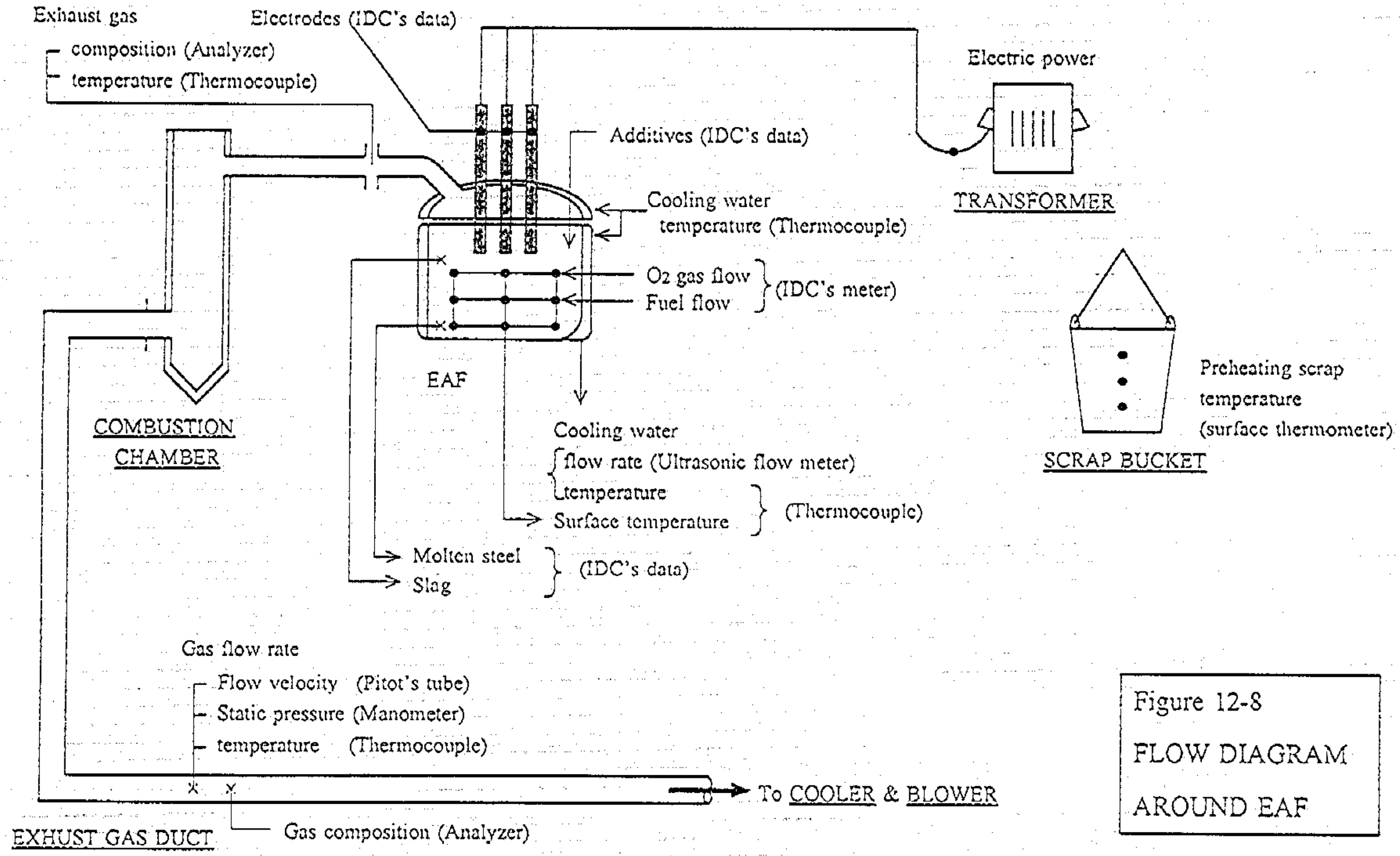

Figure 12-8
FLOW DIAGRAM
AROUND EAF

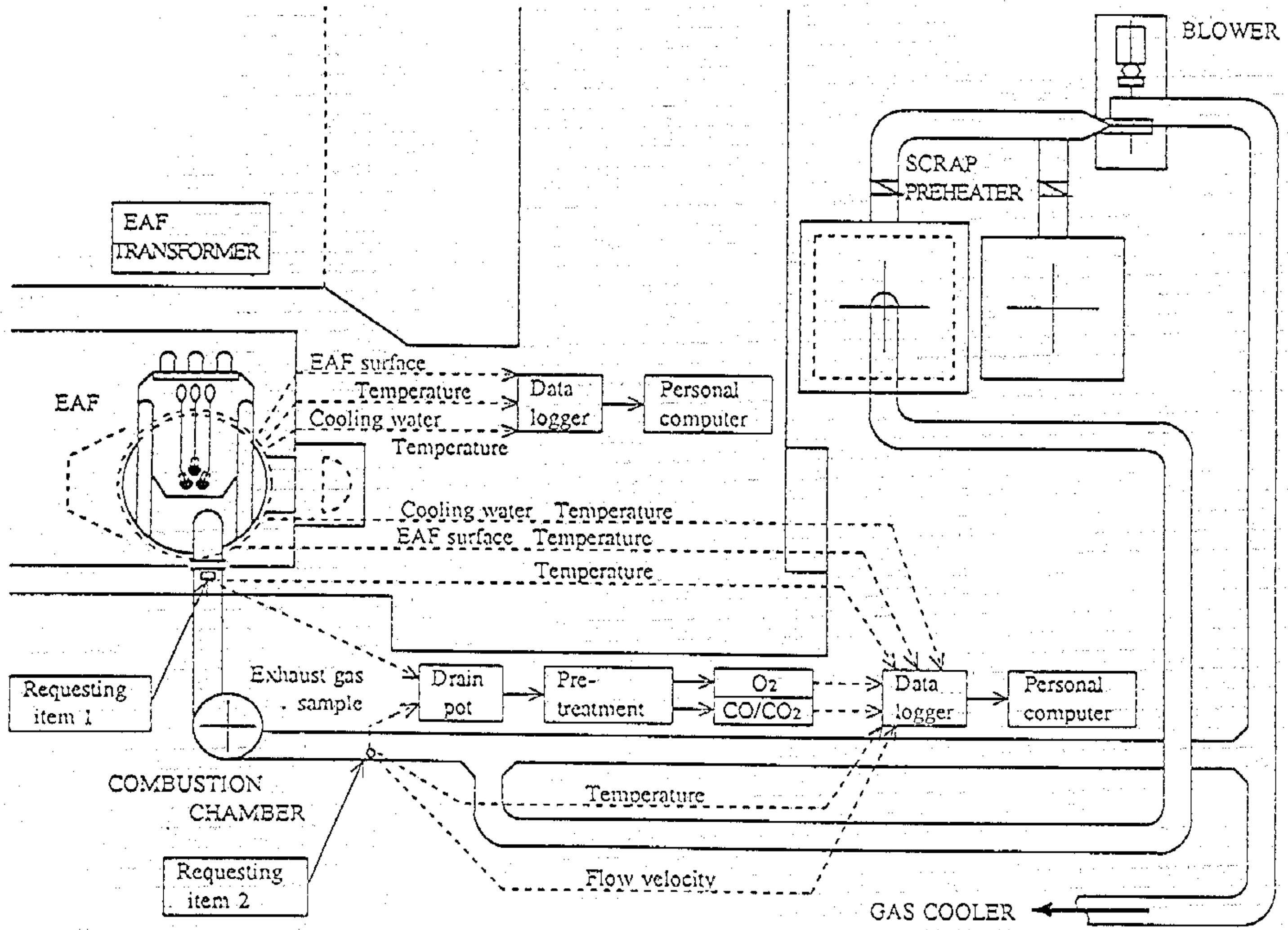

Figure 12-9
LAYOUT
AROUND EAF

(3) Measuring Frequency

1. 3 days including trial measurement 1
2. 1 heat of trial measurement and 5 heats for official measurement a day (measuring time of one heat: 1 hr), Total 11 heats
3. Total 11 heats

12-7-3 Measuring Equipment

1. Study team: mainly energy outputs with the newly prepared instruments.
2. IDC: mainly energy inputs with the existing instruments.

Table 12-12 shows additional items, numbers and descriptions of the equipment brought by the study team. The measurements by these pieces of equipment were carried out by the study team, while measurements by existing equipment were all carried out by IDC.

Table 12-12 Equipment List of the Study Team

	ITEM	DESCRIPTION
a-1)	CO/CO_2 analyzer 1 set	To measure CO and CO_2 contents of the exhaust gas at C/C inlet
a-2)	CO/CO_2 analyzer 1 set	To measure CO and CO_2 contents of the exhaust gas at C/C outlet
b-1)	O_2 analyzer 1 set	To measure O_2 content of the exhaust gas at C/C inlet
b-2)	O_2 analyzer 1 set	To measure O_2 content of the exhaust gas at C/C outlet
c)	Pretreatment unit (filter, drain pot, cooler) 1 set	To remove dusts and moisture in the exhaust gas
d-1)	Data logger 2 sets	To input into the personal computer the output data (analog signals) from the measuring devices after conversion into digital signals
d-2)	Data logger 1 set	Stand-by
e-1)	Personal computer 2 sets	To record and exhibit on the monitoring screen the output data after being converted to the digital signals by the data logger

e-2)	Personal computer 1 set	Stand-by. To be used in case of trouble of one of e-1). Actually this computer was used.
f-1)	Thermocouple PR type (JIS type R) 4 sets	To measure the temperature of the exhaust gas at the C/C inlet
f-2)	Thermocouple CA type (JIS type K) 24 sets: 1 set for outlet, 16 sets for furnace, 7 sets for spare	To measure the temperature of the exhaust gas at the C/C outlet and temperature of the furnace shell and bottom
f-3)	Thermocouple CC type (JIS type T) 10 sets (including 4 sets of spare)	To measure the temperature of the cooling water for the furnace
g-1)	Cable (100 m) for thermocouple for CA type	To connect the thermocouple to the data logger
g-2)	Cable (1,000 m) for thermocouple for CC type	To connect the thermocouple to the data logger
g-3)	Cable (300 m) for thermocouple for CA type	To connect the thermocouple to the data logger
h)	Ultrasonic flow meter 1 set	To measure the flow rate of cooling water for the furnace. Not used. IDC's instrument was used.
i)	Gas sampling unit 4 pieces	Sampler for the exhaust gas at C/C inlet. Water cooled. Stainless-steel, for C/C outlet.
j-1)	Digital manometer 2 sets	To measure the dynamic and static pressure of the exhaust gas for measurement of the flow rate at the C/C outlet
j-2)	Digital manometer 2 sets	Stand-by
k)	Pitot' tube 4 sets	Used for measurement of the flow rate of the exhaust gas at the C/C outlet
l)	Surface thermometer 2 sets	To measure the surface temperature of the scrap bucket for scrap temperature
m)	Printer 1 set	To print out the results of measurement
n-1)	Transformer 3 sets	Step down transformer (200 V to 100V) and stabilizer for instruments
n-2)	Transformer 1 set	Stand-by
o)	Pyrometer (Thermometer) 2 sets	To measure the roof surface temperature and for back-up use for measurement of surface temperature of the furnace shell and bottom.

		One is for temperatures higher than 800°C and the other is for temperatures lower than 500 °C
p) Equipment for moisture	1 set	To measure moisture in the exhaust gas.

12-8 Measurement Execution Procedure

12-8-1 Site Survey

(1) General

In order to plan measuring methods in detail, a preparatory site survey was done before the field survey (measuring for heat balance of Electric Arc Furnace (EAF) in IDC). This site survey was done by two experts. Their activities included explanation and discussions with IDC on the plant operation, site conditions, IDC's assistance to the measurement, and measuring methods.

Site survey was carried out by the measuring experts of the study team on the investigation for :

1. Proper locations for installation of instruments and protection shelter,
2. Utility supply for field instruments (electric wiring and water supply)
3. Existing on-line instruments (kinds and location)

(2) Surveyors

This preparatory field survey was done by the following two experts.

Mr. Isamu Kawakami (Process D, Iron and Steel)

Mr. Tokuyoshi Kawai (Measurement, Iron and Steel)

(3) Schedule of Site Survey

1) Overall Schedule

July 8th 1996	Narita to Frankfurt
9th	Frankfurt to Ankara
10th	Visit to the JICA office and the EIE office
11th	Ankara to Izmir
	Visit to IDC
12th	Visit to IDC

13th Izmir to Frankfurt

14th to Narita

2) **Schedule at IDC**

Time	09	10	11	12	13	14	15	16	17
July 11th					Meeting (13–16)			Site check (16–17)	
June 12th	Planning (09–10)	Site check (10–12)			Discussion and confirmation (13–16)				

(4) **Site Check**

1) **Location of Measuring Points**

1. Elbow (Combustion Chamber (C/C) inlet): Fitting point of sampling probe
   Approach to the fitting point
   Area for preparation and maintenance for sampling probe
   Feeding of cooling water for probe
   Outlet of cooling water for probe
2. Duct (C/C outlet): Probe inserting hole
   Approach to measuring point for maintenance work
3. EAF cooling water: Measuring points
   Approach to measuring points
4. EAF wall and bottom: Fitting thermocouples
   Approach to fitting points
5. Scrap bucket: Approach to bucket with hand-carried thermometers
6. Measuring instruments: Space for 2 sets for exhaust gas and EAF cooling water
7. Others: Operation room

2) **Utility on Site**

1. Electric source: 2-3 points for instruments, 200 V, 20-30 A
2. Cooling water: For sampling probe, 3/4" diameter
3. Extension bar ; For thermometer for measuring bucket temperature, 2-3 meters
4. Others: If necessary

3) Modifications for Measurement

1. Rag plate: Welding a rag plate of 200 x 200 x 10 thickness to sliding duct for U-bolt to fit sampling probe
2. Thermocouple: Welding thermocouples to the furnace shell and bottom
3. Water tap: Installation of a water tap for cooling water of sampling probe
4. Stage: Preparation for measurement and maintenance
5. Others: Prepared as necessary

4) Data Collection from Plant Instruments

1. Control room: Timer
   Watt meter
   Weighing of scrap
   Weighing of molten steel, etc.
2. Inlet energy: O_2 meter
   Fuel meter, etc.
3. Others: As necessary

12-8-2 Execution of Measurements

(1) Schedule of Measurements

The schedule of the measurements is shown below.

	Aug. 12 th	13 th	14 th	15 th	16 th	17 th	18 th	19 th	
Instruments Preparation	—								
Instruments Installation	—								
Adjustment / Rehearsal		—							
Measurement			—	—					
Instruments Removal					—				
Data Processing						—	—	—	—

1) **Aug. 12th**

1. Meeting with EIE and IDC from 8:30 to 9:00
2. Unpacking of a wooden equipment and instruments box from 9:00 to 12:30
3. Welding of a rag plate to the sliding duct from 13:30 to 15:00
4. Fitting of thermocouples to the pipe for measuring outlet temperature of cooling water for furnace from 13:30 to 15.00
5. Welding of thermocouples to the furnace from 15.00 to 21:00
6. Preparation of instruments in AM and PM
7. Some work is not finished

This work was done during the furnace brick work shutdown time.

2) **Aug. 13th**

1. Meeting with EIE and IDC from 8:30 to 9:00.
2. Some work of connection not completed in Aug.12th in AM.
3. Adjustment of instruments in AM.
4. Trial measurement of one heat in PM.

3) **Aug. 14th**

1. Meeting with EIE and IDC from 8:30 to 9.00.
2. Official measurement of five heats.

4) **Aug. 15th**

Same as Aug. 14th

5) **Aug. 16th**

1. Removing of instruments and connections in AM.
2. Packing instruments in the wooden box.

12-8-3 Preparatory Work

Preparatory work was carried out on Aug. 12 and 13 is as follows:

(1) Welding of a Rag Plate to the Sliding Duct (C/C inlet)

A rag plate supplied by the JICA Study Team was welded to the end of the sliding duct of EAF

(C/C inlet, combustion chamber inlet) on August 12 in the presence of the JICA Study Team.

Note: The rag plate with U-bolts is to hold a sampling probe for analysis of the exhaust gas and a thermocouple for measuring the exhaust gas temperature.

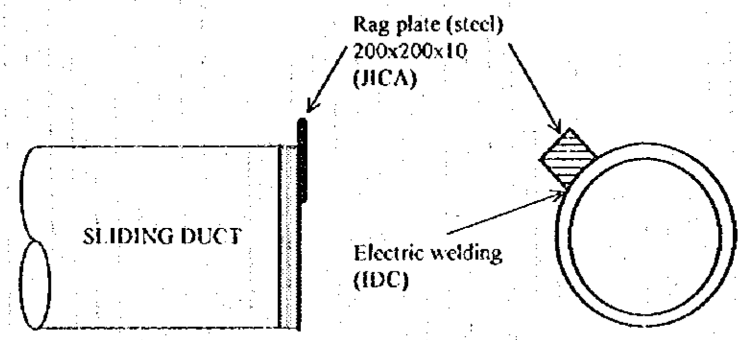

Figure 12-10 Welding of the Rag Plate

(2) Opening the Hole (C/C outlet)

Before August 12, a hole of 50 x 60 mm was opened at the tubular cooling duct behind C/C (combustion chamber).

Note: The 50 x 60 mm hole is for measuring the flow rate, composition and temperature of the exhaust gas.

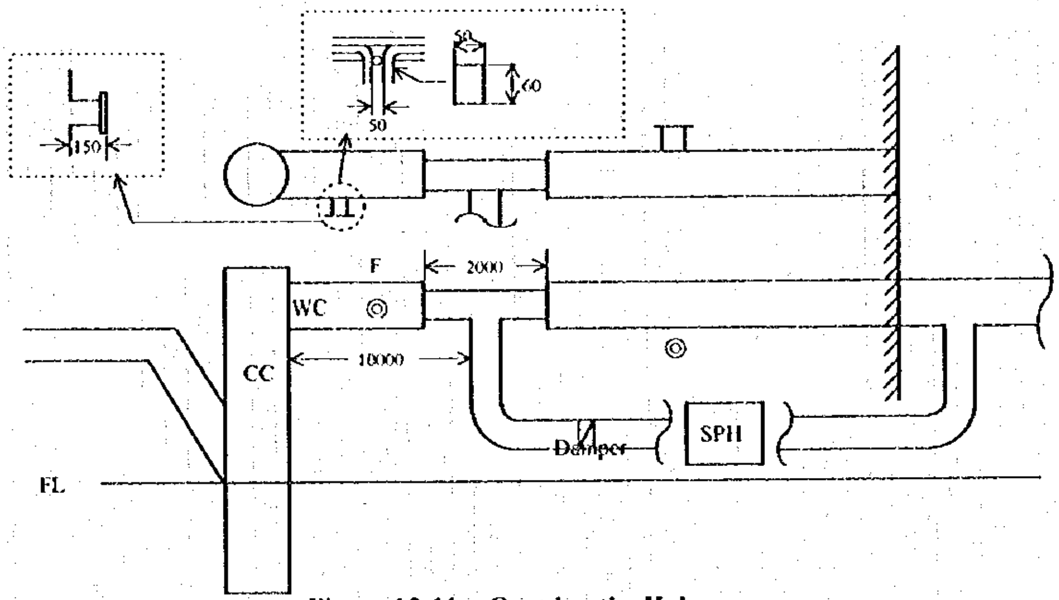

Figure 12-11 Opening the Hole

(3) Welding Thermocouples to the Furnace Shell and Bottom

Steel plates containing thermocouple supplied by the JICA study team were welded at the furnace shell and bottom on August 12 in the presence of the JICA study team.

Shell: 12 points on the cooling pipe of center of the cooling panel. 2 points for each panel of Nos. 2, 4, 6, 8, 10 and 12

Bottom: 4 points on the bottom equally spaced

Note: Thermocouples are to measure the furnace temperature.

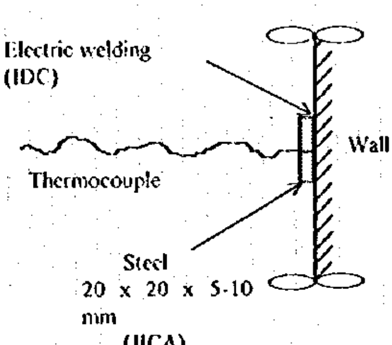

Figure 12-12 Welding Thermocouples to the Furnace Shell and Bottom

(4) Water Supply

Water tap device and basin for return water was installed near the C/C before August 12.

Note: Water is used for cooling the sampling probe at the C/C inlet.

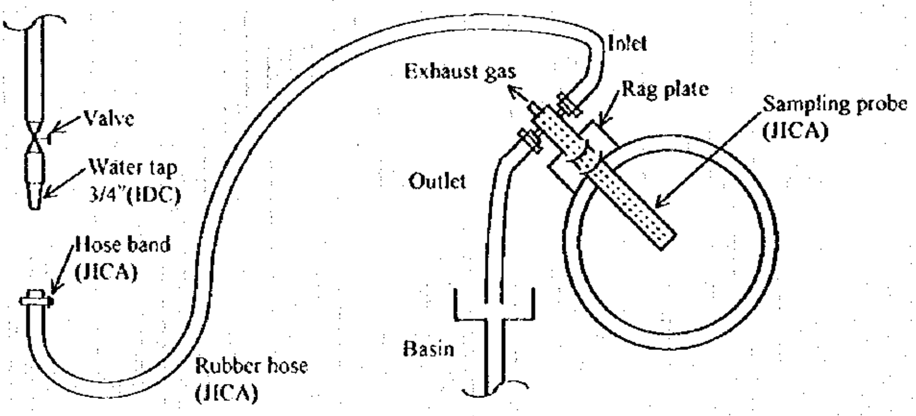

Figure 12-13 Water Supply

(5) Installation of the Holder for Cooling Water Outlet Temperature

A pipe was installed at each return water piping system before August 12.

Note: The pipe held the thermocouple to measure the furnace cooling water outlet temperature.

1: Return water piping system for the EBT
2: Return water piping system for the elbow
3: Return water piping system for the roof
4: Return water piping system for the shell-1
5: Return water piping system for the shell-2

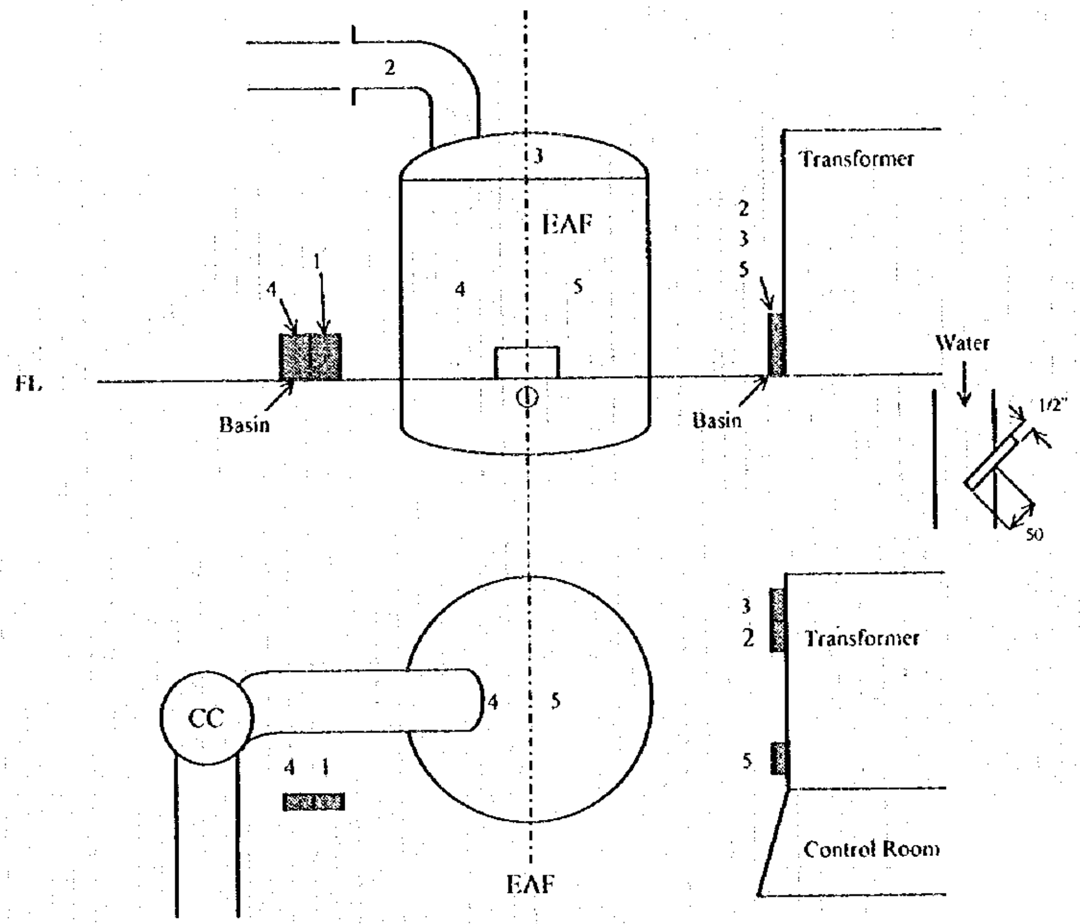

Figure 12-14 Installation of the Holder

12-9 Results of Measurement and Analysis

Measurement for the EAF heat balance was executed on following 11 heats including the trial heat.

Aug. 13	Heat No. 965729	trial
Aug. 14	Heat No. 965749	not completed in measurement of exhaust gas
Aug. 14	Heat No. 965750	not completed in measurement of exhaust gas
Aug. 14	Heat No. 965751	selected for analysis

Aug. 14	Heat No. 965752	selected for analysis
Aug. 14	Heat No. 965753	selected for analysis
Aug. 15	Heat No. 965773	
Aug. 15	Heat No. 965774	not completed in measurement of exhaust gas
Aug. 15	Heat No. 965775	not completed in measurement of exhaust gas
Aug. 15	Heat No. 965776	
Aug. 15	Heat No. 965777	

According to the procedure of JIS (the Japanese Industrial Standards), consecutive three heats of Heat No. 965751, 965752 and 965753 are selected. The operation results, measurement results, calculation of heat input and heat output and heat balance sheets are shown for three (3) selected heats in the following sections.
The study team studied and analyzed the selected three (3) heats referring to the other heats measured and observed.

12-9-1 Profile of Facilities

Table 12-13 shows profile of facilities on which measurement was executed.

Table 12-13 Profile of the Electric Arc Furnace

Name of company		IDC (IZMIR DEMIR CELIK SANAYI A. S.)
Address		Foca Celik Fabrikasi 35807 Aliaga, IZMIR, TURKEY
Furnace manufacturer		NKK Corporation (Japan)
Type	Type of furnace	AC arc furnace
	Charging method	Top charge
	Tapping method	EBT system
	Other facilities (Bottom stirrer, Bottom bubbling, Water sprayed electrode, Scrap preheater, etc.)	Water sprayed electrode, Scrap preheater
	Nominal capacity (ton)	75
Molten steel	Bath diameter (mm)	4,475

	Bath area (m^2)	7.0
	Bath depth (mm)	1,343
	Distance between sill level and roof (mm)	2,192
Roof	Thickness (mm)	
	Radius (mm)	2,900
	Diameter of electrode hole (mm)	600
	Pitch circle diameter (mm)	1,300
	Proportion of water cooling area (%)	
Shell	Inside diameter (mm)	5,215
	Thickness (mm)	Water cooled tubular panel
	Height (mm)	1,900
	Height from bottom to roof (mm)	4,300
	Proportion of water cooling area (%)	100
Hearth	Diameter (mm)	
	Thickness (mm)	725
	Height of bank (mm)	332
Working door	Width (mm)	
	Height (mm)	
Tapping hole (EBT)	Diameter (mm)	159
	Depth (mm)	800
Transformer	Capacity (MVA)	72
	Primary voltage (kV)	34.5
	Secondary voltage (V)	900
	Connection	Open delta
Reactor	Capacity (kVA)	12,000
	Reactance (Ohm)	
Electrode	Diameter (mm)	508
Oxygen injection	Type and number	Manipulator
	Capacity (Nm^3/hr)	1 1/4 inches x 2 lancings (3,000 Nm^3/hr, lance)
Burner	Type, number and capacity	5 furnace oxy-fuel burners oil: 200 liter/hr, unit O_2: 500 Nm^3/hr, unit 1 door oxy-fuel burner oil: 300 liter/hr, unit

		O_2: 700 Nm^3/hr, unit
	Kind of fuel and capacity (kg/hr)	Heavy fuel oil NO. 6
Carbon injection	Capacity and number (kg/hr)	1 set 35 kg/min

12-9-2 Long-run Operation Results

Table 12-14 shows long-run operation results of each five (5) heats of the same grade of steel which were operated before and after sampled three (3) heats for heat balance calculation.

Table 12-14 Summary of Long-Run Operation Results of Before and After Heat Measured

Date	Aug. 13	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Average
Heat Mo.	965746	965747	965748	965749	965750	965754	965755	965756	965757	965758	
1. Charged raw material (excluding hot heel)	85.800	85.700	85.080	85.700	86.000	85.600	85.440	86.020	85.680	85.620	85.660
1.1. 1st bucket (t) Scrap	43.300	44.300	43.080	41.200	42.400	41.300	40.100	41.200	41.100	40.260	41.820
1.2. 2nd bucket (t)	27.300	26.200	26.500	28.400	32.400	31.100	29.200	27.660	27.320	27.300	28.340
Scrap	21.000	23.000	22.200	24.000	29.000	28.000	25.500	7.000	27.300	27.300	23.430
Pig iron	3.300	3.200	4.300	4.400	3.400	3.100	3.700	3.360	0.000	3.000	4.000
1.3. 3rd bucket (t) Scrap	15.200	15.200	15.500	16.100	11.200	13.200	16.140	17.160	17.260	18.060	15.500
2. Output (Production) (t)	77.220	77.130	76.570	77.130	77.400	77.040	76.900	77.420	77.100	77.060	77.100
2.1. Good billet (t)	76.620	76.530	75.980	76.530	76.800	76.440	76.300	76.820	76.510	76.460	76.500
2.2. Crop end, skull (t)	0.600	0.600	0.590	0.600	0.600	0.600	0.600	0.600	0.590	0.600	0.600
3. Steel yield (%)											
3.1. Molten steel yield	90.0										
3.2. Good billet yield	89.3										
4. Operation time (min.)											
4.1. Tap-to-tap time	52	61	56	60	57	55	56	49	54	54	55
4.2. Power on-to-power off time	47	50	48	43	46	45	46	44	48	45	46
5. Consumption											
5.1. Electric power (kWh/t-output)	378	389	364	375	353	360	367	355	372	382	370
5.2. Fuel oil (kg/t-output)	4.7	4.9	4.2	6.1	6.5	4.8	0.0	4.1	4.4	4.5	4.9
5.3. Oxygen gas (Nm^3/t-output)	32.2	30.9	30.7	33.0	34.3	35.0	29.1	26.5	28.0	29.0	30.9
Burner	17.1	16.0	14.8	18.2	19.5	18.6	15.6	15.6	15.7	16.4	16.8
Lancing	15.1	14.9	15.9	14.8	16.8	16.4	13.5	10.9	12.3	12.6	14.3
5.4. Burnt lime (kg/heat)	21.4	23.1	23.9	33.7	23.2	23.0	24.1	22.9	23.5	23.6	24.2
5.5. Carbon injection (kg/heat)	8.5	8.4	8.8	10.0	8.6	9.7	9.1	9.7	12.6	13.5	9.9
6. Composition and temperature of molten steel before tapping											
6.1. C (%)	0.10	0.04	0.05	0.30	0.09	0.16	0.11	0.10	0.06	0.13	0.11
6.2. Si (%)	0.01	0.02	0.02	0.03	0.02	0.05	0.01	0.02	0.01	0.01	0.02
6.3. Mn (%)	0.05	0.03	0.04	0.07	0.04	0.03	0.04	0.06	0.05	0.05	0.05

6.4. P (%)	0.014	0.030	0.018	0.033	0.020	0.026	0.010	0.013	0.011	0.024	0.020
6.5. S (%)	0.065	0.074	0.076	0.066	0.058	0.078	0.070	0.061	0.048	0.054	0.065
6.6. Cr (%)	0.07	0.04	0.05	0.09	0.05	0.05	0.04	0.06	0.04	0.09	0.06
6.6. Temperature (deg. C)	1620	1612	1622	1616	1630	1646	1603	1636	1601	1620	1621
7. Weight of hot heel (t)	10										
8. Composition of billet (%)											0
8.1. C (%)	0.24	0.19	0.18	0.18	0.20	0.20	0.23	0.19	0.21	0.21	0.20
8.2. Si (%)	0.23	0.19	0.17	0.18	0.19	0.17	0.17	0.17	0.17	0.17	0.16
8.3. Mn (%)	0.85	0.86	0.87	0.86	0.86	0.87	0.86	0.86	0.86	0.84	0.86
8.4. P (%)	0.038	0.043	0.036	0.040	0.037	0.026	0.018	0.024	0.024	0.030	0.032
8.5. S (%)	0.039	0.052	0.048	0.047	0.045	0.044	0.040	0.037	0.039	0.039	0.043
8.6. Cu	0.46	0.51	0.52	0.47	0.45	0.45	0.39	0.41	0.41	0.36	0.44
8.7. Ni	0.14	0.13	0.12	0.12	0.13	0.15	0.13	0.16	0.13	0.14	0.14
8.8. Cr	0.13	0.11	0.11	0.12	0.10	0.08	0.07	0.10	0.10	0.10	0.10
8.9. Mo	0.020	0.018	0.016	0.015	0.016	0.019	0.016	0.023	0.017	0.018	0.02
8.10. Sn	0.019	0.021	0.024	0.019	0.019	0.021	0.017	0.016	0.017	0.015	0.02
8.11 Al	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003

Note: 1) Heat No. 965757 is excluded for average of pig iron.

2) Heat No. 965755 is excluded for average of fuel oil.

12-9-3 Results of Measurement and Heat Balance

(1) Conceced Personnel

Personnel are listed in Table 12-15.

Table 12-15 Personnel Involved in Measurement

Date	August 14, 1996		
Heat No.	965751, 965752, 965753		
Company	Study team	EIE	IDC
Staff	- I. Kawakami - H. Tokano	- Hediye Yillikci - Bora Omurtay - Mehmet Sezer - Birgul Duman	- Suleyman Eldem - Necati Unsal
Measuring person			
Flow rate, temperature and composition of exhaust gas	- T. Kawai - S. Kinoshita	- (Bora Omurtay) - (Birgul Duman)	- (Mehmet Yalcin)
Outlet temperature of cooling water for furnace	- N. Honda	- (Mehmet Sezer)	
Electric power			- Sibel Ozkan
Oxygen gas by lancings			- Uguri Egeli
Carbon injection			
Burnt lime			
Oxygen gas and fuel oil by 4 furnace/1 door burners			- Hikmet Yuzuak
Flow rate and inlet temperature of cooling water for furnace			- Talip Bostanci
Temperature of scrap bucket	- (H. Tokano)		- Duzgun Elitas
Surrounding conditions	- H. Tokano		

Note: Bracket means co-working with specialists.

(2) Summary of Results for Measured Heats

Table 12-16 Summary of Operation Results for Three (3) Measured Heats

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
1. Charged raw material (excluding hot heel) (t)	85.400	87.400	86.000
1.1. 1st bucket (t) Scrap	42.100	41.1	41.2

1.2. 2nd bucket (t)	28.200	26.100	27.400
Scrap	24.500	22.500	24.000
Pig iron	3.700	3.600	3.400
1.3. 3rd bucket (t) Scrap	15.100	20.200	17.400
2. Output (Production) (t)	76.860	78.660	77.400
2.1. Good billet (t)	76.260	78.050	76.800
2.2. Crop end, skull (t)	0.600	0.610	0.600
3. Steel yield (%)			
3.1. Molten steel yield		90.3	
3.2. Good billet yield		89.3	
4. Operation time (min.)			
4.1. Tap-to-tap time	53	53	70
4.2. Power-on-to-power-off time	43	43	57
5. Unit consumption			
5.1. Electric power (kWh/output)	363	360	379
5.2. Fuel oil (kg/t-output)	6.3	5.9	7.2
5.3. Oxygen gas (Nm^3/t-output)	33.7	35.1	32.5
Burner	20.3	16.1	18.0
Lancing	13.4	19.0	14.5
5.4. Burnt lime (kg/t-output)	24.4	22.9	28.0
5.5. Carbon injection (kg/t-output)	11.4	7.6	10.4
6. Composition and temperature of molten steel before tapping			
6.1. C (%)	0.05	0.03	0.05
6.2. Si (%)	0.01	0.01	0.01
6.3. Mn (%)	0.04	0.04	0.05
6.4. P (%)	0.026	0.026	0.025
6.5. S (%)	0.069	0.064	0.700
6.6. Cr (%)	0.06	0.07	0.06
6.6. Temperature (°C)	1641	1673	1624
7. Weight of hot heel (t)		10	
8. Composition of billet (%)			
8.1. C (%)	0.18	0.20	0.20
8.2. Si (%)	0.18	0.17	0.18
8.3. Mn (%)	0.87	0.91	0.92
8.4. P (%)	0.040	0.027	0.028
8.5. S (%)	0.043	0.055	0.048
8.6. Cu (%)	0.43	0.43	0.45
8.7. Ni (%)	0.13	0.12	0.15
8.8. Cr (%)	0.13	0.08	0.09
8.9. Mo (%)	0.018	0.017	0.017
8.10. Sn (%)	0.018	0.019	0.020
8.11 Al (%)	0.003	0.003	0.003

(3) **Results of Measurments**

Results of measurement for the (3) heats are shown in Table 12-17.

Table 12-17 Results of Measurement

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
Amount of raw materials in 1st bucket (t)	42.100	41.100	41.200
Amount of scrap in 2nd bucket (t)	24.500	22.500	24.000
Amount of pig iron in 2nd bucket (t)	3.700	3.600	3.400
Amount of raw materials in 2nd bucket (t)	28.200	26.100	27.400
Amount of raw materials in 3rd bucket (t)	15.100	20.200	17.400
Charged raw material (excluding hot heel) (t)	85.400	87.400	86.000
Amount of scrap (t)	81.700	83.800	82.600
Amount of pig iron (t)	3.700	3.600	3.400
Output (excluding hot heel) (t)	76.860	78.660	77.400
Consumption of electric power (kWh)	27,900	28,300	29,300
Unit consumption of electric power, w_1 (kWh/t-output)	363	360	379
Hot heel of raw material (t)	10	10	10
Unit weight of hot heel of raw material, m_2 (kg/t-output)	130	127	129
Temperature of hot heel, m_2 (°C)	1550	1550	1550
Unit consumption of scrap, (kg/t-output)	1063	1065	1067
Unit consumption of pig iron, (kg/t-output)	48	46	44
Unit consumption of raw materials, m_3 (kg/t-output)	1111	1111	1111
Temperature of top of 1st bucket (°C)	148	215	135
Temperature of middle of 1st bucket (°C)	131	232	132
Temperature of bottom of 1st bucket (°C)	53	82	82
Mean temperature of 1st bucket (°C)	111	176	116
Temperature of top of 2nd bucket (°C)	108	121	110
Temperature of middle of 2nd bucket (°C)	118	108	128
Temperature of bottom of 2nd bucket (°C)	66	82	82
Mean temperature of 2nd bucket (°C)	97	104	107
Temperature of top of 3rd bucket (°C)	-	-	-
Temperature of middle of 3rd bucket (°C)	36	39	37
Temperature of bottom of 3rd bucket (°C)	-	-	-
Mean temperature of 3rd bucket (°C)	36	39	37
Mean temperature of raw materials after SPH (°C)	93	123	97
Consumption of fuel oil at No. 1 burner (kg)	133	104	182
Consumption of fuel oil at No. 2 burner (kg)	162	107	136
Consumption of fuel oil at No. 3 burner (kg)	56	101	93
Consumption of fuel oil at No. 4 burner (kg)	112	117	124
Consumption of fuel oil at door burner (kg)	21	38	25
Consumption of fuel oil (kg)	484	467	560
Unit consumption of fuel oil, m4 (kg/t-output)	6.3	5.9	7.2

Mean CO_2 content in exhaust gas at elbow (CO_2) (%)	14.0	17.5	12.1
Mean CO content in exhaust gas at elbow (CO) (%)	7.1	3.5	1.5
C content of molten steel before tapping (%)	0.05	0.03	0.05
Si content of molten steel before tapping (%)	0.01	0.01	0.01
Mn content of molten steel before tapping (%)	0.04	0.04	0.05
P content of molten steel before tapping (%)	0.026	0.026	0.025
Cr content of molten steel before tapping (%)	0.06	0.07	0.06
Al content of molten steel before tapping (%)	0.000	0.000	0.000
CaO content of slag (%)	23.56	23.56	23.56
Consumption of burnt lime (kg)	1860	1790	2150
Amount of slag (kg)	6868	6610	7939
Unit weight of slag, m_{11} (kg/t-output)	89	84	103
FeO content of slag (FeO) (%)	9.01	9.01	9.01
Fe_2O_3 content of slag (Fe_2O_3) (%)	22.16	22.16	22.16
Consumption of carbon injection (kg)	875	595	805
Unit consumption of carbon injection (kg/t-output)	11.4	7.6	10.4
P_2O_5 content of slag (P_2O_5) (%)	0.48	0.48	0.48
SiO_2 content of slag (SiO_2) (%)	17.31	17.31	17.31
Temperature of molten steel before tapping (°C)	1641	1673	1624
Weight of hot heel of molten steel (t)	10	10	10
Unit weight of hot heel of molten steel (kg/t-output)	130	127	129
Power-on-to-power-off time (hr)	0.72	0.72	0.95
Flow rate of cooling water for roof (m^3/hr)	323	323	323
Average quantity of cooling water of roof, m14b (kg/t-output)	3026	2957	3964
Mean outlet temperature of cooling water for roof (°C)	39.0	40.5	39.1
Mean outlet temperature of cooling water for roof-1 (°C)	39.1	40.6	39.2
Mean outlet temperature of cooling water for roof-2 (°C)	38.9	40.4	39.0
Inlet temperature of cooling water for roof (°C)	34.0	34.0	35.0
Flow rate of cooling water for EBT (m^3/hr)	63	63	63
Average quantity of cooling water for EBT, m_{14c} (kg/t-output)	590	577	773
Mean outlet temperature of cooling water for EBT (°C)	36.8	37.8	36.5
Inlet temperature of cooling water for EBT (°C)	34.0	34.0	35.0
Flow rate of cooling water for elbow (m^3/hr)	117	117	117
Average quantity of cooling water for elbow, m_{14a} (kg/t-output)	1096	1071	1436
Mean outlet temperature of cooling water for elbow (°C)	43.4	45.0	42.9
Inlet temperature of cooling water for elbow (°C)	34.0	34.0	35.0
Flow rate of cooling water for shell-1 (m^3/hr)	273	273	274
Average quantity of cooling water for shell-1, m_{14d} (kg/t-output)	2557	2499	3363
Mean outlet temperature of cooling water for shell-1 (°C)	37.0	38.3	36.8
Inlet temperature of cooling water for shell-1 (°C)	34.0	34.0	35.0
Flow rate of cooling water for shell-2 (m^3/hr)	274	274	274
Average quantity of cooling water for shall-2, m_{14d} (kg/t-output)	2567	2508	3363
Mean outlet temperature of cooling water for shell-2 (°C)	36.8	38.0	36.8
Inlet temperature of cooling water for shell-2 (°C)	34.0	34.0	35.0
Indoor temperature (°C)	35.0	37.0	37.0

Surface area of roof (m^2)	40	40	40
Mean surface temperature of roof (°C)	65.0	65.0	65.0
Surface area of shell (m^2)	35	35	35
Mean surface temperature of shell (°C)	41.4	42.4	41.2
Mean surface temperature of shell-1 (°C)	39.3	40.3	39.4
Mean surface temperature of shell-2 (°C)	43.5	44.5	42.9
Surface area of furnace bottom (m^2)	34	34	34
Mean Surface temperature of furnace bottom (°C)	276.1	276.4	297.5
Heat in average flow of exhaust gas (1,000 kcal/min)	216	157	227
Consumption of limestone, m_{12} (kg/t-output)	7	7	8

Flow rate, temperature, heat content, composition of the exhaust gas at C/C inlet and outlet are shown as follows:

Figure 12-18: Heat Content and Flow Rate of Exhaust Gas at C/C-inlet, Heat No. 965751
Figure 12-19: Temperature of Exhaust Gas at C/C-inlet and outlet, Heat No. 965751
Figure 12-20: Composition of Exhaust Gas at C/C-inlet, Heat No. 965751
Figure 12-21: Composition of Exhaust Gas at C/C-outlet, Heat No. 965751
Figure 12-22: Heat Content and Flow Rate of Exhaust Gas at C/C-inlet, Heat No. 965752
Figure 12-23: Temperature of Exhaust Gas at C/C-inlet and outlet, Heat No. 965752
Figure 12-24: Composition of Exhaust Gas at C/C-inlet, Heat No. 965752
Figure 12-25: Composition of Exhaust Gas at C/C-outlet, Heat No. 965752
Figure 12-26: Heat Content and Flow Rate of Exhaust Gas at C/C-inlet, Heat No. 965753
Figure 12-27: Temperature of Exhaust Gas at C/C-inlet and outlet, Heat No. 965753
Figure 12-28: Composition of Exhaust Gas at C/C-inlet, Heat No. 965753
Figure 12-29: Composition of Exhaust Gas at C/C-outlet, Heat No. 965753

Those figures are attached to the Appendix-1.

(4) Heat Input

Heat inputs for the measured three (3) heats are calculated as shown in Table 12-18. As for calculation formulas, refer to Annex-4.

Table 12-18 Heat Input

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
(1) Heat quantity of electric power, Q_1 (1000 x kcal/t-output)	**312.2**	**309.6**	**325.9**
Ratio of heat quantity of electric power in heat input (%)	51.3	51.9	50.1

Unit consumption of electric power, w_1 (kWh/t-output)	363	360	379
(2) Potential heat of hot heel, Q_2 (1000 x kcal/t-output)	**41.8**	**40.8**	**41.5**
Percentage of potential heat of hot heel in heat input (%)	6.9	6.8	6.4
Unit weight of hot heel of raw materials, m_2 (kg/t-output)	130	127	129
Temperature of hot heel (°C)	1550	1550	1550
Heat content of hot heel, h_2 (kcal/kg)	321.5	321.5	321.5
(3) Sensible heat of raw materials, Q_3 (1000 x kcal/t-output)	**11.8**	**15.8**	**12.3**
Percentage of sensible heat of raw materials in heat input (%)	1.9	2.6	1.9
Unit consumption of raw materials, m_3 (kg/t-output)	1111	1111	1111
Mean temperature of raw materials after SPH (°C)	93	123	97
Heat content of raw materials after SPH h_{3h} (kcal/kg)	10.6	14.2	11.1
(4) Calorific power of fuel oil, Q_4 (kcal/t-output)	**63.0**	**59.0**	**72.0**
Percentage of calorific power of fuel oil in heat input (%)	10.4	9.9	11.1
Unit consumption of fuel oil, m_4 (kg/t-output)	6.3	5.9	7.2
Low heating value of fuel oil, q_4 (kcal/kg)	10000	10000	10000
(6) Oxidation heat of electrode, Q_6 (1000 x kcal/t-output)	**11.2**	**13.1**	**13.7**
Percentage of oxidation heat of electrode in heat input (%)	1.8	2.2	2.1
Unit consumption of electrode, m_6 (kg/t-output)	1.9	1.9	1.9
C content of electrode (%)	99.7	99.7	99.7
Amount of C oxidation of electrode (kg/t-output)	1.9	1.9	1.9
Oxidation heat of electrode at CO_2 formation, q_{6CO2} (kcal/kg)	7829	7829	7829
Oxidation heat of electrode at CO formation, q_{6CO} (kcal/kg)	2200	2200	2200
Mean CO_2 content in exhaust gas (CO_2) (%)	14.0	17.5	12.1
Mean CO content in exhaust gas (CO) (%)	7.1	3.5	1.5
(7) Oxidation heat of charge, Q_7 (1000 x kcal/t-output)	**103.8**	**107.4**	**113.7**
Percentage of oxidation heat of charge in heat input (%)	17.1	18.0	17.5
(7a) Oxidation heat of charged C, Q_{7a} (1000 x kcal/t-output)	**30.7**	**36.4**	**36.1**
Unit consumption of scrap (kg/t-output)	1063	1065	1067
Unit consumption of pig iron (kg/t-output)	48	46	44
C content of scrap (%)	0.35	0.35	0.35
C content of pig iron (%)	3.65	3.65	3.65
C content of molten steel before tapping (%)	0.05	0.03	0.05
Oxidation amount of charged C, m_{7a} (kg/t-output)	5.0	5.1	4.8
Heat of C oxidation at CO_2 formation, q_{7cco2} (kcal/kg)	8075	8075	8075
Heat of C oxidation at CO formation, q_{7cco} (kcal/kg)	2448	2448	2448
(7b) Oxidation heat of charged Si, Q_{7b} (1000 x kcal/t-output)	**21.2**	**21.1**	**21.0**
Si content of scrap (%)	0.23	0.23	0.23
Si content of pig iron (%)	1.05	1.05	1.05
Si content of molten steel before tapping (%)	0.01	0.01	0.01
Oxidation amount of charged Si, m_{7b} (kg/t-output)	2.85	2.83	2.82
Heat of Si, q_{7bSi} (kcal/kg)	7459	7459	7459
(7c) Oxidation heat of charged Mn, Q_{7C} (1000 x kcal/t-output)	**13.2**	**13.2**	**13.1**
Mn content of scrap (%)	0.75	0.75	0.75
Mn content of pig iron (%)	0.70	0.70	0.70
Mn content of molten steel before tapping (%)	0.04	0.04	0.05
Oxidation amount of Mn m_{7c} (kg/t-output)	7.91	7.91	7.81

Heat of Mn, q_{7cMn} (kcal/kg)	1674	1674	1674
(7d) Oxidation heat of charged P, Q_{7d} (1000 x kcal/t-output)	**3.2**	**3.2**	**3.3**
P content of scrap (%)	0.075	0.075	0.075
P content of pig iron (%)	0.040	0.040	0.040
P content of molten steel before tapping (%)	0.026	0.026	0.025
Oxidation amount of P, m_{7d} (kg/t-output)	0.56	0.56	0.57
Heat of P, q_{7dP} (kcal/kg)	5811	5811	5811
(7e) Oxidation heat of charged Cr, Q_{7e} (1000 x kcal/t-output)	**2.6**	**2.4**	**2.6**
Cr content of scrap (%)	0.150	0.150	0.150
Cr content of pig iron (%)	0.000	0.000	0.000
Cr content of molten steel before tapping (%)	0.060	0.070	0.060
Oxidation amount of Cr, m_{7e} (kg/t-output)	0.99	0.90	1.00
Heat of Cr, q_{7eCr} (kcal/kg)	2620	2620	2620
(7f) Oxidation heat of charged Al, Q_{7f} (1000 x kcal/t-output)	**1.3**	**1.3**	**1.3**
Al content of scrap (%)	0.017	0.017	0.017
Al content of pig iron (%)	0.000	0.000	0.000
Al content of molten steel before tapping (%)	-	-	-
Oxidation amount of Al, m_{7f} (kg/t-output)	0.18	0.18	0.18
Heat of Al, q_{7fAl} (kcal/kg)	7419	7419	7419
(7g) Oxidation heat of charged Fe, Q_{7g} (1000 x kcal/t-output)	**31.4**	**29.6**	**36.3**
Unit weight of slag, m_{7g} (kg/t-output)	89	84	103
Heat of Fe oxidation at FeO formation, q_{7gFeO} (kcal/kg)	1151	1151	1151
Heat of Fe oxidation at Fe_2O_3 formation, $q_{7gFe2O3}$ (kcal/kg)	1756	1756	1756
FeO content in slag, (FeO) (%)	9.01	9.01	9.01
Fe_2O_3 content in slag (Fe_2O_3) (%)	22.16	22.16	22.16
(8) Oxidation heat of carbon injection, Q_8 (1000 x kcal/t-output)	**56.4**	**43.4**	**62.0**
Percentage of oxidation heat of carbon injection (%)	9.3	7.3	9.5
Unit consumption of carbon injection (kg/t-output)	11.4	7.6	10.4
C content in carbon injection (%)	80.0	80.0	80.0
Oxidation amount of carbon injection, m_{8a} (kg/t-output)	9.1	6.1	8.3
(9) Heat of slag formation, Q_9 (1000 x kcal/t-output)	**8.2**	**7.7**	**9.5**
Percentage of heat of slag formation in heat input (%)	1.3	1.3	1.5
Heat of SiO_2 reaction at Ca_2SiO_4 formation, q_{9SiO2} (kcal/kg)	502	502	502
Heat of P_2O_5 reaction at $Ca_3P_2O_3$ formation, q_{9P2O5} (kcal/kg)	1070	1070	1070
SiO_2 content in slag (%)	17.31	17.31	17.31
P_2O_5 content in slag (%)	0.48	0.48	0.48
Heat Input, Q_{Input} (1000 x kcal/t-output)	**608.3**	**596.7**	**650.6**

(5) Heat Output

The Heat outputs for the three (3) measured heats are calculated as shown in Table 12-19. As for calculation formula, refer to Annex-4.

Table 12-19 Heat Output

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
(10) Potential heat of molten steel, Q_{10} (1000 x kcal/t-output)	**384.9**	**391.4**	**380.5**
Ratio of potential heat of molten steel (%)	63.3	65.7	58.5
(10a) Potential heat of output, q_{10a} (1000 x kcal/t-output)	**340.6**	**347.3**	**337.0**
Temperature of molten steel before tapping (°C)	1641	1673	1624
Heat content of molten steel before tapping, h_{10a} (kcal/kg)	340.6	347.3	337.0
(10b) Potential heat of hot heel, q_{10b} (1000 x kcal/t-output)	**44.3**	**44.1**	**43.5**
Unit weight of hot heel of molten steel, m_2 (kg/t-output)	130	127	129
(11) Potential heat of slag, Q_{11} (1000 x kcal/t-output)	**43.1**	**42.3**	**48.8**
Ratio of potential heat of slag in output (%)	7.1	7.1	7.5
Unit weight of slag, m_{11} (kg/t-output)	89	84	103
Temperature of slag (°C)	1641	1673	1624
Heat content of slag, h_{11} (kcal/kg)	484.2	503.4	474.1
(12) Heat of limestone decomposition, Q_{12} (1000 kcal/t-output)	**2.9**	**2.9**	**3.3**
Ratio of heat of limestone decomposition (%)	0.5	0.5	0.5
Unit consumption of limestone, m_{12} (kg/t-output)	7	7	8
Heat of decomposition of limestone, $q_{12CaCO3}$ (kcal/kg)	757	757	757
CaO content in limestone (%)	55	55	55
(14) Heat in cooling water, Q_{14} (1000 x kcal/t-output)	**41.9**	**54.0**	**40.9**
Ratio of heat in cooling water (%)	6.9	9.1	6.3
(14a) Heat in cooling water for elbow, Q_{14a} (1000 x kcal/t-output)	**10.3**	**11.8**	**11.3**
Average quantity of cooling water for elbow, m_{14a} (kg/t-output)	1096	1071	1436
Mean outlet temperature of cooling water for elbow (°C)	43.4	45.0	42.9
Inlet temperature of cooling water for elbow (°C)	34.0	34.0	35.0
(14b) Heat in cooling for roof, Q_{14b} (1000 x kcal/t-output)	**15.1**	**19.2**	**16.3**
Average quantity of cooling water for roof, m_{14b} (kg/t-output)	3026	2957	3964
Mean outlet temperature of cooling water for roof (°C)	39.0	40.5	39.1
Inlet cooling water for roof (°C)	34.0	34.0	35.0
(14c) Heat in cooling water for EBT, Q_{14c} (1000 x kcal/t-output)	**1.7**	**2.2**	**1.2**
Average quantity of cooling water for EBT, m_{14c} (kg/t-output)	590	577	773
Mean outlet temperature of cooling water for EBT (°C)	36.8	37.8	36.5
Inlet temperature of cooling water for EBT (°C)	34.0	34.0	35.0
(14d) Heat in cooling water for shell-1, Q_{14d} (1000 x kcal/t-output)	**7.7**	**10.7**	**6.1**
Average quantity of cooling water for shell-1, m_{14d} (kg/t-output)	2557	2499	3363
Mean outlet temperature of cooling water for shell-1 (°C)	37.0	38.3	36.8
Inlet temperature of cooling water for shell-1 (°C)	34.0	34.0	35.0
(14e) Heat in cooling water for shell-2, Q_{14e} (1000 x kcal/t-output)	**7.2**	**10.0**	**6.1**
Average quantity of cooling water for shell-2, m_{14d} (kg/t-output)	2567	2508	3363
Mean outlet temperature of cooling water for shell-2 (°C)	36.8	38.0	36.8

Inlet temperature of cooling water for shell-2 (°C)	34.0	34.0	35.0
(15) Sensible heat of exhaust gas, Q_{15} (1000 x kcal/t-output)	**121.4**	**86.2**	**167.2**
Percentage of sensible heat in exhaust gas (%)	20.0	14.5	25.7
Heat in average flow of exhaust gas (kcal/min.)	216000	157000	227000
Power on-to-power off time, t_h (hr)	0.72	0.72	0.95
Output (t/heat)	76.860	78.660	77.400
(16) Heat loss at furnace body, Q_{16} (1000 kcal/t-output)	**1.6**	**1.6**	**2.1**
Percentage of heat loss at furnace body in heat input (%)	0.1	0.1	0.1
Indoor temperature, T_{aa} (°K)	308.0	310.0	310.0
Indoor temperature (°C)	35.0	37.0	37.0
(16a) Heat loss at roof, Q_{16a} (1000 x kcal/t-output)	**0.1**	**0.1**	**0.2**
Surface area of furnace roof, A_a (m^2)	40	40	40
(16a1) Radiation heat loss at roof, q_{ra} (kcal/m_2, hr)	158	149	149
Surface temperature of roof, T_{0aa} (°K)	338.0	338.0	338.0
Surface temperature of roof (°C)	65.0	65.0	65.0
(16a2) Convection heat loss at roof, q_{ca} (kcal/m^2, hr)	197	180	180
(16b) Heat loss at shell, Q_{16b} (1000 x kcal/t-output)	**0.0**	**0.0**	**0.0**
Surface area of shell, A_a (m^2)	35	35	35
(16b1) Radiation heat loss at shell, q_{rb} (kcal/m^2, hr)	31	26	20
Mean surface temperature of shell T_{0aa} (°K)	314.5	315.4	314.2
Mean surface temperature of shell, t_{0b} (°C)	41.5	42.4	41.2
(16b2) Convection heat loss at shell, q_{cba} (kcal/m^2, hr)	23	18	13
(16c) Heat loss at bottom, Q_{16c} (1000 x kcal/t-output)	**1.5**	**1.4**	**1.9**
Surface area of furnace bottom, A_c (m^2)	34	34	34
(16c1) Radiation heat loss at bottom, q_{rc} (kcal/m^2, hr)	3198	3196	3199
Mean surface temperature of bottom, T_{0aa} (°K)	549.1	549.4	549.5
Surface temperature of bottom, t_{0c} (°C)	276.1	276.4	276.5
(16c2) Convection heat loss at bottom, q_{cc} (kcal/m^2, hr)	1425	1413	1413
(17) Other heat losses (1000 kcal/t-output)	**12.4**	**17.8**	**7.8**
Percentage of other heat losses (%)	2.0	3.0	1.2
Heat output, O_{utput} (1,000 kcal/t-output)	**608.3**	**596.2**	**650.6**

(6) Heat Balance

Heat balance sheets are shown in Figures 12-30, 12-31 and 12-32.

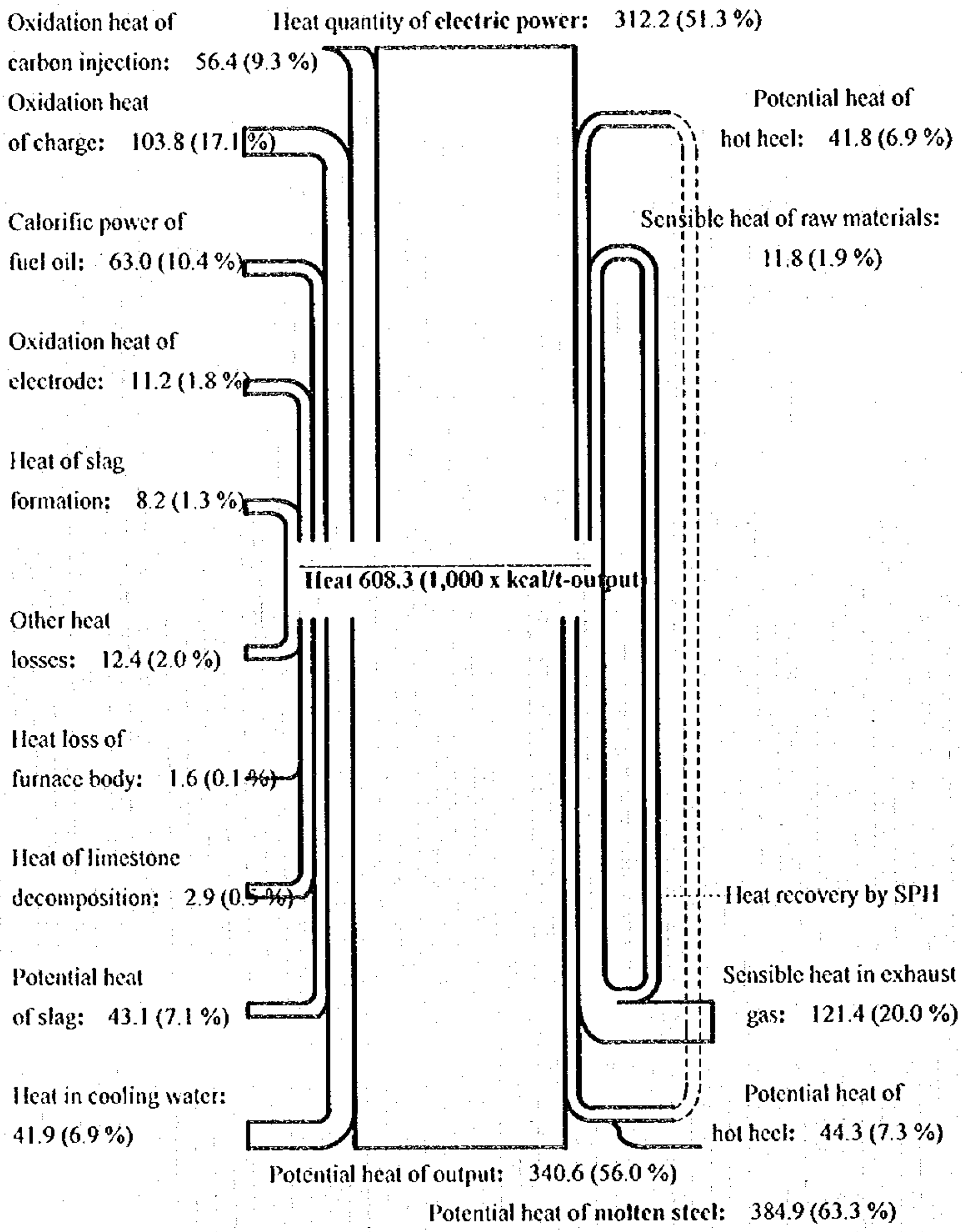

Figure 12-30 Heat Balance of Heat No. 965751

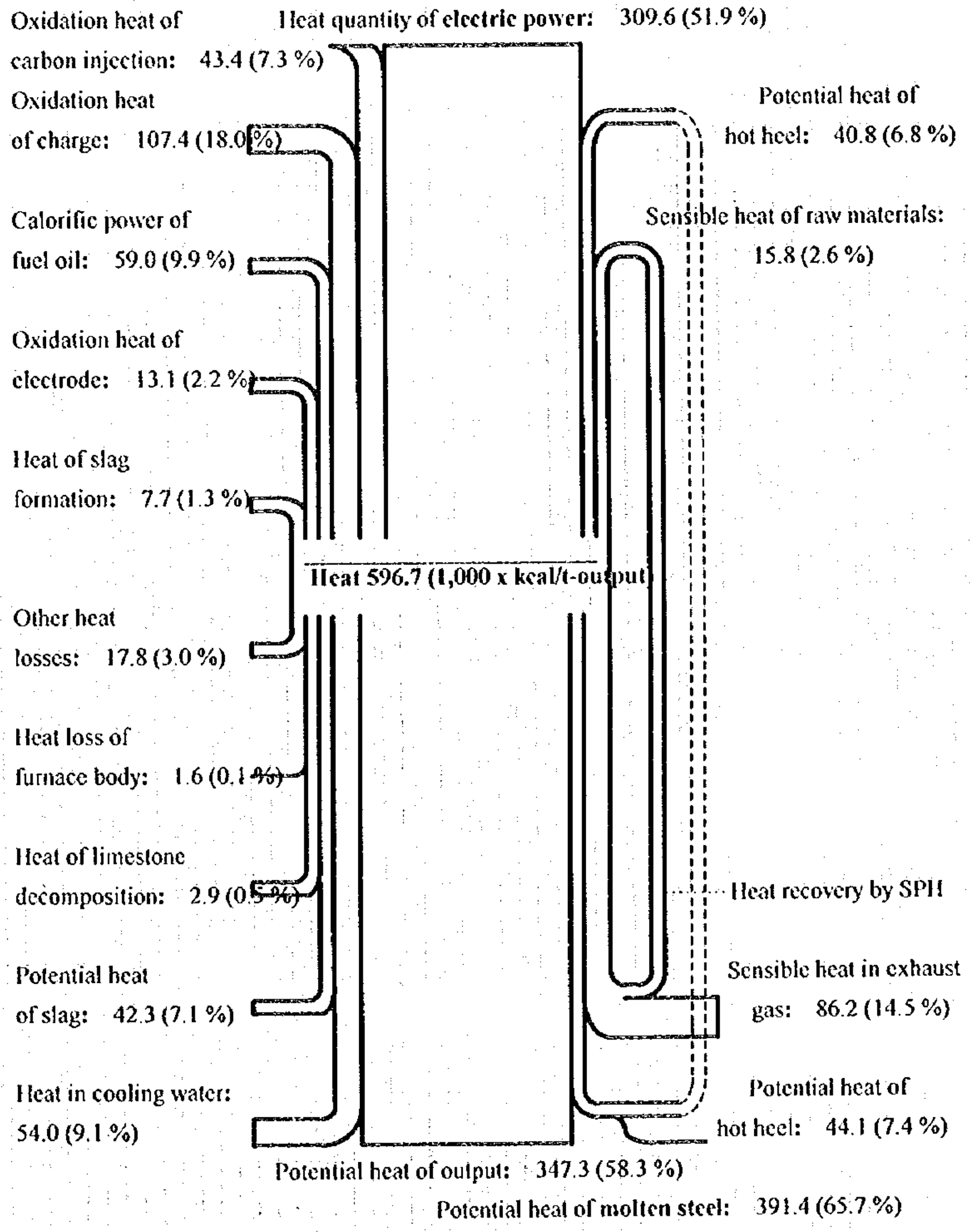

Figure 12-31 Heat Balance of Heat No. 965752

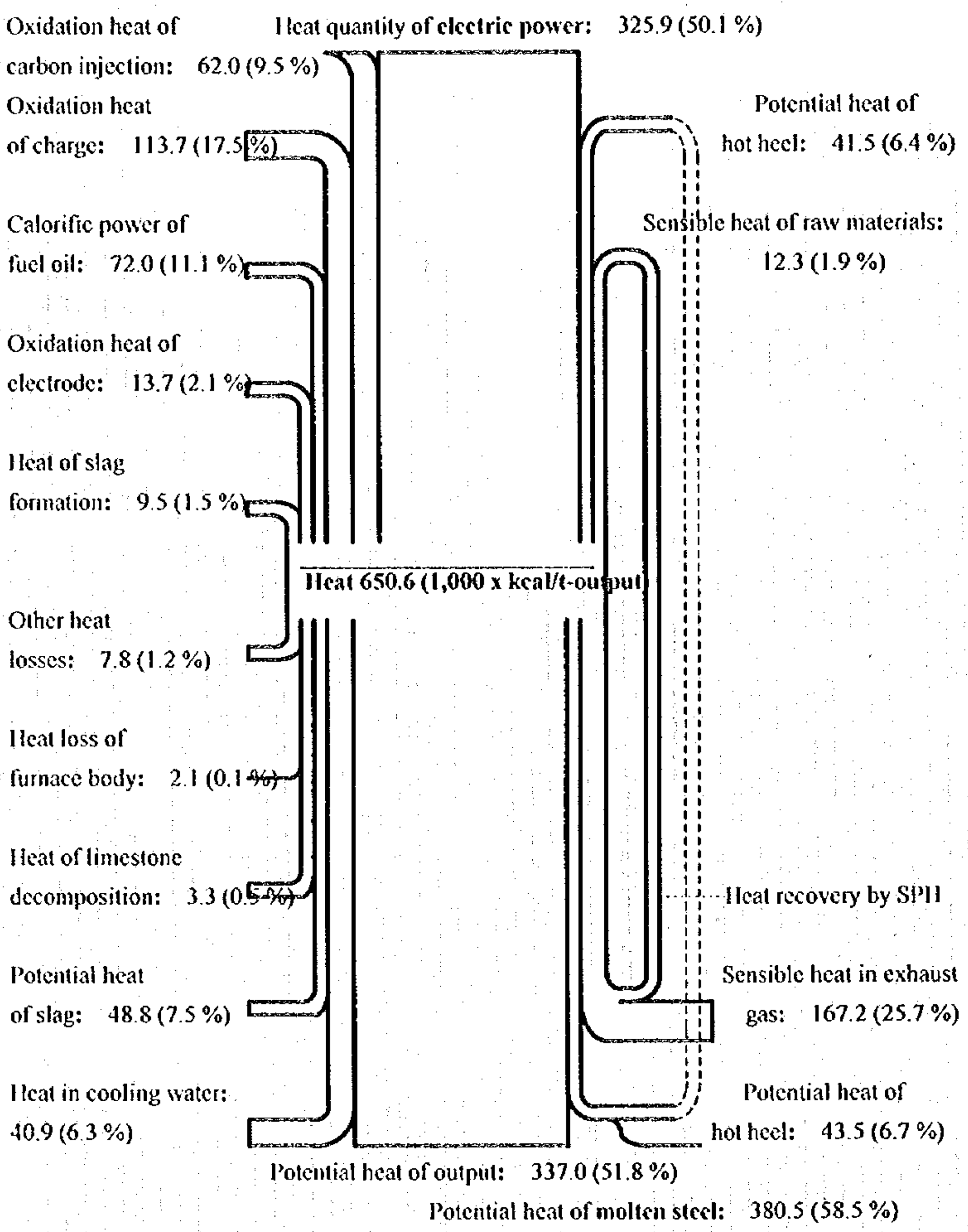

Figure 12-32 Heat Balance of Heat No. 965753

12-9-4 Analysis

(1) General Analysis

1) Observed Characteristics of Heat Balance

Each heat balance sheet shows the following characteristics.

1. "Other heat losses" shows almost the same values for all heats, 2.0 % for Heat No. 965751, 3.0 % for Heat No. 965752 and 1.2 % for No. 965753.
2. Production of one ton required 650,600 kcal for Heat No. 965753, which is approximately 7 to 8 percent higher than 608,300 kcal for Heat No. 965751 and 596,200 kcal for Heat No. 965752.

In this measurement the electrical heat loss was not measured. The electrical heat loss is usually approximately 2 percent. Therefore, for Item 1 above, "other heat losses" of 1.2 to 3.0 percent is very close to the practical minimum value and also corresponds to the accepted level of electrical heat loss. This may be interpreted to mean that the selected three heats were successfully measured. Incidentally, for other heats, Heat Nos. 965729, 965773, 965776 and 965777 for example, "other heat losses" shows 6.6, 4.9, 11.4 , and minus 0.2 percent, respectively. For Item 2 above, Heat No. 965753 required a longer tap-to-tap time than other heats; natually, heat consumption increased.

2) Comparison with Other Furnaces

Table 12-19 compares the heat balances of IDC with certain Japanese cases. The following may be noted from this table.

1. IDC's heat quantity of electric power: Not different for the Japanese cases
2. IDC's potential heat of hot heel: No comment
3. IDC's sensible heat of raw materials: Lower than the Japanese cases. This could be attributable to operation of the SPH of which improvement is required in IDC.
4. IDC's calorific power of fuel oil: Higher. This shows a better performance of IDC from the standpoint of heat balance.
5. IDC's oxidation heat of electrode: Lower. This shows inferior performance from the standpoint of heat balance, although the operation is better.
6. IDC's oxidation heat of charge: Lower. Oxidation heat of charge depends on the types of the raw materials.
7. IDC's oxidation heat of additives: Lower. Furnaces in Japan usually use lump

cokes in the first bucket which IDC does not use.

8. IDC's heat of slag formation: No comment.
9. IDC's potential heat of molten steel: Higher. This is indicative of better operation.
10. IDC's potential heat of hot heel: No comment.
11. IDC's potential heat of slag: Higher. Higher potential heat of slag is undesirable from the standpoint of heat balance.
12. IDC's heat of limestone decomposition: No comment.
13. IDC's heat in cooling water: Lower. Lower ration means that the heat balance is better.
14. IDC's sensible heat in exhaust gas: Higher. Higher sensible heat is worse from the standpoint of heat balance.
15. IDC's heat loss at furnace body: No comment.
16. IDC's other heat loss: No comment.

Table 12-19 Comparison of Heat Input and Output

Furnace	Heat No. 965751	Heat No. 965752	Heat No. 965753	125 t F'ce	80 t F'ce	50 t F'ce
Items	Ratio (%)	Ratio (%)	Ratio (%)	Ratio (%)	Ratio (%)	Ratio (%)
1. **Heat Input**						
(1) Heat quantity of electric power	51.3	51.9	50.1	50.4	47	54.9
(2) Potential heat of hot heel	6.9	6.8	6.4	8.0	-	-
(3) Sensible heat of raw materials	1.9	2.6	1.9	4.9	5	2.9
(4) Calorific power of fuel oil	10.4	9.9	11.1	0.5	4	4.7
(5) Oxidation heat of electrode	1.8	2.2	2.1	2.8	4	4.3
(6) Oxidation heat of charge	17.1	18.0	17.5	21.0	20	9.5
(7) Oxidation heat of additives	9.3	7.3	9.5	12.4	20	23.7
(8) Heat of slag formation	1.3	1.3	1.5	0.4	-	-
(9) Heat input, total	100.0	100.0	100.0	100.0	100	100.0
2. **Heat Output**						
(1) Potential heat of molten steel	56.0	58.3	51.8	51.2	51	51.5
(2) Potential heat of hot heel	7.3	7.4	6.7	8.0	-	-
(3) Potential heat of slag	7.1	7.1	7.5	4.9	5	4.4
(4) Heat of limestone decomposition	0.5	0.5	0.5	-	-	-

(5) Heat in cooling water	6.9	9.1	6.3	7.6	15.0	20.1
(6) Sensible heat in exhaust gas	20.0	14.5	25.7	16.4	15.0	-
(7) Heat loss at furnace body	0.1	0.1	0.1	-	-	-
(8) Other heat loss	2.0	3.0	1.2	11.9	14.0	24.0
(9) Heat output, total	100.0	100.0	100.0	100.0	100.0	100.0

Note: 1) Oxidation heat of additives means that of carbon charged and injected.
2) In case of IDC's heat, electrical heat loss is not measured.
3) In case of 125 t F'ce, heat loss at furnace body and electrical heat loss are not measured.
4) In case of 80 t F'ce, heat of slag formation is not measured.
5) In case of 80 t F'ce, oxidation heat of charge includes the calorific power of oil adhered to scrap of 8 %.
6) In case of 80 t F'ce, other heat loss is of heat loss at furnace body and electrical heat loss.
7) In case of 50 t F'ce, heat of slag formation is not measured.
8) In case of 50 t F'ce, sensible heat in exhaust gas is included in other heat loss.

(2) Heat Quantity of Electric Power

It may be noted from Table 12-19 that the heat quantity of electric power of about 51 percent is not different from those of the selected furnaces of Japan.

(3) Potential Heat of Hot Heel

The Potential heat of hot heel is about 7 percent in the heat input on the assumption that the temperature of hot heel is 1,550 °C. From the standpoint of heat balance, if its temperature is higher by 10 °C, energy saving of 2,100 kcal/t (2.4 kWh/t) will be realized. Therefore, power-on of the subsequent heat should start immediately to prevent the temperature drop of hot heel.

(4) Sensible Heat of Raw Materials - Effectiveness of SPH

In this measurement, temperature of raw materials is represented by bucket temperature. Raw materials are charged to the EAF by three buckets, of which the first and second buckets are preheated in SPH. Figure 12-33 shows the relationship between bucket temperature and the residence time in SPH. With the exception of one measurement, longer residence times in SPH indicate a possibility to raise the bucket temperature higher. The residence time in SPH should be as longer as possible within the tap-to-tap time limit of EAF.

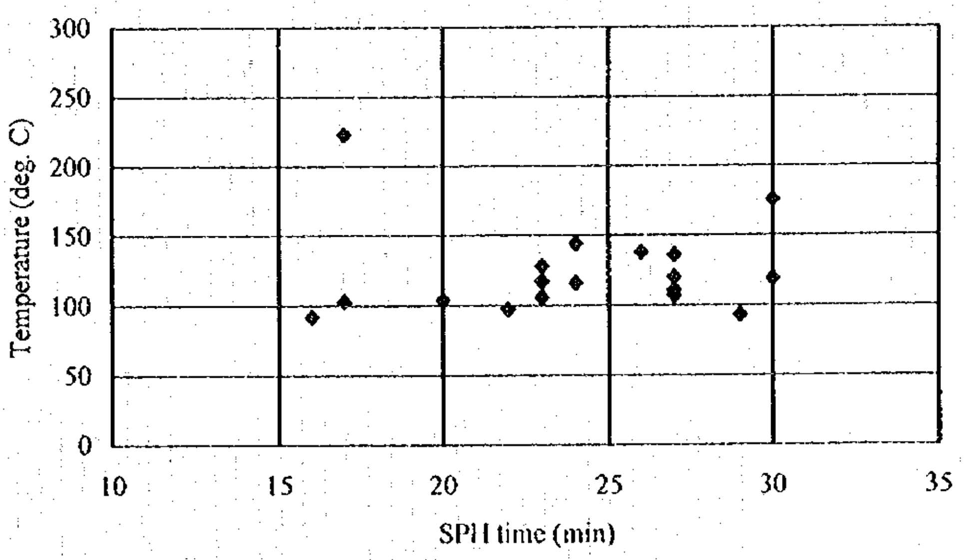

Figure 12-33 Relationship between Bucket Temperature and SPH Time

The heat balance indicates that if the third bucket could also be preheated by modification of the existing SPH, electric power of 6.8 kWh/t and production cost of 17,900 USD/M will be saved.

At present: 1st bucket 42 t x 150 °C after 30 min. preheating
2nd bucket 28 t x 100 °C after 15 min. preheating
3rd bucket 16 t x 35 °C at indoor temperature
Average 112.3 °C
Heat input = 12.88 kcal (heat of scrap at 112.3 °C for 1 kg)
x 1111 kg (unit consumption of raw materials)
/860 kcal (per kWh) = 16.6 kWh/t

Improvement: 1st bucket 42 t x 150 °C after 30 min. preheating
2nd bucket 28 t x 180 °C after 40 min. preheating
3rd bucket 16 t x 130 °C after 25 min. preheating
Average 156.0 °C
Heat input = 18.14 kcal (heat of scrap at 156 °C for 1 kg)
x 1111 kg (unit consumption of raw materials)
/860 kcal (per kWh) = 23.4 kWh/t

Saving of electric power: 23.4 - 16.6 = 6.8 kWh/t

Saving of production cost: 6.8 kWh/t x 0.044 USD/kWh = 0.299 USD/t
= 17,900 USD/ M at production of 60,000 t/M.

Schematic diagrams of SPH operation and bucket charge for existing and after modification are shown in Figure 12-34 and Figure 12-35, respectively.

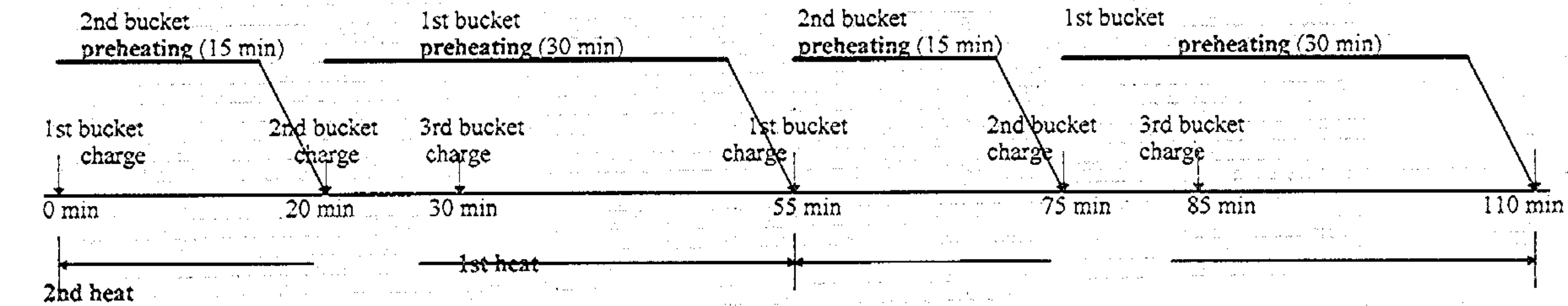

Figure 12-34 Schematic Diagram of SPH Operation and Bucket Charge - Existing -

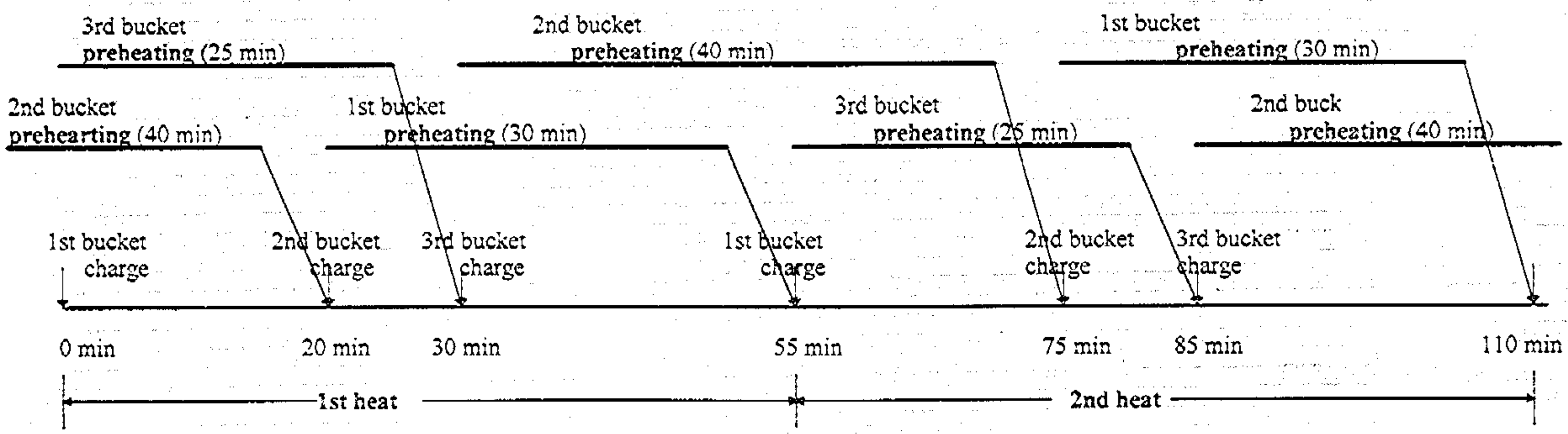

Figure 12-35 Schematic Diagram of SPH Operation and Bucket Charge - After Modification -

(5) Calorific Power of Fuel - Effectiveness of Oxy-Fuel Burners

The ratio of calorific power of fuel oil to the total heat input is approximately 10 percent. The charged material, scrap and pig iron, shall be melted of as fast as possible by energy of electric power with the help of the oxy-fuel burners and oxy-lancing method.

The ratio of O_2/Oil (Nm^3/kg) of oxy-fuel burners varies from one heat to another and with the burner as shown in Table 12-20. The ratio of O_2/Oil occasionally varies accidentally due to clogging of the burner tip. Clogging must be prevented by daily maintenance and the burner designs must be improved to prevent clogging.

Table 12-20 shows that the oxy-fuel burners were used for 24 minutes and the flow rate of fuel oil was 293 kg/hr. If the flow rate of fuel oil is increased to 380 kg/hr and a constant ratio of O_2/Oil is maintained by improvement of this system, electric power consumption of 5.2 kWh/t-output, which corresponds to the production cost of 9,700 USD/M, will be saved.

Saving of electric power: (380 - 293) kg/hr x 24 min./60 min. = 35 kg/heat
= 0.45 kg/t-output (x 10,000 kcal/kg) = 4,500 kcal/t-output (/860 kcal/kWh)
= 5.2 kWh/t-output

Saving of production cost: 5.2 kWh/t x 0.044 USD/kWh - 0.45 kg/t x 0.15 USD/kg
= 0.161 USD/t = 9,700 USD/M at production of 60,000 t/M

Table 12-20 Flow Rate of Oxygen Gas and Fuel Oil for Oxy-Fuel Burner

Heat No		965749	965750	965751	965752	965753	965773	965774	965775	965776	965777	Average
No. 1	Duration (min)	24	25	20	26	23	24	25	21	24	-	23.6
Burner	O_2 (Nm^3)	280	290	232	365	249	252	273	236	268		272
	Oil (kg)	121	105	133	104	182	94	121	95	107		118
	O_2 (Nm^3/hr)	700	696	696	842	650	630	655	674	670		690
	Oil (kg/hr)	303	252	399	240	475	235	290	271	268		304
	O_2/Oil (Nm^3/kg)	2.31	2.76	1.74	3.51	1.37	2.68	2.26	2.48	2.50		2.40
No.2	Duration (min)	24	25	25	26	23	24	25	21	24	-	24.1
Burner	O_2 (Nm^3)	248	283	285	301	255	278	293	257	278		275
	Oil (kg)	132	158	162	107	136	101	151	169	164		142
	O_2 (Nm^3/hr)	620	679	684	695	665	695	703	734	695		686
	Oil (kg/hr)	330	379	389	247	355	253	362	483	410		356
	O_2/Oil (Nm^3/kg)	1.88	1.79	1.76	2.81	1.88	2.75	1.94	1.52	1.70		2.00
No.3	Duration (min)	24	25	12	26	23	24	25	21	24	-	22.7
Burner	O_2 (Nm^3)	265	286	152	307	249	264	282	250	268		258
	Oil (kg)	96	100	56	101	93	82	95	85	87		88
	O_2 (Nm^3/hr)	663	686	760	708	650	660	677	714	670		688
	Oil (kg/hr)	240	240	280	233	243	205	228	275	218		240
	O_2/Oil (Nm^3/kg)	2.76	2.86	2.71	3.04	2.68	3.22	2.97	2.94	3.08		2.92
No.4	Duration (min)	24	25	25	26	23	24	25	21	24	-	24.1
Burner	O_2 (Nm^3)	288	307	297	308	272	332	330	275	297		301
	Oil (kg)	106	113	112	117	124	102	116	93	105		110
	O_2 (Nm^3/hr)	720	737	713	711	710	830	792	786	743		749
	Oil (kg/hr)	265	271	269	270	323	255	278	266	263		273
	O_2/Oil (Nm^3/kg)	2.72	2.72	2.65	2.63	2.19	3.25	2.84	2.96	2.83		2.76

(6) Oxidation Heat of Electrodes

The oxidation heat of electrodes is approximately 2 percent on the heat input. It is lower than that of other furnaces in Japan. Lower oxidation heat of electrodes is worse from the standpoint of heat balance but is better in operation results.

(7) Oxidation Heat of Charge

The oxidation heat of charge is approximately 18 percent, second only to the 51 percent of electrical energy in heat input. This figure varies depending on the kind of raw materials. Table 12-21 compares oxidation heat of pig iron and scrap. Calculation was done assuming the conditions to be the same as those of the measurement. Oxidation heat of pig iron is higher by 298,200 kcal/t than that of scrap. This means that pig iron has an additional value of approximately 14 USD/t compared with scrap in the heat balance. This will be a factor for judging which raw material should be purchased.

(373,400 - 98,100) kcal/860 kcal (per kWh) x 0.044 USD (per kWh)

≒ 14.09 USD/t

Table 12-21 Comparison of Oxidation Heat of Pig iron and Scrap

Kind of raw materials	pig iron	scrap
Mean CO_2 content in exhaust gas (CO_2) (%)	14.7	14.7
Mean CO content in exhaust gas (CO) (%)	4.7	4.7
(7) Oxidation heat of charge, Q_7 (1000 x kcal/t-output)	373.4	98.1
(7a) Oxidation heat of charged C, Q_{7a} (1000 x kcal/t-output)	245.8	23.6
Unit consumption of scrap (kg/t-output)	0	1000
Unit consumption of pig iron (kg/t-output)	1000	0
C content(%)	3.65	0.35
C content of molten steel before tapping (%)	0.00	0.00
Oxidation amount of charged C, m_{7a} (kg/t-output)	36.5	3.5
Heat of C oxidation at CO_2 formation, q_{7cCO2} (kcal/kg)	8075	8075
Heat of C oxidation at CO formation, q_{7cCO} (kcal/kg)	2448	2448
(7b) Oxidation heat of charged Si, Q_{7b} (1000 x kcal/t-output)	78.3	17.2
Si content	1.05	0.23
Si content of molten steel before tapping (%)	0.00	0.00
Oxidation amount of charged Si, m_{7b} (kg/t-output)	10.50	2.30
Heat of Si, q_{7bSi} (kcal/kg)	7459	7459
(7c) Oxidation heat of charged Mn, Q_{7c} (1000 x kcal/t-output)	11.7	12.6
Mn content(%)	0.70	0.75
Mn content of molten steel before tapping (%)	0.00	0.00
Oxidation amount of Mn, m_{7c} (kg/t-output)	7.00	7.50
Heat of Mn, q_{7cMn} (kcal/kg)	1674	1674
(7d) Oxidation heat of charged P, Q_{7d} (1000 x kcal/t-output)	2.3	4.4

P content (%)	0.040	0.075
P content of molten steel before tapping (%)	0.000	0.000
Oxidation amount of P, m_{7d} (kg/t-output)	0.40	0.75
Heat of P, q_{7dP} (kcal/kg)	5811	5811
(7e) Oxidation heat of charged Cr, Q_{7e} (1000 x kcal/t-output)	0.0	3.9
Cr content of scrap (%)	0.000	0.150
Cr content of molten steel before tapping (%)	0.000	0.000
Oxidation amount of Cr, m_{7e} (kg/t-output)	0.00	1.50
Heat of Cr, q_{7eCr} (kcal/kg)	2620	2620
(7f) Oxidation heat of charged Al, Q_{7f} (1000 x kcal/t-output)	0.0	1.3
Al content (%)	0.000	0.017
Al content of molten steel before tapping (%)	0.0	0.0
Oxidation amount of Al, m_{7f} (kg/t-output)	0.00	0.17
Heat of Al, q_{7fAl} (kcal/kg)	7419	7419
(7g) Oxidation heat of charged Fe, Q_{7g} (1000 x kcal/t-output)	35.3	35.3
Unit weight of slag, m_{7g} (kg/t-output)	100	100
Heat of Fe oxidation at FeO formation, q_{7gFeO} (kcal/kg)	1151	1151
Heat of Fe oxidation at Fe_2O_3 formation, $q_{7gFe2O3}$ (kcal/kg)	1756	1756
FeO content in slag, (FeO) (%)	9.01	9.01
Fe_2O_3 content in slag (Fe_2O_3) (%)	22.16	22.16

(8) Oxidation Heat of Carbon Injection

Carbon injection is originally one of the operation methods to generate foamy slag in order to save electrical energy surrounding the arc by foamy slag. But in heat balance, it is considered one of the energy sources. In the case of IDC the oxidation heat is approximately 8 percent of the heat input and is lower than that of furnaces in Japan, because furnaces in Japan usually use lump cokes in the first bucket in addition to carbon injection.

(9) Heat of Slag Formation

Table 12-22 gives consumption of burnt lime, slag generation and their heat balance recorded in Heat No. 965752 and 965753 as an example of heat of slag formation.

Table 12-22 Consumption of Burnt Lime, Slag Generation and Heat Balance

Heat No.	965752	965753
Consumption of burnt lime (kg/heat)	1790	2150
Unit consumption of burnt lime (kg/t-output)	22.8	27.8
Slag generation (kg/heat)	6610	7939
Unit weight of slag (kg/t-output)	84	103
Heat of slag formation (1,000 kcal/t-output), Heat Input	7.7	9.5

Potential heat of slag (1,000 kcal/t-output), Heat Output	42.3	48.8

The potential heat of slag of Heat No. 965753 is higher by 6,500 kcal/t-output than that of Heat No. 965752 while the heat of slag formation of the former is higher only by 1,800 kcal/t-output than the latter. This suggests excessive charging of burnt lime; therefore, the consumption of burnt lime should be restudied taking the heat balance and also content of phosphorus and sulfur in the molten steel into consideration.

If consumption of burnt lime would be decreased to 25.6 kg/t-output (2,000 kg/heat) from 38.4 kg/t-output (3,000 kg/heat), the data collected during the first field survey, Table 12-23 shows the expected improvements in lime consumption, slag generation and heat balance resulting from the decrease in the use of burnt lime.

Table 12-23 Expected Improvements from Reduction of Burnt Lime Use

	Jan. - Oct., 1995	Proposed target	Improve-ment
Consumption of burnt lime (kg/heat)	3,000	2,000	+ 1,000
Unit consumption of burnt lime (kg/t-output)	38.4	25.6	+ 12.8
Slag generation (t/heat)	11.078	7.385	+ 3.693
Unit weight of slag (kg/t-output)	142	95	+ 47
Heat of slag formation (1,000 kcal/t-output), Heat Input	13.1	8.7	- 4.4
Potential heat of slag (1,000 kcal/t-output), Heat Output	67.0	44.8	+ 22.2

Accordingly, 17,800 kcal/t-output (20.7 kWh/t-output) will be reduced in heat balance and unit consumption of burnt lime will also be reduced by 12.8 kg/t-output.

Production cost saving: Burnt lime 12.8 kg/t-MS x 0.043 USD/kg = 0.55 USD/t-MS

20.7 kWh/t/MS x 0.044 USD/kg = 0.91 USD/t-MS

Total: 1.46 USD/t-MS

= 87,000 USD/M at production of 60,000 t/M

(10) Potential Heat of Molten Steel

The potential heat of molten steel, excluding that of hot heel, is 56.0, 58.3 and 51.8 percent of the heat output. These percentages are higher than the approximate Japanese value of 51 percent and may be regarded as an indication of IDC's good performance.

(11) Potential Heat of Slag

See sub-section 12-9-4 (9) above.

(12) Heat of Limestone Decomposition

The quality of burnt lime used by IDC is not always good. It contains approximately 30 percent of uncalcined limestone. If burnt lime of good quality could be purchased at the same price as the present burnt lime, 3.4 kWh/t will be saved from the standpoint of heat balance.

2,900 kcal/t (/860 kcal/kWh) = 3.4 kWh/t at the unit consumption of burnt lime of 23.3 kg/t

(13) Heat in Cooling Water

Heat carried out by cooling water was 6.9, 9.1 and 6.3 percent on the heat output, rather large heat losses. As shown in Table 12-24, average temperature difference between the inlet and outlet was 9.7 °C for the elbow, 5.0 °C for the roof, 2.6 °C for EBT, 2.3 °C shell-1 and 2.5 °C shell-2. These temperature differences were very small. Mean maximum outlet temperatures were 49.8 °C for elbow, 42.1 °C for roof, 38.7 °C for EBT, 38.3 °C for shell-1 and 38.1 °C for shell-2. If the mean maximum outlet temperature could be raised to 58 °C, the design temperature rise of 23 °C higher than the inlet temperature of 35 °C in tubular cooling system, the quantity of cooling water would be decreased by about 7.7 t/t-output (800 m^3/hr) and 6,500 USD/M would be saved from the standpoint of heat balance.

(10,159 - 2,442) kg/t-output x 0.014 USD/t = 0.108 USD/t-output = 6,500 USD/M at 60,000 t/M of production

(1,053 - 254) m^3/hr = 799 m^3/hr

The present practice of muffling the arc by slag, thereby preventing water cooling panels from being exposed directly to the arc, is a very good one. In case IDC decreases the amount of cooling water, it should be done step by step each time by a small amount and IDC should see the results before further decreasing cooling water.

Table 12-24 Improvement of Cooling Water for Furnace

Date	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Average	Improvement
Heat No.	5749	5750	5751	5752	5753	5773	5774	5775	5776	5777		
(14) Heat in cooling water, Q_{14} (1000 x kcal/t-output)	42.2	44.5	41.9	54.0	40.9	44.3	39.4	40.8	26.7	25.7	40.6	40.6
Quantity of cooling water (kg/t-output)	9905	10576	9836	9612	12898	10113	9848	8439	8993	11373	10159	2442
Output (t/heat)	77.130	77.400	76.860	78.660	77.400	77.238	76.914	76.824	75.960	76.626	77.101	77.101
Power on-to-power off time (hr/heat)	0.72	0.77	0.72	0.72	0.95	0.73	0.72	0.63	0.65	0.83	0.74	0.74
Flow rate of cooling water (m^3/hr)	1061	1063	1050	1050	1051	1070	1052	1029	1051	1050	1053	254
(14a) Heat in cooling water for elbow, Q_{14a} (1000 x kcal/t-output)	11.8	11.3	10.3	11.8	11.3	11.3	12.5	10.5	8.8	8.0	10.9	10.9
Quantity of cooling water for elbow, m_{14a} (kg/t-output)	1092	1164	1096	1071	1436	1106	1095	959	1001	1267	1129	637
Maximum outlet temperature of cooling water for elbow (°C)	50.3	48.1	49.9	51.3	52.1	48.2	51.1	50.1	49.3	47.5	49.8	58.0
Mean outlet temperature of cooling water for elbow (°C)	44.8	43.7	43.4	45.0	42.9	42.2	45.4	45.0	44.8	41.3	43.9	52.1
Inlet temperature of cooling water for elbow (°C)	34.0	34.0	34.0	34.0	35.0	32.0	34.0	34.0	36.0	35.0	34.2	35.0
(14b) Heat in cooling for roof, Q_{14b} (1000 x kcal/t-output)	15.2	16.7	15.1	19.2	16.2	17.9	15.1	14.8	11.9	11.9	15.6	15.6
Quantity of cooling water for roof, m_{14b} (kg/t-output)	3109	3343	3026	2957	3963	3138	3024	2469	2764	3499	3129	776
Maximum outlet temperature of cooling water for roof (°C)	41.3	41.6	42.3	43.3	41.9	40.7	42.1	42.3	43.6	42.2	42.1	58.0
Mean outlet temperature of cooling water for roof (°C)	38.9	39.0	39.0	40.5	39.1	37.7	39.0	40.0	40.3	38.4	39.2	55.1

Inlet cooling water for roof (°C)	34.0	34.0	34.0	34.0	35.0	32.0	34.0	34.0	36.0	35.0	34.2	35.0
(14c) Heat in cooling water for EBT, Q_{14c} (1000 x kcal/t-output)	1.6	1.8	1.7	2.2	1.2	1.7	1.8	1.8	0.8	0.8	1.5	1.5
Average quantity of cooling water for EBT m_{14c} (kg/t-output)	588	627	590	577	773	595	590	517	539	682	608	71
Maximum outlet temperature of cooling water for EBT (°C)	38.2	40.1	39.2	39.3	37.5	36.4	40.1	38.6	39.4	38.1	38.7	58.0
Mean outlet temperature of cooling water for EBT (°C)	36.7	36.8	36.8	37.8	36.5	34.8	37.0	37.4	37.5	36.2	36.8	56.1
Inlet temperature of cooling water for EBT (°C)	34.0	34.0	34.0	34.0	35.0	32.0	34.0	34.0	36.0	35.0	34.2	35.0
(14d) Heat in cooling water for shell-1, Q_{14d} (1000 x kcal/t-output)	6.4	6.8	7.7	10.7	6.1	6.4	5.1	6.3	1.9	1.2	6.0	6.0
Quantity of cooling water for shell-1, m_{14d} (kg/t-output)	2558	2716	2557	2499	3363	2665	2565	2247	2336	2957	2646	652
Maximum outlet temperature of cooling water for Shell-1 (°C)	37.8	37.7	41.7	40.6	38.7	35.7	38.2	38.0	37.8	36.8	38.3	58.0
Mean outlet temperature of cooling water for shell-1 (°C)	36.5	36.5	37.0	38.3	36.8	34.4	36.0	36.8	36.8	35.4	36.5	44.2
Inlet temperature of cooling water for shell-1 (°C)	34.0	34.0	34.0	34.0	35.0	32.0	34.0	34.0	36.0	35.0	34.2	35.0
(14e) Heat in cooling water for shell-2, Q_{14e} (1000 x kcal/t-output)	7.2	7.9	7.2	10.0	6.1	7.0	4.9	7.4	3.3	3.9	6.6	6.6
Quantity of cooling water for shell-2, m_{14d} (kg/t-output)	2558	2726	2567	2508	3363	2609	2574	2247	2353	2968	2647	306
Maximum outlet temperature of cooling water for shell-2 (°C)	38.5	37.9	38.4	39.1	37.9	36.2	37.7	38.6	38.5	37.8	38.1	58.0
Mean outlet temperature of cooling water for shell-2 (°C)	36.8	36.9	36.8	38.0	36.8	34.7	35.9	37.3	37.4	36.3	36.7	56.6
Inlet temperature of cooling water for shell-2 (°C)	34.0	34.0	34.0	34.0	35.0	32.0	34.0	34.0	36.0	35.0	34.2	35.0

(14) Sensible Heat in Exhaust Gas

The sensible heat of the exhaust gas was 20.0 %, 14.5 % and 25.7 % of the heat output. These heat losses are slightly higher than those of the furnaces in Japan.

According to Table 12-17, CO gas remains in the exhaust gas at 1.5 to 7.1 percent. The CO gas is now burned out in the combustion chamber in which the energy of CO gas is transferred to the cooling water. If the residual CO gas could be burned in the EAF by supplying more oxygen gas and its heat of combustion could be transferred to the molten steel, better energy efficiency would be achieved. This application is called post combustion technology.

The obtainable heat of combustion of CO gas is calculated from the following equations.

$$C + O_2 = CO_2 + 33{,}810 \text{ kj/kg-C}$$

$$C + 1/2\, O_2 = CO + 10{,}250 \text{ kj/kg-C}$$

Therefore,

$$CO + 1/2\, O_2 = CO_2 + 23{,}560 \text{ kj/kg-C}$$

The heat of 23,560 kj/kg-C is arithmetically converted into 3,015 kcal/Nm^3-CO.

Based on the measured data in IDC, the heat contents of residual CO gas for each heat number are calculated.

Heat No.	CO_{IN} (%)	F_{IN} (Nm^3/min)	Time (min)	$Cb\text{-}Ht_{IN}$ (kcal/min)	$T\text{-}Cb\text{-}Ht_{IN}$ (kcal/heat)	$F\text{-}CbO_2$ (Nm^3/min)	T-CbO2 (Nm3/heat)
965751	7.1	555	43	111,600	4,800,000	18.5	796
965752	3.5	401	43	40,400	1,730,000	6.7	288
965753	1.5	657	57	29,900	1,700,000	5.0	285
Average	4.0				2,743,000		456

Note:

$Cb\text{-}Ht_{IN}$: Calculated combustion heat flow rate (kcal/min)

$Cb\text{-}Ht_{IN} = (CO_{IN}/100) \times F_{IN} \times 3{,}015$

$T\text{-}Cb\text{-}Ht_{IN}$: Total calculated combustion heat (kcal/heat)

$T\text{-}Cb\text{-}Ht_{IN} = Cb\text{-}Ht_{IN} \times \text{Time}$

Time: Power-on to power-off time (min)

$F\text{-}CbO_2$: Calculated combustion O_2 gas flow rate to burn CO gas flow rate (Nm^3/min)

$F\text{-}CbO_2 = F_{IN} \times (CO_{IN}/100) \times 1/2$

$T\text{-}CbO_2$: Total calculated combustion O_2 gas quantity to burn CO gas flow (Nm^3/heat)

$T\text{-}CbO_2 = F\text{-}CbO_2 \times Time$

The calculation results show that the heat of 2,743,000 kcal/heat (41.1 kWh/t) will be generated by burning the CO gas of 4.0 % with consumption of the oxygen gas of 456 Nm^3/heat (5.9 Nm^3/t). Namely, the 26.6 kWh/t seems to be added to the molten steel considering that the average ratio of potential heat of molten steel is 62.5 percent of heat input (See ratio of potential heat of molten steel in Table 12-19).

All of the 26.6 kWh/t will not be saved for the following reasons.

1. There is much difference between heat input mainly consisting of electric power, oxidation heat of charge and hot heel and heat generated by burning of CO gas in the exhaust gas. It is considered that the former is directly added to the molten steel and the latter is indirectly added. In other words, efficiency of heat radiation of the latter is small. Therefore the ratio of potential heat of molten steel will be far smaller than 62.5 %.
2. Heat generated above the molten steel in the EAF is absorbed not only in the molten steel but also in the shell and the roof. Considering that the heat absolution area of shell and roof is larger than the surface of molten steel, heat to be absorbed in the molten steel will be smaller than that of shell and roof.

The results shown in the above table are calculated on the assumption that all the residual CO gas of 4 percent is burned by the oxygen consumption of 5.9 Nm^3/t. However, in actual operation, generation of CO gas varies during heat melt time shown in Figure 12-20. The flow rate of oxygen gas could not be controlled following the generation of CO gas. Therefore, several times as much oxygen as 5.9 Nm^3/t will be necessary to burn all CO gas generated.

From the above considerations, the effect of post combustion technology is doubtful. In addition, this technology has not yet been introduced in Japan.

(15) Heat Loss at Furnace Body

The ratio of heat loss at furnace body to the heat output is very small.

(16) Other Heat Loss

See sub-section 12-9-4 (1) 1) above.

12-10 Energy Flowchart of Factory and Major Energy Consuming Facilities

The energy flow chart is shown in Figure 12-36.

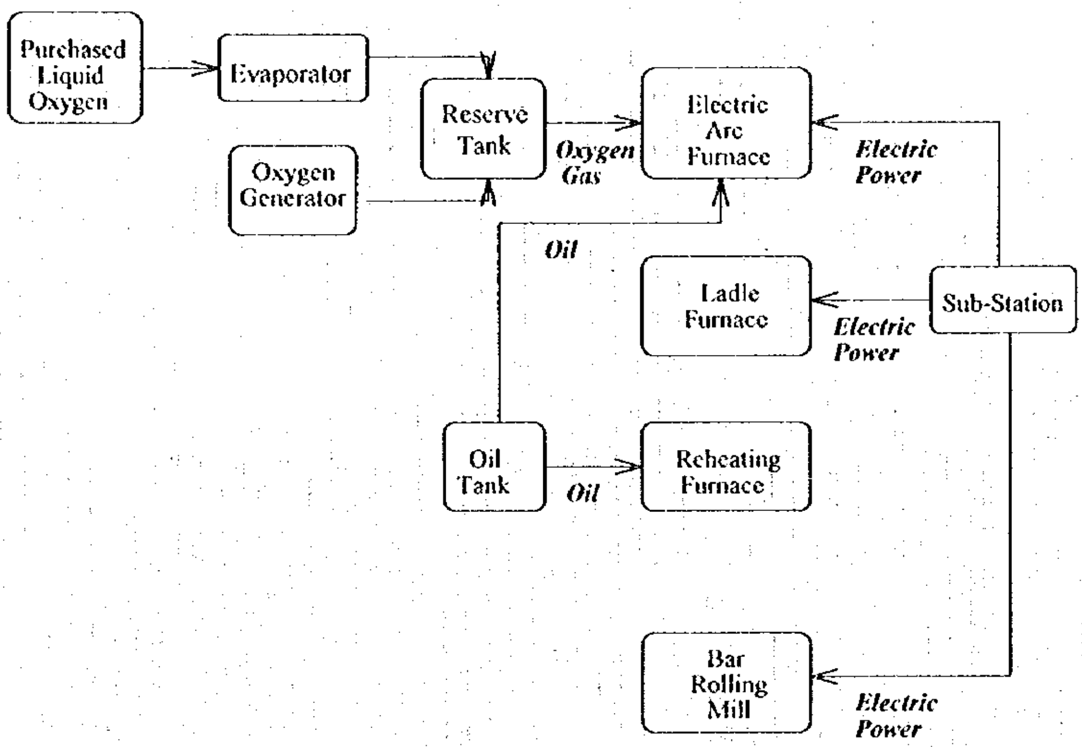

Figure 12-36 Energy Flow in IDC

Major energy consuming facilities are described in sub-section 12-6-1.

12-11 Formulation and Recommendation of Countermeasures for Energy Conservation

12-11-1 Modifications of Facilities and Operation

Based on the measurement and analysis of the heat balances of the electric arc furnace (EAF), the following measures for streamlining of energy use are recommended. Hot temperature charge of billets to the reheating furnace is also recommended based on NKK's experience. Recommendations 1 to 5 are analyzed above in monetary terms and 6 to 8 are analyzed in terms of operation improvement.

1. Modify the scrap preheaters (SPH) to accommodate a 3rd bucket for preheating.
   The following facilities should be installed to operate SPH's simultaneously and independently:
   A new 2nd hood and a new 2nd inlet duct to the existing 2nd chamber
   A new 2nd outlet duct from the existing 2nd chamber
   A new 2nd damper for a new 2nd outlet duct
   Two blowers for the existing 1st and a new 2nd outlet ducts.
2. Improve maintenance of oxy-fuel burners of EAF to keep the O_2/Oil ratio constant.
3. Standardize burnt lime addition into EAF.
4. Decrease flow rate of cooling water for EAF.
5. Introduce billet cooling system at higher temperature in front of the reheating furnace to prevent crack generation in cast billet.
   Pumping system, water piping, spray nozzles and control system should be installed. (Detail concept is shown in the end of this chapter in Annex-3 HOT CHARGE OF BILLET).
6. Turn power on as immediately as possible to prevent the drop of hot heel temperature
7. Preheat scrap as longer as possible to raise it temperature.
8. Purchase as well calcined burnt lime as possible to prevent heat loss in decomposition of limestone.

12-11-2 Enhancement of Morale

To streamline energy use, concerned people at all levels of management , engineers and workers should have their respective roles to play.

(1) Energy Conservation Activity at Management Level

The management should set the ground rules for the activities. The following three items are essential in the promotion of energy conservation throughout the steel works.

1. Establishment of policy (top management's stance)
   (1) Announcement of firm determination for energy saving
   (2) Setting quantitative target
   (3) Conditions and criteria (investment limit, ROI/PBP)
   (4) Others
2. Establishment of organization for promotion of energy use streamlining (committee of engineers)

(1) Investigation of energy consumption and costs
(2) Planning and following up of the results of activities
(3) Collection of proposals from staff and employees
(4) Budgeting
(5) Education, PR
(6) Others

3. Promotion of small team's activities (encouragement of worker team's motivation and adoption of their ideas)
   (1) Formation of teams
   (2) Introduction of study support system
   (3) Result of study presentation and following up of performance
   (4) Appraisal and prize system
   (5) Others

These are important ground rules that the measurement can set and are indispensable to creating an atmosphere for energy saving in the entire steel works.

(2) Energy Conservation of Activity at Engineer Level

The level of activity is no less important and should be the core of energy saving, because only at this level can technical studies be done.

1. Decrease heat input.
   (1) Change of heat sources.
   Auxiliary combustion (Oxy-fuel burner)
   Oxygen injection
   Scrap preheating by fuel
   (2) Utilization of waste heat
   Scrap preheating
   Utilization of hot return scrap
   Utilization of recuperator
   Hot heat operation
   Hot charge of billet
   (3) Lowering of molten steel temperature
   Increase of ladle temperature
   Ladle hood on molten steel
2. Reduction of heat loss

(1) Improvement of facilities

Furnace capacity up

High electric power system

Enhancement of performance of automatic electrode controller

Minimization of secondary conductors and electrodes

Reduction of openings on furnace

(2) Improvement of operation

Prompt analysis of molten steel

Improvement of scrap mixing

Shorter time for scrap charge

Optimization of electric power use

Shorter time of refining and repair

Effective operation of dust removal system

Prevention of electrode breakage

Elimination of waiting time of continuous casting

Prevention of uneven melting of steel

Longer carbon injection time for slag foaming

Others

3. Improvement of good quality billet yield
   (1) Reduction of errors in casting
   (2) Decrease of residual molten steel
4. Utilization of waste heat
   (1) Utilization of hot waste water (for air conditioning, boiler water preheating)
   (2) Utilization of exhaust gas (steam, electricity)
   (3) Utilization of slag sensible heat (steam, electricity)
   (4) Utilization of molten steel sensible heat (steam, electricity)

(3) Energy Conservation Activity at Workers Level

This level of activity is very important for enhancing the morale of field workers. At the same time this can put into practice their ideas based on practical knowledge and operational experience that concern not only energy saving but safety and environmental conservation.

1. Heat energy saving

(1) Proposal for small improvements

Insulation cover on slag door

Sand gasket of flange of EAF

Others

(2) Standardizing operation

Opening and closing of burners

Reheating of scrap

Opening of slag door

Removing of water from scrap

Others

2. Electric energy saving (Rotating machines: pumps, compressor, etc)

(1) Change of rotation speed

Change of pulleys

Change of motor poles

Installation of VVVF (Variable voltage variable frequency)

Others

(2) Remodeling of equipment

Impeller diameter reduction

Replacement of pumps

Optimization of pump line-up

Others

(3) Energy recovery, etc.

Suspension of pump operation (Transfer by pressure)

Suspension of blower operation (Use of stack effect)

Hydraulic turbine/expansion turbine

Pressure reduction turbine

Thermo compressor/heat pipe

Others

To perform these activities successfully, the staff, who are in the position to support the workers technically, should prepare the instruction materials and guide them in detail.

An example of these activities is shown in Annex-5.

12-12 Cost Estimation of Countermeasures

12-12-1 Modification of scrap preheater (SPH)

1. 2nd hood

2. Inlet duct and damper to 2nd chamber
3. Outlet duct and damper from 2nd chamber
4. Blowers for 1st and 2nd chambers
5. Electrical equipment
6. Erection

Total budget cost: 200,000 US Dollars

Schematic layout is shown in Figure 12-37.

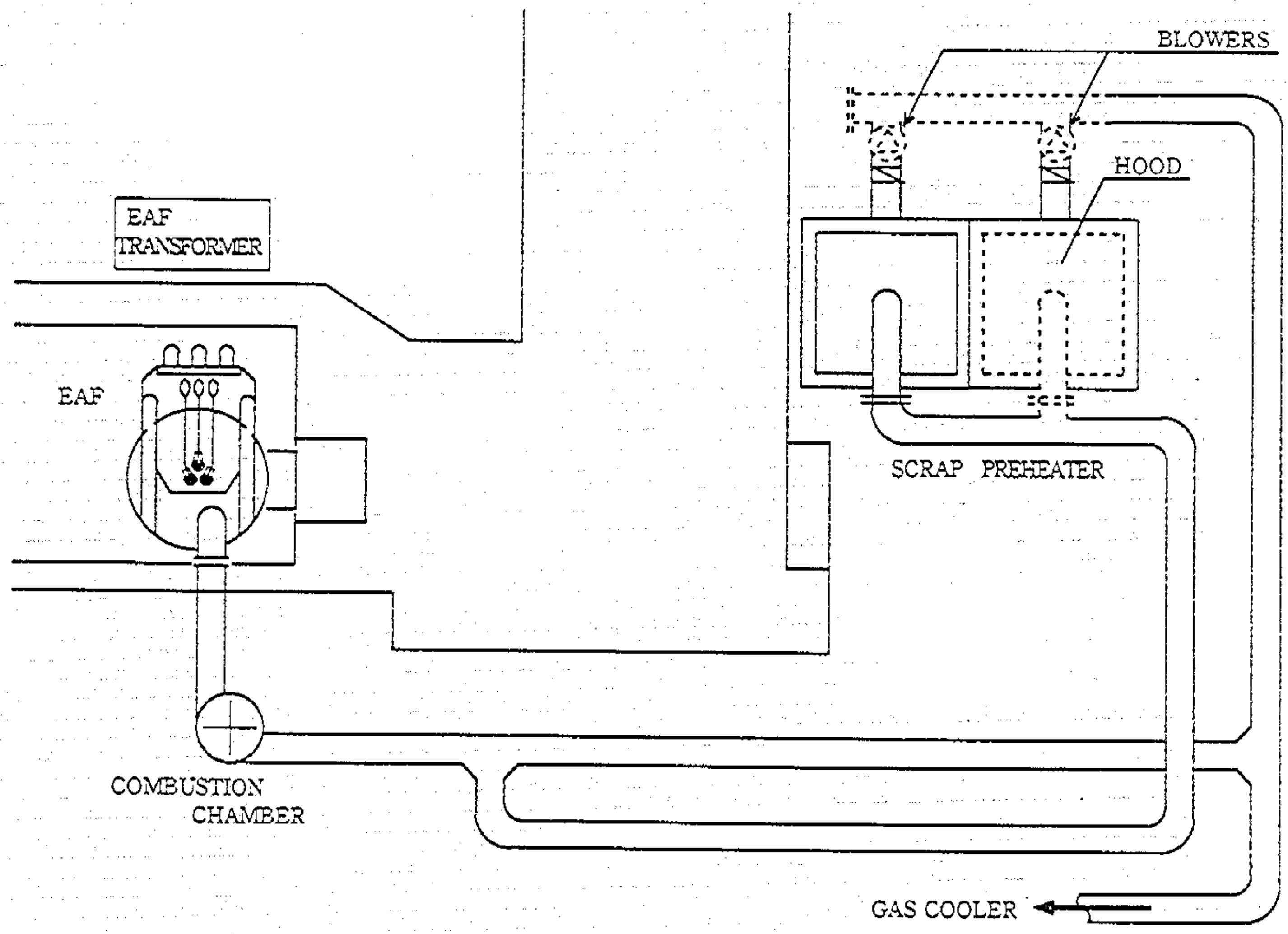

Figure 12-37 Schematic Layout of SPH Modification

12-12-2 Introduction of Billets Cooling System

1. Pumps: 2 units for 300 m^3/hr of water spray
2. Piping, valves and fittings
3. Spray nozzles: 144 pieces
4. Electrical equipment
5. Erection

Total budget cost: 21,300 US Dollars

12-13 Overall Evaluation of Countermeasures for Energy Conservation

Payout periods for the recommended modifications are calculated below.

1. Modification of scrap preheater (SPH) to accommodate preheating the 3rd bucket.

   See sub-section 12-9-4 (4).

   Saving of electric power: 6.8 kWh/t-MS (Molten Steel).

   Saving of production cost: 0.299 USD/t-MS.

   = 17,900 USD/ M at production of 60,000 t/M.

   Modification budget cost: 200,000 USD.

   Conclusion: Full recovery of investment is expected within 12 months.

2. Maintenance of oxy-fuel burners of EAF to keep the constant O_2/Oil ratio.

   See sub-section 12-9-4 (5).

   Saving of electric power: 5.2 kWh/t-output.

   Saving of production cost: 0.161 USD/t-MS.

   = 9,700 USD/M at production of 60,000 t/M.

3. Standardization of burnt lime addition into EAF.

   See sub-section 12-9-4 (9).

   Saving of burnt lime: 12.8 kg/t-MS comparing 1st half year of 1995.

   Saving of electric power: 20.7 kWh/t-MS.

   Saving of production cost: 87,000 USD/M at production of 60,000 t/M.

4. Decreasing flow rate of cooling water for EAF.

See sub-section 12-9-4 (13).

Saving of flow rate of cooling water: 800 m^3/hr.

Saving production cost: 6,500 USD/M at production of 60,000 t/M.

5. Introduction of billets cooling system in front of reheating furnace (Detail is shown in the end of this chapter titled as HOT CHARGE OF BILLET).

(1) At present: 60 - 70 % (65 %) of billet is hot charged at 300 -600 °C (average 450 °C) and heated to 1,100 - 1,150 °C (1,125 °C).

(2) Improvement: 60 - 70 % (65 %) of billet is hot charged at 690 °C and heated to 1,100 - 1,150 °C (1,125 °C).

Saving of fuel oil: Heat content (100.8 kcal/kg at 690 °C - 58.1 kcal/kg at 450 °C) x Billet weight 1,000 kg/Low heating value of fuel oil 10,000 kcal/kg = oil 4.3 kg/t-BT (billet)/Combustion efficiency 50 % = oil 8.5 kg/t-BT x 65 % = oil 5.6 kg/t-BT

Saving production cost: 5.6 kg/t-BT x 0.15 USD/kg-oil = 0.84 USD/t-BT = 50,400 USD/M at production of 60,000 t/M.

Construction cost: 21,300 USD

Conclusion: Full recovery of investment is expected within one month.

Following recommendations are guidelines for EAF's operation.

6. Turn power on immediately to prevent the drop of hot heel temperature.

If hot heel temperature is higher by 10 °C, electricity of 2.4 kWh/t-MS will be saved.

7. Preheat scrap as long as possible to obtain higher temperature.
8. Purchase as well calcined burnt lime as possible to prevent heat loss for decomposition of limestone.

12-14 Technical Guidelines for Energy Conservation

Measurement procedure is described for determination of heat balance of the electric arc furnace.

12-14-1 Heat balance

Heat balance consists of heat input and heat output.

(1) Items of Heat Input

Heat input includes the following items.

1. Heat quantity of electric power
2. Potential heat of hot metal, hot heel of raw materials and residual slag
3. Sensible heat of raw materials
4. Calorific power of fuel oil
5. Sensible heat of fuel oil
6. Oxidation heat of electrode
7. Oxidation heat of charge
8. Oxidation heat of additives
9. Heat of slag formation

(2) Items of Heat Output

Heat output includes the following items.

10. Potential heat of output and hot heel of molten steel
11. Potential heat of slag
12. Heat of decomposition for limestone and iron ore
13. Electrical heat loss
14. Heat in cooling water
15. Sensible heat of exhaust gas
16. Heat loss at furnace body
17. Other heat loss - difference between heat input (items from 1 to 9) and heat output (items from 10 to 16)

12-14-2 Measuring Items and Equipment/Instruments

(1) Measuring Items

Table 12-25 shows measuring items for calculation of heat input and output.

(2) Equipment/Instruments

Equipment/instruments are also shown in Table 12-25 and all equipment/instruments prepared by JICA are shown in Table 12-26.

Table 12-25 Measuring Items and Method and Equipment/Instruments

	Measuring Items	Measurement/ Estimation	Equipment/Instruments	Preparation of Equip./Instruments	Measuring/Estimation Interval	Remarks
1 Heat quantity of electric power	1) Consumption of electric power	1) M	1) kWh meter	1) Existing, IDC	1) Each heat	
	2) Output	2) E	2) -	2) -	2) Each heat	2) Calculation. See Note 1).
2 Potential heat of hot metal, hot heel of raw material and slag 2-1 Potential heat of hot metal						Hot metal was not used in this study.
2-2 Potential heat of hot heel	1) Weight of hot heel	1) E	1) -	1) -	1) Constant value	1) Amount of hot heel was estimated 10 t/heat in this study.
	2) Temperature of hot heel	2) E	2) -	2) -	2) Constant value	2) Hot heel temperature was estimated 1,550 °C in this study.
	3) Output	3) E	3) -	3) -	3) Each heat	3) Calculation. See Note 1).
2-3 Potential heat of residual slag						Small amount of residual slag was not considered in this study.
3 Sensible heat of raw materials	1) Consumption of raw materials	1) M	1) Weigher	1) Existing, IDC	1) Each bucket	
	2) Temperature of raw materials	2) M	2) Surface thermo-meter	2) JICA	2) At top, middle and bottom of each bucket before charge to EAF	2) Surface temperature of bucket represented scrap temperature in this study.

4 Calorific power of fuel oil	1) Consumption of fuel oil 2) Low heating value of fuel oil 3) Output	1) M 2) E 3) E	1) Integrator 2) - 3) -	1) Existing, IDC 2) - 3) -	1) Each heat 2) Constant value 3) Each heat	2) IDC prepared standard value. 3) Calculation. See Note 1).
5 Sensible heat of fuel oil						The small sensible heat of fuel oil was not considered in this study.
6 Oxidation heat of electrode	1) Unit consumption of electrode 2) C content of electrode 3) CO_2 and CO contents of exhaust gas	1) E 2) E 3) M	1) - 2) - 3) CO/CO_2 analyzer	1) - 2) - 3) JICA	1) Constant value 2) Constant value 3) Continuously	1) Unit consumption of electrode was statistically estimated in this study. 2) IDC prepared standard value.
7 Oxidation heat of charge						
7-1 Oxidation heat of charged carbon	1) Consumption of scrap, pig iron and charged carbon powder 2) C content of scrap, pig iron and charged carbon powder 3) C content of molten steel before tapping 4) CO2 and CO content of exhaust gas 5) Output	1) M 2) E 3) M 4) M 5) E	1) wheigher 2) - 3) Analyzer 4) CO/CO_2 analyzer 5) -	1) Existing, IDC 2) - 3) Existing, IDC 4) JICA 5) -	1) Each heat 2) Constant value 3) Each heat 4) Continuously 5) Each heat	1) Charged carbon powder was not used in this study. 2) IDC prepared standard value. 5) Calculation. See Note 1).

7-2 Oxidation heat of charged silicon	1) Consumption of scrap and pig iron	1) M	1) Weigher	1) Existing, IDC	1) Each heat	
	2) Si content of scrap and pig iron	2) E	2) -	2) -	2) Constant value	2) IDC prepared standard value.
	3) Si content of molten steel before tapping	3) M	3) Analyzer	3) Existing, IDC	3) Each heat	
	4) Output	4) E	4) -	4) -	4) Each heat	4) Calculation. See Note 1).
7-3 Oxidation heat of charged manganese						Same as 7-2.
7-4 Oxidation heat of charged phosphorus						Same as 7-2.
7-5 Oxidation heat of charged chromium						Same as 7-2.
7-6 Oxidation heat of charged aluminum						Same as 7-2.
7-7 Oxidation heat of charged iron	1) Slag weight	1) E	1)	1) -	1) Each heat	1) Calculation. See Note 2).
	2) FeO, Fe_2O_3 and CaO contents of slag	2) M	2) Slag analyzer	2) Existing, IDC	2) Each heat	2) Mean value of 7 heats was used in this study.
	3) Consumption of burnt lime	3) M	3) Weigher	3) Existing, IDC	3) Each heat	
	4) CaO content of burnt lime	4) E	4) -	4) -	4) Constant value	4) IDC prepared standard value.
	5) Output	5) E	5) -	5) -	5) Each heat	5) Calculation. See Note 1).
8 Oxidation heat of additives						
8-1 Oxidation heat of carbon of additives	1) Consumption of carbon injection, Si-Mn, Fe-Si and Fe-Mn	1) M	1) Weigher	1) Existing, IDC	1) Each heat	1) Fe-Si, Fe-Mn and Si-Mn were not used in this study.
	2) C content of carbon injection, Si-Mn, Fe-Si and Fe-Mn	2) E	2) -	2) -	2) Constant value	2) IDC prepared standard value.

	3) CO_2 and CO content of exhaust gas	3) M	3) CO/CO_2 analyzer	3) JICA	3) Continuously	
	4) Output	4) E	4) -	4) -	4) Each heat	4) Calculation. See Note 1).
8-2 Oxidation heat of silicon of additives						Fe-Si, Fe-Mn and Si-Mn were not used in this study.
8-3 Oxidation heat of manganese of additives						Fe-Si, Fe-Mn and Si-Mn were not used in this study.
9 Heat of slag formation	1) Slag weight	1) E	1) -	1) -	1) Each heat	1) Calculation. See Note 2).
	2) CaO, SiO_2 and P_2O_5 content of slag	2) M	2) Slag analyzer	2) Existing, IDC	2) Each heat	2) Mean value of 7 heats was used in this study.
	3) Consumption of burnt lime	3) M	3) Weigher	3) Existing, IDC	3) Each heat	
	4) CaO content of burnt lime	4) E	4) -	4) -	4) Constant value	4) IDC prepared standard value.
	5) Output	5) E	5) -	5) -	5) Each heat	5) Calculation. See Note 1).
10 Potential heat of Molten steel						
10-1 Potential heat of output	1) Temperature of molten steel before tapping	1) M	1) Thermocouple	1) Existing, IDC	1) Each heat	
10-2 Potential heat of hot heel of molten steel	1) Weight of hot heel	1) E	1) -	1) -	1) Constant value	1) Amount of hot heel was estimated 10 t/heat in this study..
	2) Temperature of hot heel	2) M	2) Thermocouple	2) Existing, IDC	2) Each heat	2) Temperature of hot heel is same as that of molten steel before tapping.
	3) Output	3) E	3) -	3) -	3) Each heat	3) Calculation. See Note 1).

11 Potential heat of slag	1) Slag weight	1) E	1) -	1) -	1) Each heat	1) Calculation. See Note 2).
	2) CaO content of slag	2) M	2) Slag analyzer	2) Existing, IDC	2) Each heat	2) Mean value of 7 heats was used in this study.
	3) Consumption of burnt lime	3) M	3) Weigher	3) Existing, IDC	3) Each heat	
	4) CaO content of burnt lime	4) E	4) -	4) -	4) Constant value	4) IDC prepared standard value.
	5) Output	5) E	5) -	5) -	5) Each heat	5) Calculation. See note 1).
12 Heat of decomposition						
12-1 Heat of Limestone Decomposition	1) Consumption of limestone	1) E	1) -	1) -	1) Each heat	1) Limestone of 30 % was included in burnt lime in this study.
	2) CaO content of limestone	2) E	2) -	2) -	2) Constant value	2) IDC prepared standard value.
	3) Output	3) E	3) -	3) -	3) Each heat	3) Calculation. See Note 1).
12-2 Heat of iron ore decomposition						Iron ore was not used in this study.
13 Electrical heat loss 13-1 Heat loss in secondary conductors 13.2. Heat loss of transformer						Electrical heat loss was not measured.

14 Heat in cooling water						
14-1 Heat in cooling water for elbow	1) Flow rate of cooling water 2) Outlet temperature of cooling water 3) Inlet temperature of cooling water 4) Power-on to power-off time 5) Output	1) M 2) M 3) M 4) M 5) E	1) Magnetic flow meter 2) Thermocouple 3) Thermocouple 4) Clock 5) -	1) Existing, IDC 2) JICA 3) Existing, IDC 4) Existing, IDC 5) -	1) At start of heat 2) Continuously 3) At start of heat 4) Each heat 5) Each heat	5) Calculation. See Note 1).
14-2 Heat in cooling water for roof						Same as 14-1.
14-3 Heat in cooling water for EBT						Same as 14-1.
14-4 Heat in cooling water for shell						Same as 14-1.
15 Sensible heat of exhaust gas	1) CO_2/CO content of exhaust gas 2) O_2 content of exhaust gas 3) Temperature of exhaust gas 4) Dynamic and static pressure of exhaust gas 5) Power-on to power-off time 6) Output	1) M 2) M 3) M 4) M 5) M 6) E	1) CO/CO_2 analyzer 2) O_2 analyzer 3) Thermocouple 4) Digital manometer 5) Clock 6) -	1) JICA 2) JICA 3) JICA 4) JICA 5) Existing, IDC 6) -	1) Continuously 2) Continuously 3) Continuously 4) Continuously 5) Each heat 6) Each heat	6) Calculation. See Note 1).

16 Heat loss at furnace body						
16-1 Heat loss at roof	1) Power-on to power-off time	1) M	1) Clock	1) Existing, IDC	1) Each heat	
	2) Surface area of roof	2) E	2)	2) -	2) Constant value	2) IDC prepared standard value.
	3) Output	3) E	3) -	3) -	3) Each heat	3) Calculation. See Note 1).
	4) Surface temperature	4) M	4) Pyrometer	4) JICA	4) A few times a heat	4) Mean value of ten times measurement was used for each heat in this study.
	5) Indoor temperature	5) M	5) Pyrometer	5) JICA	5) At start of heat	
16-2 Heat loss at shell	1) Power-on to power-off time	1) M	1) Clock	1) Existing, IDC	1) Each heat	
	2) Surface area of shell	2) E	2) -	2) -	2) Constant value	2) IDC prepared standard value.
	3) Output	3) E	3) -	3) -	3) Each heat	3) Calculation. See Note 1).
	4) Surface temperature	4) M	4) Pyrometer	4) JICA	4) Continuously	
	5) Indoor temperature	5) M	5) Pyrometer	5) JICA	5) At start of heat	
16-3 Heat loss at bottom						Same as 16-2

Note 1) Output means molten steel tapped into the ladle. It consists of billets, crop and skulls in the ladle and tundish. These weights could not be actually weighed. Output is calculated as follows:

Output = Charged raw materials x steel yield

Steel yield is statistically determined.

Note 2) As generated slag could not be actually weighed, slag weight is calculated by mass balance of CaO as follows:

Amount of slag = Consumption of burnt lime x CaO content of burnt lime/CaO content of slag.

Table 12-26 Equipment/Instruments Prepared by JICA

ITEM		DESCRIPTION
a-1)	CO/CO_2 analyzer 1 set	To measure CO and CO_2 contents of the exhaust gas at C/C inlet
a-2)	CO/CO_2 analyzer 1 set	To measure CO and CO_2 contents of the exhaust gas at C/C outlet
b-1)	O_2 analyzer 1 set	To measure O_2 content of the exhaust gas at C/C inlet
b-2)	O_2 analyzer 1 set	To measure O_2 content of the exhaust gas at C/C outlet
c)	Pretreatment unit (filter, drain pot, cooler) 1 set	To remove dusts and moisture in the exhaust gas
d-1)	Data logger 2 sets	To input into the personal computer the output data (analog signals) from the measuring devices after they are converted into digital signals
d-2)	Data logger 1 set	Stand-by
e-1)	Personal computer 2 sets	To record and exhibit on the monitoring screen the output data after being converted to digital signals by the data logger
e-2)	Personal computer 1 set	Stand-by. To be used in case of trouble of one of e-1). Actually this computer was used.
f-1)	Thermocouple PR type (JIS type R) 4 sets	To measure the temperature of the exhaust gas at C/C inlet
f-2)	Thermocouple CA type (JIS type K) 24 sets: 1 set for outlet, 16 sets for furnace, 7 sets for spare	To measure the temperature of the exhaust gas at C/C outlet and temperature of the furnace shell and bottom
f-3)	Thermocouple CC type (JIS type T) 10 sets (including 4 sets of spare)	To measure the temperature of the cooling water for the furnace
g-1)	Cable of 100 m for thermocouple for CA type	To connect the thermocouple to the data logger
g-2)	Cable of 1,000 m for thermocouple for CC type	To connect the thermocouple to the data logger
g-3)	Cable of 300 m for thermocouple for CA	To connect the thermocouple to the data logger

	type	
h)	Ultrasonic flow meter 1 set	To measure the flow rate of cooling water for the furnace. Not used. IDC's instrument was used.
i)	Gas sampling unit 4 pieces	Sampler for the exhaust gas at C/C inlet. Water cooled. Stainless-steel-made for C/C outlet.
j-1)	Digital manometer 2 sets	To measure the dynamic and static pressure of the exhaust gas for measurement of the flow rate at the C/C outlet.
j-2)	Digital manometer 2 sets	Stand-by
k)	Pitot' tube 4 sets	Used for measurement of the flow rate of the exhaust gas at the C/C outlet.
l)	Surface thermometer 2 sets	To measure the surface temperature of the scrap bucket for scrap temperature
m)	Printer 1 set	To print out the of measurement results.
n-1)	Transformer 3 sets	Step down transformer (200 V to 100V) and stabilizer for instruments
n-2)	Transformer 1 set	Stand-by
o)	Pyrometer (Thermometer) 2 sets	To measure the roof surface temperature and for back-up use for measurement of surface temperature of the furnace shell and bottom. One is for temperatures higher than 800°C and the other is for temperatures lower than 500 °C
p)	Equipment for moisture 1 set	To measure moisture in the exhaust gas.

12-14-3 Calculation Formulas and Reference Figures for Heat Balance, and Calculation of Heat Content of Exhaust Gas

The heat balance calculating method in arc furnace complies with Heat Balance System in Arc Furnace (JIS G 0703).

(1) Calculation Formulas and Reference Figures for Heat Balance

Calculation formulas and reference figures for the heat balance are shown below:

Table 12-27 Calculation Formulas for Heat Input
Table 12-28 Calculation Formulas for Heat Output
Table 12-29 Heat Content (Iron, Steel and Slag)
Table 12-30 Reaction Heat

Table 12-27 Calculation Formulas for Heat Input

(1) Heat Quantity of Electric Power, Q_1 (kcal/t-output)	$Q_1 = W_1 \times 860$ W_1: Unit consumption of electric power (kWh/t-output) 860: Conversion factor (kcal/kWh)
(2) Potential Heat of Hot Metal, Hot Heel of Raw Materials and Slag, Q_2 (kcal/t-output)	$Q_2 = Q_3 + Q_{2b} + Q_{2c}$ **(a) Potential Heat of Hot Metal, Q_{2a} (kcal/t-output)** $Q_{2a} = M_{2a} \times H_{2a}$ M_{2a} : Unit consumption of hot metal (kg/t-output) H_{2a} : Heat content of metal (kcal/kg) Note: Hot metal was not used in this study. **(b) Potential Heat of Hot Heel, Q_{2b} (kcal/t-output)** $Q_{2b} = M_{2b} \times H_{2b}$ M_{2b} : Unit consumption of hot heel (kg/t-output) H_{2b} : Heat content of hot heel (kcal/kg) Note: 1) The amount of hot heel was estimated to be 10t/heat in this study. 2) Heat content depends on the hot heel temperature which was estimated to be 1,550 °C in this study. **(c) Potential Heat of Residual Slag, Q_{2c} (kcal/t-output)** $Q_{2c} = M_{2c} \times H_{2c}$ M_{2c} : Unit consumption of residual slag (kg/t-output) H_{2c} : Heat content of residual slag (kcal/kg) Note: Small amounts of residual slag were not considered in this study.
(3) Sensible Heat of Raw Materials, Q_3 (kcal/t-output)	$Q_3 = M_3 \times (H_{3h} - H_{3a})$ M_3: Unit consumption of raw materials (kg/t-output) H_{3h}: Heat content of raw materials at temperature after preheating (kcal/kg) H_{3a}: Heat content of raw materials at indoor temperature (kcal/kg) Note: 1) H_{3a} was assumed 0 kcal/kg of heat content

	at 0 °C as basis in this study.
(4) Calorific Power of Fuel Oil, Q_4 (kcal/t-output)	$Q_4 = M_4 \times q_4$ M_4: Unit consumption of fuel oil (kg/t-output) q_4: Low heating value of fuel oil (kcal/kg)
(5) Sensible Heat of Fuel Oil, Q_5 (kcal/t-output)	$Q_5 = M_5 \times C_5 \times (Z_{5f} - Z_{5a})$ M_5: Unit consumption of fuel oil (kg/t-output) C_5: Mean specific heat of fuel oil (kcal/kg) Z_{5f}: Temperature of fuel oil (°C) Z_{5a}: Indoor temperature (°C) Note: Small sensible heat of fuel oil was not considered in this study.
(6) Oxidation Heat of Electrode, Q_6 (kcal/t-output)	$Q_6 = M_6 \times C_e \times 10^{-2} \times (q_{6CO_2} \times CO_2/(CO_2 + CO) + q_{6CO} \times CO/(CO_2 + CO))$ M_6: Unit consumption of electrode (kg/t-output) C_e: Carbon content of electrode (%) q_{6CO_2} : Oxidation heat of electrode in CO_2 formation (kcal/kg) q_{6CO} : Oxidation heat of electrode in CO formation (kcal/kg) CO_2 : CO_2 content of exhaust gas (%) CO: CO content of exhaust gas (%) Note: Unit consumption of electrode was estimated 1.9 kg/t-output.
(7) Oxidation Heat of Charge, Q_7 (kcal/t-output)	$Q_7 = Q_{7a} + Q_{7b} + Q_{7c} + Q_{7d} + Q_{7e} + Q_{7f} + Q_{7g}$ **(a) Oxidation Heat of Charged Carbon, Q_{7a} (kcal/t-output)** $Q_{7a} = M_{7a} \times (q_{7CO_2} \times CO_2/(CO_2 + CO) + q_{7CO} \times CO/(CO_2 + CO))$ $M_{7a} = M_{7aPig\ iron} + M_{7aScrap} + M_{7aCarbon\ powder} - 1{,}000 \times C_{Tap} \times 10^{-2}$ $M_{7aPig\ iron} = M_{7Pig\ iron\ Charge} \times C_{Pig\ iron} \times 10^{-2}$ $M_{7aScrap} = M_{7Scrap\ Charge} \times C_{Scrap} \times 10^{-2}$ $M_{7aCarbon\ powder} = M_{7Carbon\ powder\ Charge} \times C_{Carbon\ powder} \times 10^{-2}$ M_{7a}: Oxidation amount of charged carbon (kg/t-output) $M_{7aPig\ iron}$: Carbon in pig iron (kg/t-output)

$M_{7aScrap}$: Carbon in scrap (kg/t-output)

$M_{7aCarbon\ powder}$: Carbon in charged carbon powder (kg/t-output)

$M_{7Pig\ iron\ Charge}$: Unit consumption of pig iron (kg/t-output)

$M_{7Scrap\ Charge}$: Unit consumption of scrap (kg/t-output)

$M_{7Carbon\ powder\ Charge}$: Unit consumption of charged carbon powder (kg/t-output)

$C_{Pig\ iron}$: C content of pig iron (%)

C_{Scrap}: C content of scrap (%)

$C_{Carbon\ powder}$: C content of charged carbon powder (%)

C_{Tap}: C content of molten steel before tapping (%)

1,000: Output (kg)

q_{7CO2} : Heat of carbon oxidation in CO_2 formation (kcal/kg)

q_{7CO} : Heat of carbon oxidation in CO formation (kcal/kg)

CO_2 : CO_2 content of exhaust gas (%)

CO: CO content of exhaust gas (%)

Note: Charged carbon powder was not used in this study.

(b) Oxidation Heat of Charged Silicon, Q_{7b} (kcal/t-output)

$$Q_{7b} = M_{7b} \times q_{7b}$$

$$M_{7b} = M_{7bPig\ iron} + M_{7bScrap} - 1{,}000 \times Si_{Tap} \times 10^{-2}$$

$$M_{7bPig\ iron} = M_{7Pig\ iron\ Charge} \times Si_{Pig\ iron} \times 10^{-2}$$

$$M_{7bScrap} = M_{7Scrap\ Charge} \times Si_{Scrap} \times 10^{-2}$$

M_{7b}: Oxidation amount of charged silicon (kg/t-output)

$M_{7bPig\ iron}$: Silicon in pig iron (kg/t-output)

$M_{7bScrap}$: Silicon in scrap (kg/t-output)

$M_{7Pig\ iron\ Charge}$: Unit consumption of pig iron (kg/t-output)

$M_{7Scrap\ Charge}$: Unit consumption of scrap (kg/t-output)

$Si_{Pig\ iron}$: Si content of pig iron (%)

Si_{Scrap}: Si content of scrap (%)

Si_{Tap}: Si content of molten steel before tapping (%)

1,000: Output (kg)

q_{7b} : Heat of silicon (kcal/kg)

(c) Oxidation Heat of Charged Manganese, Q_{7c} (kcal/t-output)

Same as (b).

(d) Oxidation Heat of Charged Phosphorus, Q_{7d} (kcal/t-output)

Same as (b).

(e) Oxidation Heat of Charged Chromium, Q_{7e} (kcal/t-output)

Same as (b).

(f) Oxidation Heat of Charged Aluminum, Q_{7f} (kcal/t-output)

Same as (b).

(g) Oxidation heat of Charged Iron, Q7g (kcal/t-output)

$Q_{7g} = M_{7g} \times (FeO \times 0.777 \times q_{7gFeO} + Fe_2O_3 \times 0.699 \times q_{7gFe2O3}) \times 10^{-2}$

M_{7g}: Unit weight of slag (kg/t-output)

FeO: FeO content of slag (%)

Fe_2O_3: Fe_2O_3 content of slag (%)

q_{7gFeO}: Heat of iron oxidation in FeO formation (kcal/kg)

$q_{7gFe2O3}$: Heat of iron oxidation in Fe_2O_3 formation (kcal/kg)

0.777: Ratio of Fe in FeO

0.699: Ratio of Fe in Fe_2O_3

Note: Unit weight of slag was calculated as follows in this study:

$M_{7g} = M_{7gLime} \times CaO_L/CaO_S$

M_{7gLime}: Unit consumption of burnt lime (kg/t-output)

CaO_S: CaO content of slag (%)

CaO_L: CaO content of burnt lime (%)

Note: Mean value of seven heats was used for slag analysis in this study.

(8) Oxidation Heat of Additives, Q_8 (kcal/t-output)

$Q_8 = Q_{8a} + Q_{8b} + Q_{8c}$

(a) Oxidation Heat of Carbon in Additives, Q_{8a} (kcal/t-output)

$Q_{8a} = M_{8a} \times (q_{8CO2} \times CO_2/(CO_2 + CO) + q_{8CO} \times CO /(CO_2 + CO))$

$M_8 = M_{8aCarbon\ injection} + M_{8aSi\text{-}Mn} + M_{8aFe\text{-}Si} + M_{8aFe\text{-}Mn}$

$M_{8aCarbon\ injection} = M_{8Carbon\ injection\ Additives} \times C_{Carbon\ injection} \times 10^{-2}$

$M_{8aSi\text{-}Mn} = M_{8Si\text{-}Mn\ Additives} \times C_{Si\text{-}Mn} \times 10^{-2}$

$M_{8aFe\text{-}Si} = M_{8Fe\text{-}Si\ Additives} \times C_{Fe\text{-}Si} \times 10^{-2}$

$M_{8aFe\text{-}Mn} = M_{8Fe\text{-}Mn\ Additives} \times C_{Fe\text{-}Mn} \times 10^{-2}$

M_{8a}: Carbon of additives(kg/t-output)

$M_{8aCarbon\ injection}$: Carbon in carbon injection (kg/t-output)

$M_{8aSi\text{-}Mn}$: Carbon in Si-Mn (kg/t-output)

$M_{8aFe\text{-}Si}$: Carbon in Fe-Si (kg/t-output)

$M_{8aFe\text{-}Mn}$: Carbon in Fe-Mn (kg/t-output)

$M_{8Carbon\ injection\ Additives}$: Unit consumption of carbon injection (kg/t-output)

$M_{8Si\text{-}Mn\ Additives}$: Unit consumption of Si-Mn (kg/t-output)

$M_{8Fe\text{-}Si\ Additives}$: Unit consumption of Fe-Si (kg/t-output)

$M_{8Fe\text{-}Mn\ Additives}$: Unit consumption of Fe-Mn (kg/t-output)

$C_{Carbon\ injection}$: C content of carbon injection (%)

$C_{Si\text{-}Mn}$: C content of Si-Mn (%)

$C_{Fe\text{-}Si}$: C content of Fe-Si (%)

$C_{Fe\text{-}Mn}$: C content of Fe-Mn (%)

q_{8CO2} : Heat of carbon oxidation in CO_2 formation (kcal/kg)

q_{8CO} : Heat of carbon oxidation in CO formation (kcal/kg)

CO_2 : CO_2 content of exhaust gas (%)

CO: CO content of exhaust gas (%)

Note: Si-Mn Fe-Si and Fe-Mn were not used in this study.

(b) Oxidation Heat of Silicon in Additives, Q_{8b} (kcal/t-output)

$Q_{8b} = M_{8b} \times q_{8b}$

$M_{8b} = M_{8bSi\text{-}Mn} + M_{8bFe\text{-}Si} + M_{8bFe\text{-}Mn}$

$M_{8bSi\text{-}Mn} = M_{8Si\text{-}Mn\ Additives} \times Si_{Si\text{-}Mn} \times 10^{-2}$

$M_{8bFe\text{-}Si} = M_{8Fe\text{-}Si\ Additives} \times Si_{Fe\text{-}Si} \times 10^{-2}$

$M_{8bFe\text{-}Mn} = M_{8Fe\text{-}Mn\ Additives} \times Si_{Fe\text{-}Mn} \times 10^{-2}$

M_{8b}: Silicon in additives (kg/t-output)

$M_{8bSi\text{-}Mn}$: Silicon in Si-Mn (kg/t-output)

$M_{8bFe\text{-}Si}$: Silicon in Fe-Si (kg/t-output)

$M_{8bFe\text{-}Mn}$: Silicon in Fe-Mn (kg/t-output)

$M_{8Si\text{-}Mn\ Additives}$: Unit consumption of Si-Mn (kg/t-output)

$M_{8Fe\text{-}Si\ Additives}$: Unit consumption of Fe-Si (kg/t-output)

$M_{8Fe\text{-}Mn\ Additives}$: Unit consumption of Fe-Mn (kg/t-output)

$Si_{Si\text{-}Mn}$: Si content of Si-Mn (%)

$Si_{Fe\text{-}Si}$: Si content of Fe-Si (%)

$Si_{Fe\text{-}Mn}$: Si content of Fe-Mn (%)

1,000: Output (kg)

q_{8b} : Heat of silicon (kcal/kg)

Note: Si-Mn, Fe-Si and Fe-Mn were not used in this study.

(c) Oxidation Heat of Manganese in Additives, Q_{8c} (kcal/t-output)

Same as (b).

(9) Heat of Slag Formation, Q_9 (kcal/t-output)

$Q_9 = M_9 \times (SiO_2 \times q_{9SiO2} + P_2O_5 \times q_{9P2O5}) \times 10^{-2}$

M_9: Unit weight of slag (kg/t-output)

Note: See (7) (g).

q_{9SiO2}: Heat of SiO_2 reaction in Ca_2SiO_4 formation (kcal/kg)

q_{9P2O5}: Heat of P_2O_5 reaction in $Ca_3P_2O_3$ formation (kcal/kg)

SiO_2: SiO_2 content of slag (%)

	P_2O_5: P_2O_5 content of slag (%) Note: The mean value of seven heats was used for slag analysis in this study.
Heat Input, **$Q_{Heat\ Input}$ (kcal/t-output)**	**$Q_{Heat\ Input} = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8 + Q_9$ (kcal/t-output)**

Table 12-28 Calculation Formulas for Heat Output

(10) Potential Heat of Molten Steel, Q_{10} (kcal/t-output)	$Q_{10} = Q_{10a} + Q_{10b}$ **(a) Potential Heat of Output (excluding hot heel), Q_{10a} (kcal/t-output)** $Q_{10a} = 1{,}000 \times H_{10a}$ 1,000: Output (kg) H_{10a}: Heat content of molten steel before tapping (kcal/g) Note: Heat content is dependent on temperature. **(b) Potential Heat of Hot heel, Q_{10a} (kcal/t-output)** $Q_{10b} = M_{10b} \times H_{10b}$ M_{10b}: Unit weight of hot heel (kg/t-output) H_{10b}: Heat content of hot heel (kcal/g) Note: 1) Amount of hot heel was assumed 10 t/heat in this study. 2) Heat content is dependent on temperature.
(11) Potential Heat of Slag, Q_{11} (kcal/t-output)	$Q_{11} = M_{11} \times H_{11}$ M_{11}: Unit weight of slag (kg/t-output) H_{11}: Heat content of slag (kcal/g) Note: 1) Concerning unit weight of slag, see (7) (g) in Heat Input. 2) Heat content is dependent on temperature which is same as that of molten steel in this study.
(12) Heat of Decomposition, Q_{12} (kcal/t-output)	$Q_{12} = Q_{12a} + Q_{12b}$ **(a) Heat of Limestone Decomposition, Q_{12a} (kcal/t-output)** $Q_{12a} = 10^{-2} \times M_{12a} \times CaO \times q_{12aCaCO3}$ M_{12a}: Unit consumption of limestone (kcal/t-output) $q_{12aCaCO3}$: Heat of decomposition of limestone (kcal/kg) CaO: CaO content of limestone (%) Note: 1) 30 % of limestone was included in burnt lime in this study. **(b) Heat of Iron Ore Decomposition, Q_{12b} (kcal/t-output)**

	$Q_{12b} = 10^{-2} \times M_{12b} \times (FeO \times q_{12bFeO} + Fe_2O_3 \times q_{12bFe2O3})$ M_{12b}: Unit consumption of iron ore (kcal/t-output) q_{12bFeO}: Heat of decomposition of FeO in iron ore (kcal/kg) $q_{12bFe2O3}$: Heat of decomposition of Fe_2O_3 in iron ore (kcal/kg) FeO: FeO content in iron ore (%) Fe_2O_3: Fe_2O_3 content in iron ore (%) Note: Iron ore was not used in this study.
(13) Electrical heat Loss, Q_{13} (kcal/t-output)	$Q_{13} = Q_{13a} + Q_{13b}$ **(a) Heat Loss in Secondary Conductors, Q_{12a} (kcal/t-output)** $Q_{13a} = (R_0 \times I_0^2 \times T \times 860) \times 3.6/T$ $R_0 = R_S + O \times (E_1 + E_2 + E_3)/S$ $I_0 = (W_0 \times 10{,}000)/(3^{1/2}\ V0 \times \cos U)$ $W_0 = W_r/T$ $V_0 = V \times T'/T$ $\cos U = W_p/(W_p^2 + W_Q^2)^{1/2}$ R_0: Combined resistance of secondary conductor and electrode (Ohm) I_0: Mean current (A) t: Output (ton) R_S: Combined resistance of secondary conductor resistance and contact resistance between electrode and holder (Ohm) O: Specific resistance of electrode (Ohm-cm) S: Sectional area of electrode (cm^2) E_1, E_2, E_3: Average length of electrode in each phase exposed from roof W_0: Mean electric power (kW) V_0: Mean voltage (V) cos U: Mean power factor (-) W_p: Electric power consumed (kW) W_Q: Reactive energy (kVar)

V: Secondary voltage of transformer tap(V)

T': Conducting period of each tap in transformer (hr)

T: Power-on to power-off time (hr)

Note: Heat loss in secondary conductor was not measured.

(b) Heat Loss of Transformer, Q_{13b} (kcal/t-output)

$Q_{13b} = (W_1 - W_2) \times 860/t$

W_1 = Electric power on primary side of transformer (kWh)

W_2 = Electric power on secondary side of transformer (kWh)

Note: Heat loss in secondary conductor was not measured.

(14) Heat in Cooling Water, Q_{14} (kcal/t-output)

$Q_{14} = Q_{14a} + Q_{14b} + Q_{14c} + Q_{14d}$

(a) Heat in Cooling Water for Elbow, Q_{14a} (kcal/t-output)

$Q_{14a} = M_{14a} \times C_{14} \times (t_{a14aO} - t_{14aI})$

$M_{14a} = F_{14a} \times T/t$

M_{14a}: Average quantity of cooling water (kg/t-output)

C_{14}: Specific heat of water (kcal.kg, °C) = 1

t_{14aO}: Mean outlet temperature of cooling water (°C)

t_{14aI}: Mean inlet temperature of cooling water (°C)

F_{14a}: Flow rate of cooling water (kg/hr)

T: Power-on to power-off time (hr)

t: Output (ton)

(b) Heat in Cooling Water for Roof, Q_{14b} (kcal/t-output)

Same as (a).

(c) Heat in Cooling Water for EBT, Q_{14c} (kcal/t-output)

Same as (a).

(d) Heat in Cooling Water for Shell, Q_{14d} (kcal/t-output)

Same as (a).

(15) Sensible Heat of Exhaust Gas, Q_{15} **(kcal/t-output)**	$Q_{15} = H_{15} \times T \times 60/t$ H_{15} = Heat in average flow of exhaust gas (kcal /min) T = Power-on to power-off time (hr) t = Output (ton) Note: Heat in average flow of exhaust gas is described in another pages (3. Calculation of Heat Content of Exhaust Gas).
(16) Heat Loss at Furnace Body, Q_{16} **(kcal/t-output)**	$Q_{16} = Q_{16a} + Q_{16b} + Q_{16c}$ **(a) Heat Loss at Roof,** Q_{16a} **(kcal/t-output)** $Q_{16a} = T \times (q_{16aR} + q_{16aC}) \times A/t$ $q_{16aR} = 4.88 \times r \times [(T_0/100)^4 - (T_a/100)^4]$ $q_{16aC} = p \times (t_0 - t_a)^{1.25}$ q_{16aR}: Radiation heat loss at roof (kcal/m$_2$, hr) q_{16aC}: Convection heat loss at roof (kcal/m$_2$, hr) T: Power-on to power-off time (hr) A: Surface area of roof (m$_2$) t: Output (ton) r: Degree of blackness on furnace surface due to radiation (0.8) T_0: Surface temperature of roof (°C) T_a: Indoor temperature (°C) p: 2.8 for horizontal wall facing upward, roof 2.2 for vertical wall facing sideways, shell 1.5 for horizontal wall facing downward, bottom Note: Degree of blackness of 0.8 is based on "Heat Calculating Figures for Iron and Steel Making (1966)" by the Japan and Steel Association, Society of Japan Academic Development). **(b) Heat Loss at Shell,** Q_{16b} **(kcal/t-output)** Same as (a) **(c) Heat Loss at Bottom,** Q_{16c} **(kcal/t-output)** Same as (a)
(17) Other Heat Loss, Q_{17} **(kcal/t-output)**	$Q_{17} = Q_{heat\ input} - (Q_{10} + Q_{11} + Q_{12} + Q_{13} + Q_{14} + Q_{15} + Q_{16}$

Table 12-29 Heat Content (Iron, Steel and Slag)

Unit: kcal/kg

Temperature (°C)	Pig iron	Pure iron	Mild steel	0.23 % C	0.4 % C	0.8 % C	1.2 % C	18 Cr - 8 Ni	13 Cr	Slag *
0	-	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0	-
50	-	-	-	5.6	5.6	5.4	5.4	5.9	5.2	-
100	-	11.0	-	11.4	11.4	11.2	11.2	12.0	10.8	19.1
150	-	-	-	17.4	17.4	17.4	17.4	18.3	16.8	-
200	-	23.0	-	23.6	23.5	23.8	23.9	24.7	23.0	39.9
250	-	-	-	30.0	29.8	30.3	30.4	31.1	29.3	-
300	-	35.0	-	36.6	36.4	37.1	37.1	37.7	35.9	60.0
350	-	-	-	43.5	43.2	44.1	44.0	44.3	42.8	-
400	-	49.0	-	50.6	50.2	51.3	51.1	51.1	50.0	81.0
450	-	-	-	58.1	57.5	58.8	58.8	58.1	57.6	-
500	-	64.0	-	66.0	65.3	66.8	66.1	65.2	65.8	104.9
550	-	-	-	74.4	73.5	75.1	74.0	72.7	74.4	-
600	-	82.0	-	83.3	82.0	83.6	82.3	80.5	83.8	129.0
650	-	-	-	92.7	90.7	92.3	91.2	88.0	93.5	-
700	-	102.0	-	102.8	99.9	101.5	101.0	95.5	104.0	151.9
750	-	-	-	119.9	118.8	126.8	125.9	102.9	114.8	-
800	-	125.0	-	131.3	126.2	133.6	133.7	110.6	123.0	177.0
850	-	-	-	140.1	132.3	141.5	141.5	118.3	132.6	-
900	-	145.7	-	147.8	138.8	148.9	148.9	126.0	140.6	201.8
950	-	-	-	155.6	146.3	156.3	156.4	133.8	148.4	-
1000	-	163.0	-	163.3	153.7	163.9	163.8	141.5	156.1	227.9
1050	-	-	-	171.1	161.3	171.5	171.5	149.3	163.9	-
1100	-	178.0	-	178.8	168.8	179.3	179.1	157.2	171.7	254.8
1150	-	-	-	186.7	176.5	187.2	186.9	165.2	179.5	-
1200	264.9	194.0	-	194.6	184.3	195.2	194.7	173.2	187.2	286.9
1250	-	-	-	202.7	192.3	203.3	202.7	181.3	195.0	-
1300	280.9	209.0	-	210.9	200.5	211.4	210.7	189.4	202.8	321.7
1350	-	-	-	(219.2)	(208.9)	(219.5)	(218.7)	(197.5)	(210.6)	-
1400	301.9	231.0	-	(227.5)	(217.5)	(227.5)	(226.7)	(205.6)	(218.4)	365.7
1450	-	-	-	(236.1)	(226.3)	(235.6)	(234.7)	(213.6)	(226.2)	-
1500	322.0	247.9	(311.0)	-	-	-	-	-	-	406.8
1550	-	-	-	-	-	-	-	-	-	431.6
1600	343.0	331.0	332.0	-	-	-	-	-	-	459.8
1650	-	-	-	-	-	-	-	-	-	489.6
1700	364.0	349.9	353.0	-	-	-	-	-	-	519.7

* Basic slag of steelmaking process; CaO = 43.55 %, SiO_2 = 34.22 %, FeO = 10.27 %, Fe_2O_3 = 3.68 %, Al_2O_3 = 4.68 %, MgO = 11.84 % and MnO = 6.60 %

Table 12-30 Reaction Heat

Unit: kcal/kg

Item		Reaction Heat		Reaction
Oxidation Heat	Graphite carbon	7,829	(Graphite carbon)	$C + O_2 = CO_2$
	Graphite carbon	2,200	(Graphite carbon)	$C + 1/2\ O_2 = CO$
	C	8,075	(C)	$C + O_2 = CO_2$
	C	2,448	(C)	$C + 1/2\ O_2 = CO$
	Si	7,459	(Si)	$Si + O_2 = SiO_2$
	Mn	1,674	(Mn)	$Mn + 1/2\ O_2 = MnO$
	P	5,811	(P)	$P + 5/4\ O_2 = 1/2\ P_2O_5$
	Cr	2,620	(Cr)	$Cr + 3/4\ O_2 = 1/2\ Cr_2O_3$
	Al	7,419	(Al)	$Al + 3/4\ O_2 = 1/2\ Al_2O_3$
	Fe	1,151	(Fe)	$Fe + 1/2\ O_2 = FeO$
	Fe	1,756	(Fe)	$Fe + 3/4\ O_2 = 1/2\ Fe_2O_3$
Formation Heat	Slag	502	(SiO_2)	$2\ CaO + SiO2 = CaSiO_4$
	Slag	1,070	(P_2O_5)	$3\ CaO + P_2O_5 = Ca_3P_2O_3$
Decomposition Heat	Iron ore	896	(FeO)	$FeO = Fe + 1/2\ O_2$
	Iron ore	1,228	(Fe_2O_3)	$Fe_2O_3 = 2\ Fe + 3/2\ O_2$
	Lime stone	757	(CaO)	$CaCO_3 = CaO + CO_2$

(2) Calculation of Heat Content of Exhaust Gas

1) Measurement of Velocity, Flow Rate and Composition of Exhaust Gas

At C/C-outlet point, velocity and flow rate of exhaust gas are continuously measured based on JIS Z 8808 -7 ("Method of measuring dust concentration in flue gas" 7. Measurement of Velocity and Flow of Flue Gas).

Gas composition is also measured continuously both at C/C-outlet point and C/C-inlet point.

2) Calculation of Heat Content of Exhaust Gas

Combined gas flow rate at C/C-outlet with change of gas composition from CC-inlet point to CC-outlet point, mass balance equilibrium gives gas flow rate at C/C-inlet. To calculate the heat content of exhaust gas at C/C-inlet point, linearized specific heat is referred to JIS G 0703 ("Method of heat balance calculation of arc furnace")

$$g_0 = [\{44 \times CO_{2OUT} + 32 \times O_{2OUT} + 28 \times (100 - CO_{2OUT} - O_{2OUT})\} \times (1 - H / 100) + 18 \times H] / (22.4 \times 100) \quad (kg/Nm^3) \text{ --------- } (1)$$

$$g = \{g_0 \times 273/(273 + T_{OUT})\} \times \{(P_{Atm} \times 100/9.81 + SP_{OUT}) / (13.6 \times 760)\} \quad (kg/m^3) \text{ ---------- } (2)$$

$$V = 0.854 \times \sqrt{2 \times 9.81 \times DP_{OUT} / g} \quad (m/s) \text{ --------- } (3)$$

$$F_{OUT} = V \times p \times (1840 / 2000)^2 \times 60 \times \{273 / (273 + T_{OUT})\} \times (P_{Atm} \times 100 / 9.81 + SP_{OUT}) / (13.6 \times 760) \quad (Nm^3/min) \text{ ---------} (4)$$

$$F_{IN} = F_{OUT} \times (CO_{IN} + CO_{2IN}) / (CO_{OUT} + CO_{2OUT}) \quad (Nm^3/min) \text{ --------- } (5)$$

$$q_{IN} = F_{IN} \times T_{IN} \times \{q_{CO} \times CO_{IN} + q_{CO2} \times CO_{2IN} + q_{O2} \times O_{2IN} + q_{N2} \times (100 - CO_{IN} - CO_{2IN} - O_{2IN})\} / (4.186 \times 100)$$

$$q_{CO} = 0.00013\ T \times T_{IN} + 1.28\ (kj / Nm^3 C)$$

$$q_{CO2} = 0.000397\ T \times T_{IN} + 1.826\ (kj / Nm^3 C)$$

$$q_{O2} = 0.000148\ T \times T_{IN} + 1.33\ (kj / Nm^3 C)$$

$$q_{N2} = 0.000128\ T \times T_{IN} + 1.271\ (kj / Nm^3 C) \quad (kcal/min) \text{---------} (6)$$

Whereas;

g_0: Gas density at 0°C and 1 atm. pressure. (kg/Nm^3)

g: Gas density at actual state. (kg/m^3)

V: Gas velocity at actual state. (m/s)

Note: Measurement was done using a Pitot tube, of coefficient 0.845.

F_{OUT}: Gas flow rate at C/C-outlet. (Nm^3/min)

Note: Duct diameter is 1840 mm.

F_{IN}: Estimated gas flow rate at C/C-inlet. (Nm$_3$/min)

q_{IN}: Estimated gas heat content at C/C-inlet. (kcal/min)

DP_{OUT}: Gas dynamic pressure at C/C-outlet. (mmAq)

SP_{OUT}: Gas static pressure at C/C-outlet. (mmAq)

P_{Atm}: Atmospheric pressure. (hPa)

T_{OUT}: Gas temperature at C/C-outlet. (°C)

CO_{OUT}: CO content of exhaust gas at C/C-outlet. (%)

CO_{2OUT}: CO_2 content of exhaust gas at C/C-outlet. (%)

O_{2OUT}: O_2 content of exhaust gas at C/C-outlet. (%)

N_{2OUT}: N_2 content of exhaust gas at C/C-outlet. (%)

T_{IN}: Gas temperature at C.C. outlet. (°C)

CO_{IN}: CO content of exhaust gas at C/C-inlet. (%)

CO_{2IN}: CO_2 content of exhaust gas at C/C-inlet. (%)

O_{2IN}: O_2 content of exhaust gas at C/C-inlet. (%)

N_{2IN}: N_2 content of exhaust gas at C/C-inlet. (%)

p: Pi, 3.14

H: Moisture (%)

12-14-4 Data Sheets for Measurement

Results of measurement of the exhaust gas, outlet temperature of cooling water and surface temperature of furnace body are automatically recorded in the personal computer. Other data are recorded on the data sheets.

Examples of data sheets for measurement are shown below:

Table 12-31 Operational Data: Electric Power

Date	
Heat No.	
Name	

Time		Voltage	Electric power	Remarks	
hr	min	(V)	(kWh)		
	0				
	5				
	10				
	15				
	20				
	25				

Table 12-32 Operational Data: Manipulator and Additives

Date	
Heat No.	
Name	

Time hr	min	O2 by lancing (Nm3)		Carbon injection (kg)		Additives - CaO (kg)		Additives - Kg)	
	0								
	5								
	10								
	15								
	20								
	25								

Table 12-33 Operational Data: Oxy-Fuel Burner

Date	
Heat No.	
Name	

		No. 1 Furnace burner				No. 2 Furnace burner			
Time		O_2		Oil		O_2		Oil	
hr	min	(Nm3)		(kg)		(kg)		Kg)	
	0								
	5								
	10								
	15								
	20								

Table 12-34 Operational Data: Scrap

Date	
Heat No.	
Name	

1st bucket		**2nd bucket**	
Bucket No.		Bucket No.	
Time		Time	
Temperature (°C)		**Temperature (°C)**	
Upper		Upper	
Middle		Middle	
Lower		Lower	
Raw materials (kg)		**Raw materials (kg)**	
Scrap		Scrap	
Pig iron		Pig iron	
Total		Total	

3 rd bucket			
Bucket No.		-	-
Time		-	-
Temperature (°C)		-	
Upper		-	-
Middle		-	-
Lower		-	-
Raw materials (kg)		**Raw materials (kg)**	
Scrap		Scrap	
Pig iron		Pig iron	
Total		Total	

Table 12-35 Operational Data: Cooling Water

Date	
Heat No.	
Name	

Time	
Flow rate (m^3/hr) EBT	
Elbow	
Roof	
Shell-1	
Shell-2	
Total	
Inlet temperature (°C)	

12-14-5 Measurement Results

Following data shall be recorded.

1. Profile of facilities
2. Long-run operation results of each five heats of same grade steel which are operated before and after sampled three consecutive heats for heat balance.
3. Concerned personnel for measurement
4. Operation results of sampled three heats for heat balance
5. Results of measurement of sampled three heats for heat balance

Examples are shown as follows:

Table 12-36 Profile of the Electric Arc Furnace

Name of company		IDC (IZMIR DEMIR CELIK SANAYI A. S.)
Address		Foca Celik Fabrikasi 35807 Aliaga, IZMIR, TURKEY
Furnace manufacturer		NKK Corporation (Japan)
Type	Type of furnace	AC arc furnace
	Charging method	Top charge
	Tapping method	EBT system
	Other facilities (bottom stirrer, bottom bubbling, water sprayed electrode, scrap preheater, etc.)	Water sprayed electrode, Scrap preheater
	Nominal capacity (ton)	
Molten steel	Bath diameter (mm)	
	Bath area (m^2)	
	Bath depth (mm)	
	Distance between sill level and roof (mm)	
Roof	Thickness (mm)	
	Radius (mm)	
	Diameter of electrode hole (mm)	
	Pitch circle diameter (mm)	
	Ratio of water cooling area (%)	
Shell	Inside diameter (mm)	
	Thickness (mm)	
	Height (mm)	
	Height from bottom to roof (mm)	
	Ratio of water cooling area (%)	
Hearth	Diameter (mm)	
	Thickness (mm)	
	Height of bank (mm)	
Working door	Width (mm)	
	Height (mm)	
Tapping hole (EBT)	Diameter (mm)	
	Depth (mm)	

Transformer	Capacity (MVA) Primary voltage (kV) Secondary voltage (V) Connection
Reactor	Capacity (kVA) Reactance (Ohm)
Electrode	Diameter (mm)
Oxygen injection	Type and number Capacity (Nm^3/hr)
Burner	Type, number and capacity Kind of fuel and capacity (kg/hr)
Carbon injection	Capacity and number (kg/hr)

Table 12-37 Summary of Long-Run Operation Results of Before and After Heat Measured

Date	Aug. 13	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Aug. 14	Average
Heat Mo.	965746	965747	965748	965749	965750	965754	965755	965756	965757	965758	
1. Charged raw material (excluding hot											
1.1. 1st bucket (t) Scrap											
1.2. 2nd bucket (t)											
Scrap											
Pig iron											
1.3. 3rd bucket (t) Scrap											
2. Output (Production) (t)											
2.1. Good billet (t)											
2.2. Crop end, skull (t)											
3. Steel yield (%)											
3.1. Molten steel yield											
3.2. Good billet yield											
4. Operation time (min.)											
4.1. Tap-to-tap time											
4.2. Power on-to-power off time											
5. Consumption											
5.1. Electric power (kWh/t-output)											
5.2. Fuel oil (kg/t-output)											
5.3. Oxygen gas (Nm3/t-output)											
Burner											
Lancing											
5.4. Burnt lime (kg/heat)											
5.5. Carbon injection (kg/heat)											
6. Composition and temperature of molten steel before tapping											
6.1. C (%)											
6.2. Si (%)											

6.3. Mn (%)	
6.4. P (%)	
6.5. S (%)	
6.6. Cr (%)	
6.6. Temperature (deg. C)	
7. Weight of hot heel (t)	
8. Composition of billet (%)	
8.1. C (%)	
8.2. Si (%)	
8.3. Mn (%)	
8.4. P (%)	
8.5. S (%)	
8.6. Cu	
8.7. Ni	
8.8. Cr	
8.9. Mo	
8.10. Sn	
8.11 Al	

Note: 1) Heat No. 965757 is excluded for average of pig iron.
2) Heat No. 965755 is excluded for average of fuel oil.

Table 12-38 Concerned Personnel for Measurement

Date	August 14, 1996		
Heat No.	965751, 965752, 965753		
Company	Study team	EIE	IDC
Staff	- I. Kawakami - H. Tokano	- Hediye Yillikci - Bora Omurtay - Mehmet Sezer - Birgul Duman	- Suleyman Eldem - Necati Unsal
Measuring person			
Flow rate, temperature and composition of exhaust gas	- T. Kawai - S. Kinoshita	- (Bora Omurtay) - (Birgul Duman)	- (Mehmet Yalcin)
Outlet temperature of cooling water for furnace	- N. Honda	- (Mehmet Sezer)	
Electric power			- Sibel Ozkan
Oxygen gas by lancings			- Uguri Egeli
Carbon injection			
Burnt lime			
Oxygen gas and fuel oil by 4 furnace/1 door burners			- Hikmet Yuzuak
Flow rate and inlet temperature of cooling water for furnace			- Talip Bostanci
Temperature of scrap bucket	- (H. Tokano)		- Duzgun Elitas
Surrounding conditions	- H. Tokano		

Note: Bracket means co-working with specialists.

Table 12-39 Operation Results of Three Sampled Heats

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
1. Charged raw material (excluding hot heel) (t)			
1.1. 1st bucket (t) Scrap			
1.2. 2nd bucket (t)			
Scrap			
Pig iron			
1.3. 3rd bucket (t) Scrap			
2. Output (Production) (t)			
2.1. Good billet (t)			
2.2. Crop end, skull (t)			
3. Steel yield (%)			
3.1. Molten steel yield			
3.2. Good billet yield			
4. Operation time (min.)			
4.1. Tap-to-tap time			
4.2. Power-on-to-power-off time			
5. Unit consumption			
5.1. Electric power (kWh/output)			
5.2. Fuel oil (kg/t-output)			
5.3. Oxygen gas (Nm^3/t-output)			
Burner			
Lancing			
5.4. Burnt lime (kg/t-output)			
5.5. Carbon injection (kg/t-output)			
6. Composition and temperature of molten steel before tapping			
6.1. C (%)			
6.2. Si (%)			
6.3. Mn (%)			
6.4. P (%)			
6.5. S (%)			
6.6. Cr (%)			
6.6. Temperature (°C)			
7. Weight of hot heel (t)			
8. Composition of billet (%)			
8.1. C (%)			
8.2. Si (%)			
8.3. Mn (%)			
8.4. P (%)			
8.5. S (%)			
8.6. Cu (%)			
8.7. Ni (%)			

8.8. Cr (%)
8.9. Mo (%)
8.10. Sn (%)
8.11 Al (%)

Table 12-40 Measurement Results

Date	Aug. 14	Aug. 14	Aug. 14
Heat No.	965751	965752	965753
Amount of raw materials in 1st bucket (t)			
Amount of scrap in 2nd bucket (t)			
Amount of pig iron in 2nd bucket (t)			
Amount of raw materials in 2nd bucket (t)			
Amount of raw materials in 3rd bucket (t)			
Charged raw material (excluding hot heel) (t)			
Amount of scrap (t)			
Amount of pig iron (t)			
Output (excluding hot heel) (t)			
Consumption of electric power (kWh)			
Unit consumption of electric power, w_1 (kWh/t-output)			
Hot heel of raw material (t)			
Unit weight of hot heel of raw material, m_2 (kg/t-output)			
Temperature of hot heel, m_2 (°C)			
Unit consumption of scrap, (kg/t-output)			
Unit consumption of pig iron, (kg/t-output)			
Unit consumption of raw materials, m_3 (kg/t-output)			
Temperature of top of 1st bucket (°C)			
Temperature of middle of 1st bucket (°C)			
Temperature of bottom of 1st bucket (°C)			
Mean temperature of 1st bucket (°C)			
Temperature of top of 2nd bucket (°C)			
Temperature of middle of 2nd bucket (°C)			
Temperature of bottom of 2nd bucket (°C)			
Mean temperature of 2nd bucket (°C)			
Temperature of top of 3rd bucket (°C)			
Temperature of middle of 3rd bucket (°C)			
Temperature of bottom of 3rd bucket (°C)			
Mean temperature of 3rd bucket (°C)			
Mean temperature of raw materials after SPH (°C)			
Consumption of fuel oil at No. 1 burner (kg)			
Consumption of fuel oil at No. 2 burner (kg)			
Consumption of fuel oil at No. 3 burner (kg)			
Consumption of fuel oil at No. 4 burner (kg)			
Consumption of fuel oil at door burner (kg)			
Consumption of fuel oil (kg)			
Unit consumption of fuel oil, m4 (kg/t-output)			
Mean CO_2 content in exhaust gas at elbow (CO_2) (%)			
Mean CO content in exhaust gas at elbow (CO) (%)			
C content of molten steel before tapping (%)			
Si content of molten steel before tapping (%)			

Mn content of molten steel before tapping (%)
P content of molten steel before tapping (%)
Cr content of molten steel before tapping (%)
Al content of molten steel before tapping (%)

CaO content of slag (%)
Consumption of burnt lime (kg)
Amount of slag (kg)
Unit weight of slag, m_{11} (kg/t-output)

FeO content of slag (FeO) (%)
Fe_2O_3 content of slag (Fe_2O_3) (%)

Consumption of carbon injection (kg)
Unit consumption of carbon injection (kg/t-output)

P_2O_5 content of slag (P_2O_5) (%)
SiO_2 content of slag (SiO_2) (%)

Temperature of molten steel before tapping (°C)

Weight of hot heel of molten steel (t)
Unit weight of hot heel of molten steel (kg/t-output)

Power-on-to-power-off time (hr)

Flow rate of cooling water for roof (m^3/hr)
Average quantity of cooling water of roof, m14b (kg/t-output)
Mean outlet temperature of cooling water for roof (°C)
Mean outlet temperature of cooling water for roof-1 (°C)
Mean outlet temperature of cooling water for roof-2 (°C)
Inlet temperature of cooling water for roof (°C)

Flow rate of cooling water for EBT (m^3/hr)
Average quantity of cooling water for EBT, m_{14c} (kg/t-output)
Mean outlet temperature of cooling water for EBT (°C)
Inlet temperature of cooling water for EBT (°C)

Flow rate of cooling water for elbow (m^3/hr)
Average quantity of cooling water for elbow, m_{14a} (kg/t-output)
Mean outlet temperature of cooling water for elbow (°C)
Inlet temperature of cooling water for elbow (°C)

Flow rate of cooling water for shell-1 (m^3/hr)
Average quantity of cooling water for shell-1, m_{14d} (kg/t-output)
Mean outlet temperature of cooling water for shell-1 (°C)
Inlet temperature of cooling water for shell-1 (°C)

Flow rate of cooling water for shell-2 (m^3/hr)
Average quantity of cooling water for shell-2, m_{14d} (kg/t-output)
Mean outlet temperature of cooling water for shell-2 (°C)
Inlet temperature of cooling water for shell-2 (°C)

Indoor temperature (°C)

Surface area of roof (m^2)
Mean surface temperature of roof (°C)

Surface area of shell (m^2)
Mean surface temperature of shell (°C)
Mean surface temperature of shell-1 (°C)

Mean surface temperature of shell-2 (°C)
Surface area of furnace bottom (m^2)
Mean Surface temperature of furnace bottom (°C)
Heat in average flow of exhaust gas (1,000 kcal/min)
Consumption of limestone, m_{12} (kg/t-output)