Energy Saving in Ironmaking Processes*

By Shunsuke TAKAGI**

I. Preface

Japan depends on oil-based fuels for 77% of its energy needs, and on coal-based fuels for 15%. The steel industry uses 80% of the coal consumed in Japan.¹⁾ Especially, its iron-making department is a heavy coal user. It uses coal as a raw material and a fuel source for smelting and supplies by-product gases to many in-house departments for reutilization as the secondary energy.

In the steel industry that is known as a heavy energy eater, the iron-making department consumes approximately 90% of the primary energy purchased and supplies the secondary energy, equivalent to approximately 20% of the primary energy, to other departments. Accordingly, it may safely be said that the energy structure of the iron-making department determines the energy balance of the whole steelworks. In discussing the energy in the iron-making department, therefore, its relation with other departments should always be heeded, as reported elsewhere.³⁾ In this report, however, discussion will be confined to the energy-saving measures related to the iron-making department only.

II. Energy Situation in the Iron-making Department

1. Blast Furnace Fuel Ratio and Energy Balance

Of the energy consumed by an integrated steelworks, the iron-making department accounts for a little more than 70%, approximately 55% being for the blast furnace operation (Fig. 1).⁴⁾ Approxi-

mately 85% of the energy consumption in this department takes the form of fuel rate (coke rate plus oil rate plus tar rate). Therefore, it can be inferred that lowering the fuel rate will contribute greatly to the energy saving of the department. Actually, however, that is not the case. As shown in Fig. 2, the fuel rate was reduced by approximately 20% during the 15 year period between 1960 and 1975. But the energy consumption in the iron-making process in the same period remained substantially unchanged, as shown in Fig. 3.⁵⁾ One reason is that the reduction in the fuel rate cannot be achieved without improving metallurgical processes; such improvement calls for the use of energy in a different form. Another reason is that with decreasing fuel rate, by-products, such as blast furnace gas (BFG), decrease. Consequently, the decreased energy input does not lead to proportional energy saving as a whole. The same can be said of the whole iron-making department (Fig. 4²⁾). This relationship will be discussed later.

2. Energy Efficiency and Waste Heat Recovery in Iron-making Department

Let us take, for example, an integrated steelworks that produces 10 million t of crude steel annually. Of the primary energy supplied to its iron-making department, 23.0% is used for reducing iron ore, 16.0% is passed to the BOF plant as the latent and sensible heats of hot metal, 12.0% and 12.8% are supplied to other departments as COG and BFG, respectively. Namely, a total of 63.8% is effectively utilized. The remaining 36.2%, which is equivalent

Fig. 1. Kinds and uses (final) of purchased energy.

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** Production Control Department, Head Office, Nippon Steel Corporation, Otemachi, Chiyoda-ku, Tokyo 100.

to approximately $1\,600 \times 10^3$ kcal/t-hot metal (H.M.) produced, is discharged in various forms. Table 1⁶⁾ lists those items of the waste energy which are recoverable. They account for 26.8% of the net energy, approximately $4\,400 \times 10^3$ kcal/t-H.M. consumed in the iron-making department, and approximately 74% of the aforementioned unutilized energy.

To recover those listed waste energies, however, the following problems generally should be solved.²⁾

(1) The gases discharged from the furnaces and ovens, being much larger in quantity than those from heating furnaces and the like, are difficult to cope with.

(2) With only a few exceptions, they are discharged at either higher or lower temperatures than between 500°C and 700°C that are convenient for recovery.

(3) They call for careful handling, entraining

Fig. 3. Energy consumption in the blast furnace process.

Fig. 4. Energy-consumption trends in iron-making department.

Table 1. Waste energy recoverable from the iron-making department.*

Equipment	Kind of waste energy	Quantity of waste energy (kcal/t-product)	Quantity of waste energy (kcal/t-H.M.**)
Coke oven	Coke sensible heat	390×10^3 kcal/t-coke	181×10^3 kcal/t-H.M.
	By-product sensible heat	337×10^3	157×10^3
	Waste gas sensible heat	98×10^3	46×10^3
Sintering furnace	Sinter sensible heat	750×10^3 kcal/t-sinter	195×10^3 kcal/t-H.M.
	Sinter main waste gas	92×10^3	120×10^3
Blast furnace	Slag sensible heat	134×10^3 kcal/t-H.M.*	134×10^3 kcal/t-H.M.
	Top gas sensible heat	56×10^3	56×10^3
	Top gas pressure	100×10^3	100×10^3
	Cooling water loss	82×10^3	82×10^3
Hot stove	Waste gas sensible heat	74×10^3 kcal/t-H.M.	73×10^3 kcal/t-H.M.
	Cooling water loss	33×10^3	33×10^3
Total			$1\,177 \times 10^3$ kcal/t-H.M.

* Blast furnace coke rate=400 kg/t-H.M., and sinter consumption=1 200 kg/t-H.M.

** H.M.=hot metal

much dust and corrosive substances when discharged.

(4) Securing of applications for the recovered energy and of an installation space for the recovery equipment sometimes proves difficult, especially with an existing oven or furnace.

(5) Energy recovery technology should be developed along with resources recycling techniques, such as those for blast-furnace slag.

By overcoming these difficulties, several recovery techniques have been established, as described later. They permit recovering a total of approximately 229×10^3 kcal/t-H.M. from the sensible heat of coke, sinter and pellets, blast furnace top gas, and hot stove waste gas.⁶⁾ This accounts for 19.4% of the recoverable energy ($1\,180 \times 10^3$ kcal/t-H.M.) in Table 1, and 3.8% of energy needs per ton of crude steel (approximately $6\,000 \times 10^3$ kcal).

III. Energy-saving Measures in the Iron-making Department

As implied by the blast furnace fuel rate, fuels used in the iron-making process serve not only as a heat source but also as a raw material for the metallurgical reaction. Therefore, energy saving is inseparable from the improvement of the metallurgical process. For this reason, the iron-making department has been endeavoring to lower the fuel rate since before energy saving came to be clamored. The same is true of the coking and sintering processes.

As the by-product gases and tar are supplied to other departments, energy saving is inseparable from the overall energy balance, too. In addition, price differences between them and substitutable fuels should be considered.

Accordingly, energy consumption in the iron-making department should not be determined simply from the calorific viewpoint; the following factors also should be considered:

- 1) Optimum operating conditions suited for coal and iron ore properties.
- 2) Proportion and importance of by-product gases *etc.* in the overall energy balance of the steel-works.
- 3) Price differences among coal and other fuels.

In this chapter, however, individual energy saving techniques will be discussed independently.

1. Techniques for Lowering Blast Furnace Fuel Rate

As mentioned before, lowering the blast furnace fuel rate does not necessarily lead to pronounced net energy saving in the iron-making department. But the low fuel rate stabilizes the smelting process in the blast furnace. Further, it realizes low-cost operation through the reduced use of high-priced, imported coking coal. Consequently, the lowering of the fuel rate has been, and will be, one of the most important improvement targets in the iron-making department.

Figure 5 shows the trends of improvement in the fuel rate and iron-making technology.⁷⁾ The following is a stepwise briefing of the technological development.

- (1) The first step was to "secure adequate per-

meability in the blast furnace" by increasing the percentage of voids therein. For this purpose, ore and coke screening was intensified and coke strength increased. To reduce slag volume, coke with lower ash content and iron ore with higher Fe content were used. Ore fines were sintered; especially self-fluxing sinter greatly increased reducibility.

(2) The second step was "the establishment of the combined blast technique". The higher permeability secured by the first step permitted using higher hot-blast temperatures. The resultant flame temperature rise was controlled by adding moisture, then by fuel oil injection. Oxygen enrichment permitted injecting more fuel oil. The permeability impairment due to the resultant burden ratio (*i.e.*, the ratio of ore to coke) increase was overcome by the high-pressure operation.

(3) The third step comprised "the improvement of the reducing gas utilization rate and the development of the relevant control system". The reaction process in the blast furnace was studied by various methods, including the dissection of blast furnaces. The burden properties and distribution were improved on the basis of the study results. Probe data and computers also were amply used to further improve the gas utilization rate.

As will be understood from the above, the iron-

Fig. 5. Japan's progress trends in fuel rate and iron-making technology.

making technology has continued steady progress toward rationalization.

Several factors contributing to the fuel rate reduction will be discussed in the following.

1. Improvement in Coke Quality

In the blast furnace, coke functions as a heat source and a reducing agent, and also serves to secure burden permeability, thus constituting to the basis of a stable blast furnace operation. Other fuel rate lowering techniques depend on the coke properties, especially on the coke strength. Figure 6 shows the composite effects of the coke quality on the blast furnace performance.⁸⁾ Figure 7 shows the effect of the coke quality on the permeability improvement in large blast furnace.⁸⁾

2. Iron Ore Treatment

Although the favorable effects of iron sizing, *e.g.*, crushing and screening, were known a long time, it was after the World War II that many steelworks came to adopting this technology on the recommendation offered by a technical advisory mission sent from the U.S.A.⁹⁾

Recently, the size range has been narrowed to between 10 and 25 mm. In addition, such ores as are likely to crack under heat and less reducible are crushed to be sintered.¹⁰⁾

3. Increased Use of Agglomerates (Sinter and Pellets)

The intensified treatment resulted in increased occurrence of the undersize fines. With those and purchased ore fines, which were amply supplied to Japan, the commercial production of self-fluxing sinter started from about the mid-1950s. Having good reducibility and melting property, self-fluxing sinter improves burden permeability in the lower portion of the blast furnace. The commercial production of pellets start-

Fig. 6. Relationship between coke quality and blast furnace performance (Yawata Works).

Fig. 7. Relationship between coke strength (DI_{150}^{150}) and permeability (Kimitsu and Oita Works of Nippon Steel Corp.)

ed in 1953, and its imports on the long-term contract basis in 1963. Originally, pellets were inferior to sinter in the swelling index, reducibility at high temperatures, and melting property. But they became comparable to sinter as a result of such improvements as addition of self-fluxing constituents and dolomite. Figure 8 shows the trends in the agglomerates blending ratio, and Fig. 9 shows the effect of the sinter blending ratio on the coke rate reduction.¹¹⁾

4. Combined Blasting and High-top-pressure Operation

With the raw materials improvement for higher permeability, it became possible to raise the ore-coke ratio, thus lowering the coke rate. First, higher hot-blast temperature came to be used, the resultant higher flame temperature being controlled by moisture addition. This moisture served also as a hydrogen source and improved the efficiency of ore reduction. But fuel oil injection introduced later took over the flame temperature control and hydrogen supply functions of the moisture, so much so that more modern practice has it to dehumidify the blast, decreasing the heat absorbed at the tuyeres. Detailed discussion of the dehumidifying effect is given elsewhere,¹²⁾ but it is said that depriving each Nm^3 of the

Fig. 8. Trends in the agglomerates blending ratio. (from Data by the Japan Iron and Steel Federation).

Fig. 9. Effects of the sinter blending ratio on coke rate reduction.

Table 2. Coke-rate lowering factors and effects.

Factor	Measure taken	Effect (kg CR)	Remarks
Fuel oil injection	+1 kg/t-H.M.	-1.0~1.4	Using 50~100 kg-oil/t-H.M.
Blast temperature	+100°C	-8~20	900~1 250°C
Humidity	-10 g/Nm ³	-6~10	
Sinter	+10%	-5~10	
Pellets	+10%	-5~10	0~20%
Fluxes	10 kg/t-H.M.	-2~3	
Ash in coke	-1%	-5~10	
Intensified ore treating	8~40 → 8~30 mm 8~30 → 10~25 mm	-10~13 -5~7	Using 30~40%
Undersize ratio (up to 5 mm)	-1%	-4~7	
Silicon content in hot metal	-0.1%	-4~7	
Slag ratio	-100 kg/t-H.M.	-15~25	250~350 kg/t-H.M.
Prerduced pellets	+10%	-15~25	Total Fe 67~69% Metal Fe 38~41%
Mean in-furnace gas flow velocity	-0.1 m/s	-2.5~3.0	2.5~5.0 m/s

Fig. 10. Trends in production rate, oxygen enrichment, hot-blast temperature, fuel, coke and fuel oil + tar rates (national average).

blast of 10 g of moisture lowers the fuel rate by 6 to 10 kg/t-H.M. produced, as shown in Table 2.¹³⁾ Oxygen enrichment was adopted to increase production rates, and also permitted injecting more fuel oil. But in the recent production curtailment the enrichment rate has been lowering. Figure 10 shows trends in production rate, oxygen enrichment, hot-blast temperature and fuel rate, and Fig. 11 shows a successful example of heavy fuel oil injection.¹⁴⁾ Based on the theory of combined blasting, appropriate limits for the satisfactory combination of oxygen enrichment and fuel oil injection were determined, such as the perfect combustion limit of fuel oil, the theoretical limit of the flame temperature, the upper limit of the hot-blast rate and the lower limit of the critical reten-

Fig. 11. Oil rate and corrected coke rate at Tobata No. 2 BF of Nippon Steel Corp.

tion time. Figure 12 exemplifies a smooth operation based on the favorable limits.¹⁵⁾ High-top-pressure operation was introduced in 1962. Most of the blast furnaces built since have been of the high-pressure type. Many conventional ordinary-pressure furnaces also have been changed to the high-pressure type when relining. The highest top pressure now employed is 3.0 kg/cm², and all blast furnaces larger than 3 000 m³ are adopting top pressures between 2.0 and 3.0 kg/cm². High-pressure operations have two advantages. To begin with, the wind rate in a blast furnace is limited by such burden irregularities as hanging, slip and channelling that are caused by an excess gas lifting energy. But this wind rate limit can be relieved by increasing the top-gas pressure to lower the flow speed of ascending gas. Second, this increase in pressure accelerates the reducing reaction and the streamlined gas flow accelerates heat exchange between gas and solid and lowers fuel rate. Figure 13 shows the effect of top pressure on production rate increase and fuel rate decrease.¹⁶⁾

Fig. 12. Appropriate fuel oil injection range.

Fig. 13. Effect of top pressure on production rate increase and fuel rate decrease.

5. Improvement in Burden Distribution and Gas Utilization Rate

To lower fuel rate, gas utilization rate should be raised by causing the reducing gas rising from the tuyeres to react efficiently with iron ore. To achieve this, behaviors of the gases and solids in the blast furnace should be clarified and improved. Many sensors in the furnace top, shaft and other parts measure temperature and pressure distributions, and movable armors and rotating chute improve them. With these sensors, measures and mathematical models developed based on the knowledge derived from the investigation of dissected furnaces and other data, the ore-coke balance is controlled in the center, peripheral and intermediate portions of a furnace, so that the gas flow be so distributed as to permit maximum utilization of reducing gas. Figure 14 shows an arrangement of blast furnace sensors;¹⁷⁾ Fig. 15 shows how the gas utilization rate changed before and after the use of a movable throat armor;¹⁸⁾ and Fig. 16 shows an associated change in the shaft temperature pattern.¹⁹⁾ If appropriately used, the movable throat armor can lower fuel rate by approximately 10 kg/t-H.M. Its energy-saving effect is pronounced because it alleviates energy use in other forms such as high-temperature blast and high sinter mixing ratio in the blast furnace burden.

6. Use of Semi-reduced Iron Ore

If the furnace burden is prereduced to a certain extent, fuel rate can be lowered proportional to the extent of prereduction. Prereduced pellets are extensively used for facilitating dust disposal, as shown

Fig. 14. Blast furnace reaction sensors.

Fig. 15. Change in gas utilization rate before and after the employment of movable armor distribution control.

Fig. 16. Distribution pattern changed by movable armor control.

in Fig. 17.²⁰⁾ But, at present, they do not pay for other purposes, such as energy saving.

7. Coke-rate Lowering Factors and Effects

Fuel rate of the blast furnace has been improved by accumulating various techniques in the iron-

making department. Such operating factors and effects are listed in Table 2.

8. Outlook for Blast Furnace Fuel Rate Reduction

This section describes an outlook for fuel rate reduction. The all-time minimum fuel rate is 431 kg/t-H.M. (365 kg of coke plus 66 kg of fuel oil), recorded in March 1975 by Kimitsu No. 3 of Nippon Steel Corp. This rate is considered a practical reduction goal for the time being. Table 3 shows the operating data with which the record was made.²¹⁾

Recently two reports were issued as to the future goal or limit of fuel rate reduction, as briefed in Table 4.^{21,22)} On the basis of these actual data, the reasonable goal for the near future, achievable with existing techniques, may be estimated as 425 to 430 kg/t-H.M. When the development of new techniques and improvement in raw materials are taken into account, further, the goal for the future will be between 400 and 405 kg/t-H.M.

9. Relationship between Operating Factors and Total Iron-making Energy

Operating factors are varied to lower the fuel rate, and several studies have been made on interesting relationships between the factors so changed and total energy. Figure 18 shows an example of such studies, which discusses a change in energy purchased by the steelworks as a whole.⁶⁾ Therefore, if other departments remain as before, the change is due solely to the iron-making energy. As seen from Fig. 18, an increase in gas utilization rate and fuel oil injection are

advantageous for total energy saving, while an increase in hot blast temperature and sinter ratio disadvantageous. But the data for Fig. 18 were obtained by varying the individual factors independently; when they are considered in combination, different results may emerge. For example, a rise in blast temperature accompanies an increase in fuel oil ratio, entailing overall energy saving. Fine coke is cheaper than lump coke, and increased use of sinter permits using more fine coke and less lump coke, thus lowering overall energy cost.

As shown in Table 5, the IISI made an extensive study of energy changes in a model plant.⁵⁾

2. Other Blast Furnace Energy Saving Techniques

Energy saving of blast furnaces had long been achieved by mainly lowering their fuel rate. Recently, however, some new waste energy utilization techniques came to be employed, such as the power generation utilizing the high top pressure and the recovery of waste heat from hot stoves. Although details are discussed elsewhere,²³⁾ recovery of pressure energy by the former technique is epoch-making. No less important is the recovery of heat from the relatively low-temperature hot stove waste gas (at 250°C on average). When the top pressure is 2.0 to 2.5 kg/cm² and 1 400 to 1 500 Nm³ of blast furnace gas is gener-

Fig. 17. Relationship between metallization rate and fuel rate.

Fig. 18. Percent change in energy balance when coke rate is lowered by 30 kg/t-pig iron.

Table 3. Operating data when Kimitsu No. 3 BF of Nippon Steel Corp. recorded all-time minimum fuel rate (March 1975).

Description	Data	Description	Data
Production	9 533 t/d	Agglomerate ratio	100.0%
Production rate	2.35 t/m ³ /d	Ash in coke	12.0%
Coke rate	365 kg/t	Slag volume	323 kg/t
Oil rate	66 kg/t	Hot metal temperature	1 508°C
Fuel rate	431 kg/t	Silicon in hot metal [Si]	0.30%
Ore-coke ratio	4.47 (—)	Top gas temperature	107°C
Hot blast volume	6 374 Nm ³ /min	Gas utilization rate	51.9%
Oxygen	5 476 Nm ³ /h	FeO in sinter	7.0%
Hot blast temperature	1 316°C	Mean sinter size	19.1 mm
Hot blast humidity	7.1 g/Nm ³	Solution loss carbon	97.4 kg/t
Top pressure	2 279 g/cm ²	Direct reduction rate	32.9%
Sinter ratio	92.5%	Hydrogen reduction rate	9.7%
Pellet ratio	7.5%	Indirect reduction rate	57.4%

Table 4. Limit of blast furnace fuel rate.

Description	Unit	Model 1					Model 2		
		Base	Near future		Distant future		Base	Future	
		Data	Data	Fuel reduction effect	Data	Fuel reduction effect	Data	Data	Fuel reduction effect
Fuel rate	kg/t	460	425	△ 35	405	△ 55	455	402	△ 53
Coke rate	„	390	355		335		379	330	
Fuel oil rate	„	70	70		70		75	72	
Sinter and pellet ratio	%	80	88	△ 4	88	△ 4	100	100	
Slag ratio	kg/t	325	310	△ 4	310	△ 4	321	218	
Ash in coke	%	11	11	0	11	0	11.7	10	
Hot blast temperature	°C	1 240	1 300	△ 9	1 300	△ 9	1 275	1 350	
Hot blast humidity	g/Nm ²	12	5	△ 5	5	△ 5	10.7	0	
Silicon in hot metal	%	0.50	0.40	△ 6	0.4	△ 6	0.35	0.33	
Shaft efficiency	—	0.94	0.96	△ 7	0.98	△ 14	—	—	
Furnace heat loss	kcal	—	—		-2×10 ⁴	△ 6	—	—	
Hot metal temperature	°C	1 520	1 520	0	1 470	△ 7	1 514	1 514	
Gas utilization rate	%	—	—	—	—	—	49.8	57.8	
FeO in burden	%	—	—	—	—	—	6.8	0.0	
Solution loss carbon	kg/t	—	—	—	—	—	91.6	95.5	
Ore reduction rate (JIS Test)	%	—	—	—	—	—	—	75	

Note: Model 1: Prepared at the 50th Ironmaking Comm. of Joint Research Society of ISIJ, by Fukuyama Works of Nippon Kokan K.K.
Model 2: Prepared at the 51th Ironmaking Comm. of the Same by Kimitsu Works of Nippon Steel Corp.

ated per ton of hot metal, 40 kWh of power is generated, recovering 34×10^3 kcal, or 34% of gas pressure energy, for each ton of hot metal. When the hot stove discharges 800 to 900 Nm³ of waste gas at 250°C per ton of hot metal, 20×10^3 kcal, or approximately 30% of waste gas energy is recovered for each ton of hot metal. It is reported that this technique raises the heat efficiency of a hot stove by 3 to 4%.⁶⁾ Figure 19 is a flow diagram of a hot-stove waste gas heat recovery system.²⁴⁾

Efforts will be continued to make effective utilization of the waste energies listed in Table 1. For example, not only blast furnace slag itself but also its sensible heat will be utilized in the future.

3. Energy Saving in the Coking Process

In discussing energy saving in the coking process, the following three problems should be considered:

- 1) Coal as the raw material;
- 2) Heat consumption by coking; and
- 3) Sensible heat of coke, by-product and waste gases.

1. Coking Coal Problems (Saving of Hard Coking Coal and Use of Non- and Weekly-coking Coal)

Japan's steel production increased sharply until 1973 when the tonnage reached 120 million. Despite some production drop due to the subsequent business recession, the tonnage is still above the 100 million mark. To maintain this production level, the nation's steel industry consumes 65 million t of coking coal, of which approximately 10 million t are purchased from domestic sources and 55 million t imported from many countries including the U.S.A., Australia and Canada. Various grades of coal from

Fig. 19. Schematic diagram of hot-stove waste heat recovery system.

different sources are blended and prepared into high-quality metallurgical coke.

Coal reserves of the world are believed to total 6 to 8 trillion t, of which economically minable ones are 430 billion t, with coking coal accounting for 20 to 30% thereof. But the increasing difficulties relating to capital investment, labor securing, environmental and resources preservation have braked their development and made a sharp coal production increase unexpected. Consequently, with the progressive increase in coking coal consumption, its supply grew increasingly tight and unstable. In addition, its

Table 5. Effects of changes of blast furnace

			Basic conditions (Model plant)		Change of condition	Energy change in coking pelletizing & sintering processes (10 ³ kcal/t-H.M.)	
Raw material conditions	Ratio of sinter to pellets		Sinter Pellets	70% 30%	+10% −10%	Sintering Pelletizing Total	+ 89.9 − 47.3 + 42.6
	Ratio of lump ore in the burden		Sinter Pellets Lump ore	70% 30% 0%	−10% +10%	Pelletizing	− 47.3
	Slag volume		Slag volume	280 kg	+100 kg	Coking	+ 6.5
	Ash in coke		Ash in coke	11%	+ 1%	Coking	+ 4.9
	Semi-reduced pellets		Sinter Pellets (oxide) Semi-reduced pellets	70% 30%	+112 kg	Prereducing Coking Total	+274.4 − 23.8 +250.6
Injection of auxiliary fuels	Additional fuel oil		Coke rate Fuel oil rate	400 kg 65 kg	0 +10 kg	Coking	− 11.9
	Replacement of fuel oil by	Natural gas	Coke rate Fuel oil rate Natural gas	400 kg 65 kg 0	0 −65 kg +90 Nm ³	Coking	+ 0.4
		Coke oven gas	Coke rate Fuel oil rate COG	400 kg 65 kg 0	0 −65 kg +196 Nm ³	Coking	± 0
		Coal	Coke rate Fuel oil rate Coal	400 kg 65 kg 0	0 −65 kg +80 kg	Coking	± 0
New technologies	Oxygen enrichment		Coke rate Fuel oil rate Oxygen	400 kg 65 kg 1.5%	(+1.7%) 3.2%	Coking	− 19.4
	High temperature blast		Coke rate Fuel oil rate Blast temp.	400 kg 65 kg 1 250°C	(−100°C) 1 150°C	Coking	+ 32.4
	Low humidity blast		Coke rate Fuel oil rate Moisture	400 kg 65 kg 15 g/Nm ³	(−5 g/Nm ³) 10 g/Nm ³	Coking	− 11.6
	High top pressure		Coke rate Fuel oil rate Top pressure	400 kg 65 kg 2.5 kg/cm ² g	(−0.5 kg/cm ² g) 2.0 kg/cm ² g	Coking	+ 8.6
	Bosh injection of reformed gas		Coke rate Fuel oil rate Reformed gas	400 kg 65 kg 0	−100 kg 0 351 Nm ³	Coking	−108.0
Si in hot metal			Coke rate Fuel oil rate Si	400 kg 65 kg 0.65%	+0.1%	Coking	+ 4.3

* Energy consumption per ton of hot metal on the basis of the Model Plant is 4 232 × 10³ kcal/t-H.M.

operating conditions on energy consumption.

Energy change in blast furnace operation					Total energy change	
Coke rate (kg/t-H.M.) (10 ³ kcal/t-H.M.)	Fuel oil rate (kg/t-H.M.) (10 ³ kcal/t-H.M.)	Electric power (kWh/t-H.M.) (10 ³ kcal/t-H.M.)	Gas & others (10 ³ kcal/t-H.M.)	Sub-total (10 ³ kcal/t-H.M.)	(10 ³ kcal/t-H.M.)	%*
± 0	± 0	± 0	± 0	± 0	+43	+1.02
(Provided that suitably sized ores of good quality are available, the energy in blast furnace will not change.				± 0	−47	−1.11
+ 6.0 + 43.2	± 0 ± 0	+ 2.1 + 5.1	− 10.5	+ 37.8	+44	+1.04
—	—	—	+ 2.3	+ 2.3	+ 7	+0.17
− 22.0 −158.4	± 0 ± 0	− 3.0 − 7.4	+ 11.2	−154.6	+96	+2.27
− 11.0 − 19.2	+ 10.0 +100.0	+ 0.6 + 1.4	− 13.7	+ 8.5	− 3	−0.07
+ 0.4 + 2.9	− 65.0 −650.0	+ 4.2 +10.4	+675.7	+ 39.0	+39	+0.92
± 0 ± 0	− 65.0 −650.0	+ 1.1 + 2.7	+691.2	+ 43.9	+44	+1.04
± 0 ± 0	+ 65.0 +650.0	− 1.5 − 3.7	+629.2	− 24.5	−25	−0.59
− 18.0 −129.0	+ 15.0 −150.0	− 7.9 −19.5	− 29.3	− 28.4	−48	−1.13
+ 30.0 +210.0	− 16.5 +165.0	+ 2.6 + 6.3	− 53.5	+ 3.8	+36	+0.85
− 10.7 − 77.0	+ 5.6 + 56.0	− 1.0 − 2.5	+ 22.1	− 1.4	−13	−0.31
+ 8.0 + 57.6	± 0 ± 0	− 8.6 −21.0	− 20.8	+ 15.8	+24	+0.56
−100.0 −720.0	± 0 ± 0	−12.0 −29.4	+867.3	+117.9	+10	+0.24
+ 4.0 + 28.8	± 0 ± 0	+ 1.0 + 2.5	− 8.1	+ 23.2	+28	+0.66

quality deteriorated, and prices rose especially after the oil crisis. Although temporarily eased by the recent steel production cutback, the problem of quantity remains unchanged in the long run. Figure 20 shows how coking coal prices rose,⁸⁾ and Fig. 21 shows how the cost ratios of main iron-making raw materials changed with the coking coal prices.⁸⁾

To cope with such a situation, efforts have been made to lower the coke rate in the blast furnace, while the coking department is developing methods to maintain the coke quality despite the degraded coals. Figure 22 shows three typical ways of utilization of lower-quality coal with conventional coke ovens.

In the first technique 30 to 40% of the coal to be charged is formed into briquettes with a binder on a roll mill type briquetting machine, then blended with

the rest. This brings about an increase in the charging density (by 7 to 9%) and also an improvement in the coking property of the charge as a whole through expansion of the briquetts during carbonization, so that this technique permits the use of non-coking coal to 5 to 10%, even up to 20% under certain conditions. Since existing coking facilities, with an addition of a briquetting process only, are all that is necessary, many steelworks employ this technique, as listed in Table 6,²⁵⁾ so much so that approximately 40% of metallurgical coke today used is prepared by this process. Figure 23 shows the ratio of non-coking coal used in this process and its effect on blast furnace operation; non-coking coal creates no problem up to 20% blending.²⁵⁾

In the second technique, coal is charged preheated to approximately 200°C. It improves the charging density (by 10 to 13%) and utilizes a change in the softening and fusing properties of coal during carbonization. According to the method of transporting preheated coal, this technique is classified into the Coaltec system (charging by pipe), Precarbon system (charging by chain conveyor), and Simcar system (charging by car). Muroran Works of Nippon Steel Corp. is going to start operating a precarbon system in late 1979.

In the third technique, the low cokability of coal is made up for by adding such caking agents as pitch and asphalt. Caking agents are classified into the oil-based group (asphalt and heat-reformed pitch) and the coal-based group (tar pitch and solvent-refined

Fig. 20. Trends in mean prices of domestic and imported coals (CIF).

Fig. 21. Cost ratio change in main iron-making raw materials. (Reference: fuel rate)

Table 6. Briquetting equipment in operation.

Company	Steelworks	Capacity (t/day)	Operation started
Nippon Steel Corp.	Yawata	2 400	November 1971
	Kimitsu*	2 900	October 1976
	Oita	2 400	April 1977
Nippon Kokan K.K.	Keihin	800	August 1973
	Fukuyama	3 000	September 1975
Sumitomo Metal Industries, Ltd.	Wakayama**	1 700	May 1975
	Kashima**	4 700	October 1975
Kobe Steel, Ltd.	Kakogawa***	3 000	November 1976
Total		20 900	

* Operated by Nippon Steel Chemical Co., Ltd.
** Operated by Sumikin Coke Co., Ltd.
*** Operated by The Kansai Coke and Chemicals Co., Ltd.

Process	Process flow	Effect	Basic feature
Briquette blending	<div><div>Fine coal (60~70%)</div><div>Binder (30~40%)</div><div>Briquetting</div><div>Charging</div><div>Coke oven</div></div>	D_{15}^{150} 2~1% up Using 5~10% non-coking coal	Coke quality improvement Using existing oven
Charging preheated coal	<div><div>Fine coal</div><div>Drying, Preheating</div><div>Charging</div><div>Coke oven</div></div>	D_{15}^{150} 2~4% up Using 5~10% non-coking coal	Coke quality improvement Using new oven
Adding caking agent	<div><div>Fine coal</div><div>Addition</div><div>Charging</div><div>Coke oven</div></div> <div><div>Caking agent</div><div>Reforming</div><div>Artificial coking coal</div></div>	Fluidity up D_{15}^{150} 2~3% up Aiming at using 5% non-coking coal with 3~5% addition	Coke quality improvement Applicable to existing oven

Fig. 22. Lower-quality coking coal utilization techniques (with conventional coke ovens).

coal extracts). Though already used practically somewhere, the oil-based group involves a problem of high sulfur content, whereas the coal-based group is still in the developmental stage. Whether oil-based or coal-based, the caking agents have to solve the problems of sulfur content and price.

Besides those methods, coke strength can be increased, if not so much, by oiling, selective crushing, and dry coal charging, all of which are being practiced.

With all these measures, use of non- or weakly-

Fig. 23. Effect of briquette-blended coke on blast furnace operation.

(): productivity coefficient
Figures in () indicate the values without formed coke supply.

Fig. 24. Results of formed coke usability tests.

- HBNPC
- DKS
- Auscoke
- Simon Eng. Process
- Coal Mining Research Center
- USSR
- BF-L
- CONSOL-BNR
- FMC
- U.S. Steel

Fig. 25. Basic raw materials and methods of formed coke manufacturing.

coking coal in the coke oven is limited. To permit their increased use, the formed coke manufacturing process is being developed.

Formed coke differs considerably from the conventional coke made by coke ovens, both in raw materials and shape. The usability tests, performed on actual blast furnaces since 1971, have disclosed that formed coke can be used as metallurgical coke if its quality is suitably controlled (Fig. 24²⁵). This technique should be made ready for practical use before the raw materials situation grows severer. Figure 25 shows several formed coke manufacturing processes, classified by raw materials, forming and carbonizing methods.⁸⁾

For the coking section, it is more important than the saving of heat consumption to overcome the tight coal supply problem by establishing the above-described low-quality coal utilization techniques.

2. Energy Saving in Coking Process

Figure 26 shows an example of heat balance in coking process, which indicates that energy saving in the process depends on the following three points:

- 1) Reduction of heat consumption in coking that accounts for approximately 90% of total heat input;
- 2) Recovery of sensible heat of red-hot coke that accounts for approximately 40% of total heat output;

Fig. 26. An example of coke oven heat balance.

3) Recovery of sensible heat of by-product and waste gases.

Operation of a coke oven should be so controlled that coking in all coking chambers terminates substantially simultaneously. For this purpose, the combustion chamber temperatures should be equalized. To economize the heat consumption, coal and heat supplies to the individual coking and combustion chambers should be equalized, combustion efficiency increased on the basis of air-fuel ratio control, and temperature distribution streamlined according to the coking chamber taper. It is also necessary to control heat input in accordance with changes in the quantity and moisture of the coal charged. Conventionally these controls depended on the skill of oven operators. Recently, however, fuel gas calorific value control devices and automatic air ratio controller on interlocking of the waste gas oxygen analyzer with the flue damper, are widely employed. Overall combustion control systems, combining the aforementioned controls with detection of the combustion chambers temperatures and the coking completion timing in the coking chambers, are being introduced, too. Reportedly, automatic combustion control has reduced 10 000 kcal of heat per ton of coal charged.²⁶⁾

Details of the sensible heat recovery from red-hot coke has been discussed elsewhere,²⁷⁾ but at the Yawata Works of Nippon Steel Corp., for example, 83% of the sensible heat is being recovered in the form of steam by dry quenching, an amount which equals to approximately 40% of the total heat input of in the coke oven.⁸⁾

Utilization of the sensible heat of by-product and waste gases remains to be studied, because their temperatures are low compared with the amount of heat contained therein.

4. Energy Saving in the Sintering Process

Figure 27 shows an energy balance of the sintering process. As seen, 86% of the heat input is supplied by the combustion of such solid fuels as fine coke and blast furnace dust. Meanwhile, only 30% of the heat output is effectively utilized for such reactions as decomposition of limestone and combined water, with the remainder released as the main waste gas and waste heat from the cooler.

Accordingly, fuel consumption in the sintering process can be reduced by such heat-input-related measures as the lowering of fine coke consumption through the enhancement of its combustion efficiency and the sinter bed permeability improvement leading to higher yield and by such heat-output-related measures as the energy saving through the utilization of unrecovered energy and the appropriate operation of the equipment.

1. Saving of Fine Coke Consumption by Improving Sintering Process

(1) Improvement of Fine Coke Particle Size

It is generally known that consumption of fine coke depends on its particle size distribution. Combustion speed of coke differs with its size. Therefore, if the range of its particle size distribution is narrowed, more uniform combustion speed and heat out put will be obtained. This, in turn, equalizes the reaction in the sinter bed. Being highly reactive, fine-grained coke burns too rapidly. Conversely, coarse-grained coke causes sporadic distribution in the sinter bed, which lowers production efficiency, and also deposition of sinter on the grate bar. Therefore, both fine- and coarse-grained coke should be reduced. Figure 28 exemplifies the effect of an improvement in the coke particle size.²⁸⁾

(2) Preparation of Sintering Raw Materials

To obtain better coke combustion and smoother sintering reaction in the sinter bed, coke should be kept in a readily combustible condition. More specifically, the permeability of the sinter bed should be improved so that as much coke as possible contacts the air and the heat of combustion is transmitted uniformly. Reportedly, the following measures, in combination, reduced coke breeze consumption by approximately 4 kg for each ton.¹⁰⁾

- 1) Increasing the quasi-particle strength by intensified mixing and binder addition;
- 2) Coarsening feed materials by adding crushed lump ore; and
- 3) Divided addition of coke breeze.

2. Consumption Saving through Yield Improvement

In the present downdraft sintering process, the heat generated by the combustion of coke accumulates in the lower portion, thus creating a heat shortage in the sinter bed top and a heat surplus in the bottom.

Fig. 27. Heat input-output balance of a sintering machine.

Fig. 28.
Effects of fine coke particle size on sintering process.

This difficulty can be overcome if the coke blending ratio can be changed continuously from the top to the bottom so that excess heat in the bottom be decreased.

For this purpose, air is blown from behind when feeding materials onto the sinter bed, whereby coke density in the top becomes richer taking advantage of the differences in particle size and specific gravity. This method saves approximately 10% of ignition fuel.²⁹⁾

In the summer of 1978, Yawata Works of Nippon Steel Corp. introduced a two-layer charging technique that reduces excess heat by charging feed materials blended with different percentages of fine coke to the top and bottom of the sinter bed through individual feeders. This technique saves approximately 4 kg of fine coke for each ton.

3. Electric Power Saving through Equipment Operation Rationalization

The air-leakage rate for the main exhaust system of the sintering machine is as high as 10 to 50%. The leakage rates at the sinter cooler and dust precipitator also are considerably high. Lowering these leakage rates, no doubt, reduces air supply and saves power consumption.

Besides these, a sintering plant has many blowers consuming much electric power. Therefore, considerable power can be saved by minimizing their idling time, by correcting the run point to be closed to the high efficiency point wherever the actual blowing volume and the design specification differ much, and by other careful steps.

4. Recovery of Unutilized Heat

Scale, sludge and dust from a steelworks are being recovered by various methods. But many heat sources remain unutilized.

(1) Utilization of Blast Furnace Wet Dust

Blast furnace wet dust is a useful resource containing approximately 40% carbon. Containing also zinc, however, it has not been used as a raw material for sintering, being used principally as a reducing

agent for the zinc removal reduction process only. Taking advantage of the fact that zinc occurs largely in the finer-grained portion of blast furnace wet dust, a technique to remove as much as 80% of zinc by wet classification was developed recently. This technique permits recovering of 70 to 80% of the flue dust with a liquid cyclone, thus using it as a sinter feed material and saving fine coke consumption.^{30,31)}

(2) Recovery of Cooler Waste Heat

The produced sinter is cooled before it is charged into the blast furnace. During this cooling process, heat of approximately 150 000 kcal/t-sinter used to be discharged into the atmosphere as waste hot air. Recently, however, a technique was developed to utilize this hot air as combustion air of COG for the ignition furnace; this preheating saves COG consumption by the amount equivalent to the sensible heat of hot air. At present, the heat recovered is equivalent to 2 to 2.5 Nm³ COG/t-sinter, or approximately 7% of the cooler waste heat discharged.

Also being developed is a power generation technique utilizing the cooler waste heat that is recovered as high-pressure hot water, as discussed elsewhere.³²⁾

5. Future Trends

Fine coke supplies approximately 80% of the heat consumed in the sintering plant. Owing to various technical improvements, this fine coke consumption has dropped to 51 kg/t-sinter in 1976 on the nationwide average (Fig. 29). In a couple of years, the figure will fall below 50.

With the blast furnace coke rate lowering remarkably, use of fine coke in the sintering plant should be further reduced in order to keep the quantities of fine and lump coke balanced in a steelworks.

Even though some sintering plants are operating on approximately 20 kg fine coke/t-sinter, extensively utilizing miscellaneous carbon sources,³³⁾ desirably, greater energy saving efforts should be made. Ways will be found in utilization of new resources including blast furnace sludge and dust and anthracite coal and development of heat requirement reduction techni-

Fig. 29. Trends in sintering coke consumption (national average).

ques through the study of sintering mechanism. Further, in addition to the techniques discussed above to recover part of the waste heat from the sintering process, techniques to recover the lower-temperature heat should be developed, too.

5. Energy Saving in the Pelletizing Process

In March and May, 1976, Hirohata Works of Nippon Steel Corp. and Kakogawa Works of Kobe Steel, Ltd, each having a grate kiln type pelletizing plant, introduced a technique to recover the low-temperature waste heat from the pellet cooler that had been discharged into the atmosphere. The recovered heat came to be utilized for the drying and crushing of raw materials and drying green pellets on the grate.^{34,35)}

For a pelletizing plant with an annual production capacity of 2.5 million t, this technique saves energy equivalent to approximately 20 000 kl of fuel oil (approximately 20%) per year.³⁶⁾

IV. Conclusions

The iron-making department of the steel industry consumes approximately 13% of the energy consumed in Japan. Therefore, energy saving in this department has a very great influence on the nation's energy balance. The energy source used by the iron-making department serves also as a material for the metallurgical reaction to reduce iron ore. To achieve considerable saving, therefore, mere improvement in the heat and energy techniques is not enough, but the metallurgical reaction in the blast furnace should be studied. Fortunately, a remarkable technical progress has recently been achieved in this field. Although the blast furnace had remained long a "black box", its internal condition and reaction have been disclosed considerably in recent years. Under such circumstances, greater improvement will be accomplished in the future.

But the energy problem cannot be solved from the standpoint of the iron-making department only. Careful measures should be taken, giving consideration to the energy balance of the whole steelworks, price and demand trends of various energy sources. It will be important to establish a full-fledged energy control system centered on the iron-making department, too.

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