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OPTIMUM BURDEN DISTRIBUTION IN THE BLAST FURNACE - A REVIEW OF PAPERS PRESENTED AT THE 6TH McMASTER SYMPOSIUM ON IRON AND STEELMAKING

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by

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SUMMARY

With the exception of burden quality, the burden distribution at the top of the blast furnace is the most important factor controlling high iron productivity under lower fuel consumption. Raw materials effect burden distribution by having tendencies to segregate during charging because of differences in size, shape, and density of pellets, sinters, ores, and cokes. Recently ore/coke ratios have been more manageably controlled by the installation of moveable armour and Paul Wurth tops on modern blast furnaces.

Although ideal heat and gas exchange using plug flow conditions must be considered at the top of the blast furnace, consideration must also be given to heat losses through the walls, refractory wear and burden permeability. As a result most blast furnace operators prefer to operate their blast furnaces with a moderate central flow of gas with an inverted V-shaped melting zone. At present this is generally achieved by distributing the smaller ore, sinter and pellets more heavily at the walls of the blast furnace and the larger, more permeable coke layers more heavily near the center of the furnace. The burdening can be monitored across the radius of the stockline by use of temperature and gas probes. Higher temperatures and CO gas concentrations are characteristic of high gas flow in that region of the furnace and burdening practises can be altered to improve or adjust the gas distribution.

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OPTIMUM BURDEN DISTRIBUTION IN THE BLAST FURNACE - A REVIEW OF PAPERS PRESENTED AT THE 6TH McMASTER SYMPOSIUM ON IRON AND STEELMAKING

The primary function of the blast furnace is to produce iron of correct specifications at the required rate over a long campaign using minimum amounts of energy, at the lowest possible cost, and at safest operating conditions. Among a number of operating conditions controlled by the blast furnace operator, the burden distribution at the top of the blast furnace is the most important for high productivity under lower fuel consumption. Raw materials effect burden distribution by having different angles of repose after being charged to the blast furnace because of differences in particles size, shape, density, and types (e.g. ore, sinter, or pellet or coke). The size and shape of the softening and melting zones of the blast furnace effect the flow of gas and can also effect burden distribution which in turn determines the nature of the softening zone.

Until recently most blast furnaces had double bell tops and burden distribution was controlled mainly by altering the amounts and ratios of ore, sinter, pellets and coke charges. Recently, moveable armour has been installed on many blast furnaces having bell tops and can be adjusted to deflect the charged materials into the desired regions of the blast furnace (see Figure 1). The Paul Wurth top (Figure 2) is a more versatile charging system which can place the charge material at any desired spot on the stock-line of the blast furnace. However, the operator must completely understand how to optimize the burden distribution to take full advantage of this equipment.

Standish(1) has shown that blast-furnace stack gases should have ideal plug flow which maintains the highest concentrations and temperature levels in the flowing gases and optimizes heat exchange, momentum transfer, and chemical reaction. However, dispersion in blast furnaces is quite large due to uneven particle size distribution and ideal plug flow cannot be achieved. Ore, sinter, and pellet sizes are regulated by their reducibility at 950-1000°C while coke size is larger and regulated by the bosh requirements for a permeable coke grid. It is preferable to charge layers of ore and coke into the blast furnace, provided the layers have reasonable thickness (e.g. 40 cm) rather than mixtures of ore and coke because the former has increased burden permeability. The interfacial pressure drop for layers is minimized when the larger coke is layered on top of the smaller ore particles.

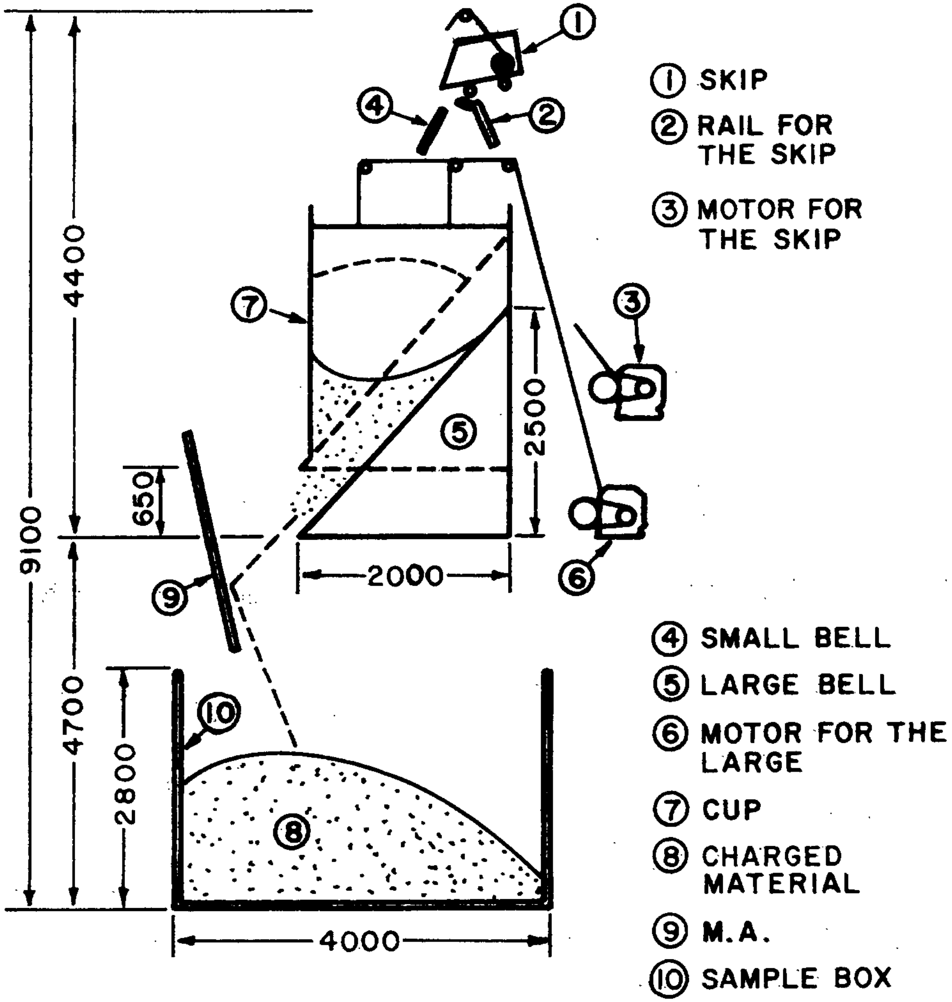


Fig. 1 The M.A. apparatus

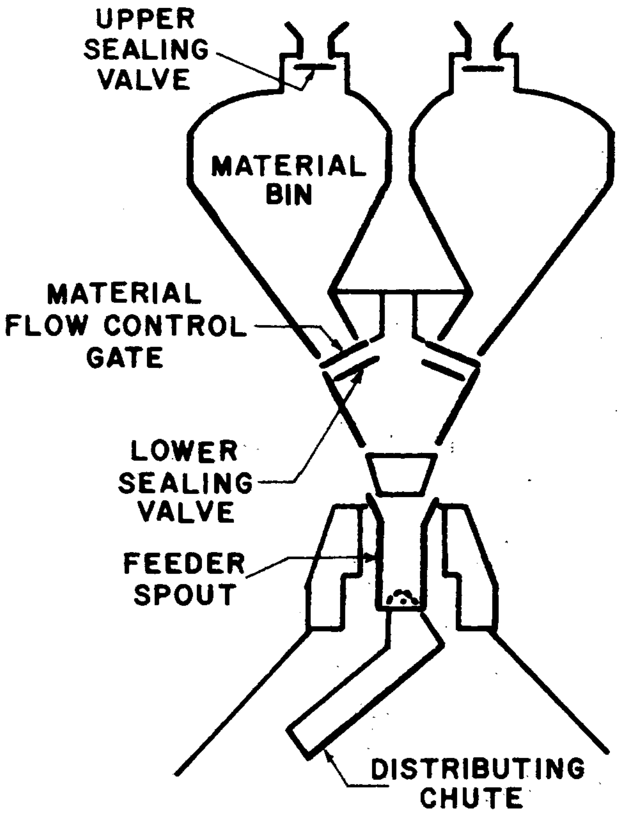


Fig. 2 Bell-less top of No. 2 blast furnace at Chiba Works

Standish suggests that the rate determining step in ironmaking is not melting or smelting but the efficiency of heat and chemical exchange in the stack. He compares the productivity of a Midrex furnace having good plug flow (8.0 tonnes/day/m^3) with that of a 5000 m^3 blast furnace (2.4 tonnes/day/m^3) to indicate that blast furnace efficiency can still be greatly improved and that gas flow should be kept as uniform as possible by burdening the blast furnace uniformly with layers of coke and ore of as narrow a size range as possible.

Disection of Tsurumi No. 1, Kawasaki No. 3 and Kawasaki No. 4 quenched blast furnaces by NKK (2) indicated that the solid materials in all blast furnace descended in layers until the melting zone was reached. The Kawasaki No. 3 blast furnace had a V shaped melting zone (Figure 3) while Tsurumi had an inverted V shaped melting zone. The shape of the melting zone is very important to gas flow in the lower part of the furnace. In the Kawasaki furnaces gas is deflected by the melting zones toward the walls before being dispersed uniformly through the burden. In the Tsurumi No. 1 furnace the gas flow is directed by the molten zone toward the center of the furnace before being dispersed in the stack and causes a more central gas flow. The Tsurumi furnace had a lower ore/coke ratio at the center of the furnace than the Kawasaki furnaces which had a more uniform ore/coke distribution across the furnace (Figure 4). The latter distribution caused some solid layers of ore to come down in the central region of the furnace and decrease the central gas flow. The observed and calculated gas permeability of the Kawasaki furnace is lower than the Tsurumi No. 4 when both pellets and sinter were used. Temperature profiles at the stock-line are also shown in Figure 4. Blast rates and productivity can be improved with central furnace working by increasing the coke/iron ratio at the furnace center.

Nippon Steel Corporation (3) described the importance of the softening and melting zones of their blast furnaces. Kukioka No. 4 furnace when quenched showed a W shaped melting layer and a low fuel rate of 477 kg/tonne. Hirohata No. 1 furnace had the inverted V shaped melting zone but operation was characterized by a high productivity. Studies on a blast furnace model with a melting burden indicated a W or V shaped melting zone occurs when the ore layers in the central portion of the furnace are thick

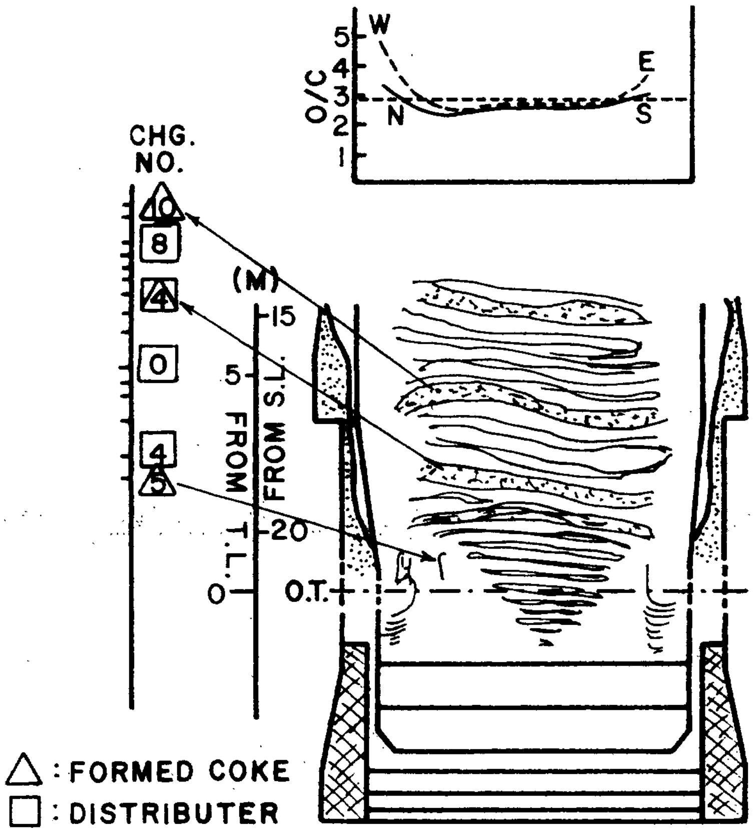


Fig. 3 Inner state of lower part of Kawasaki No. 3 blast furnace and its ore/coke distribution in the shaft.

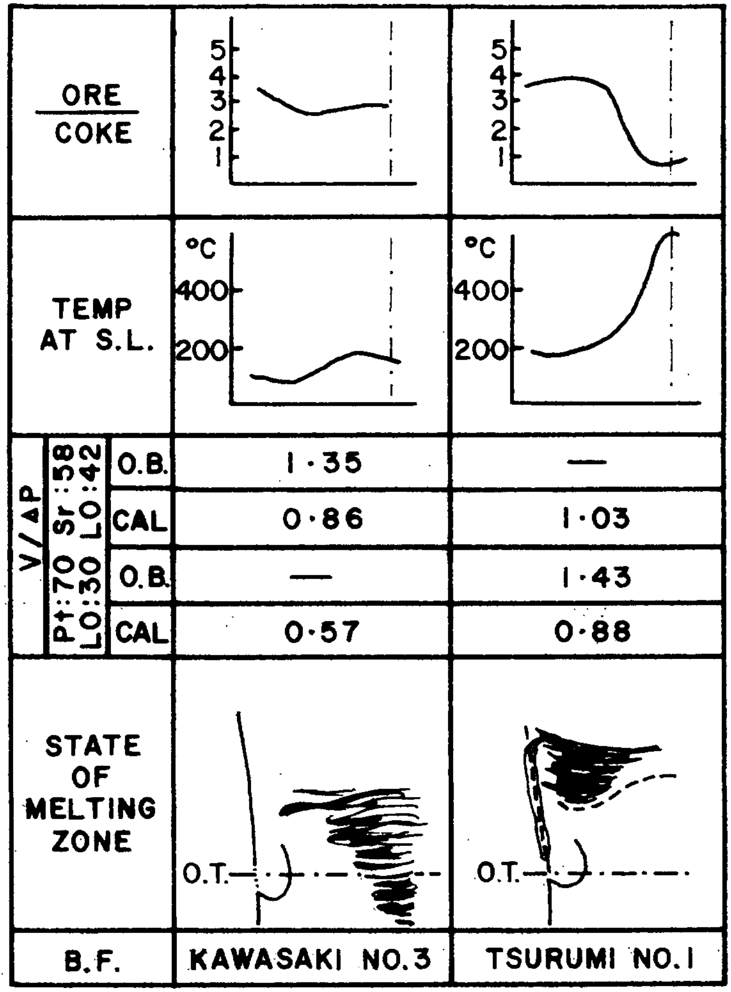
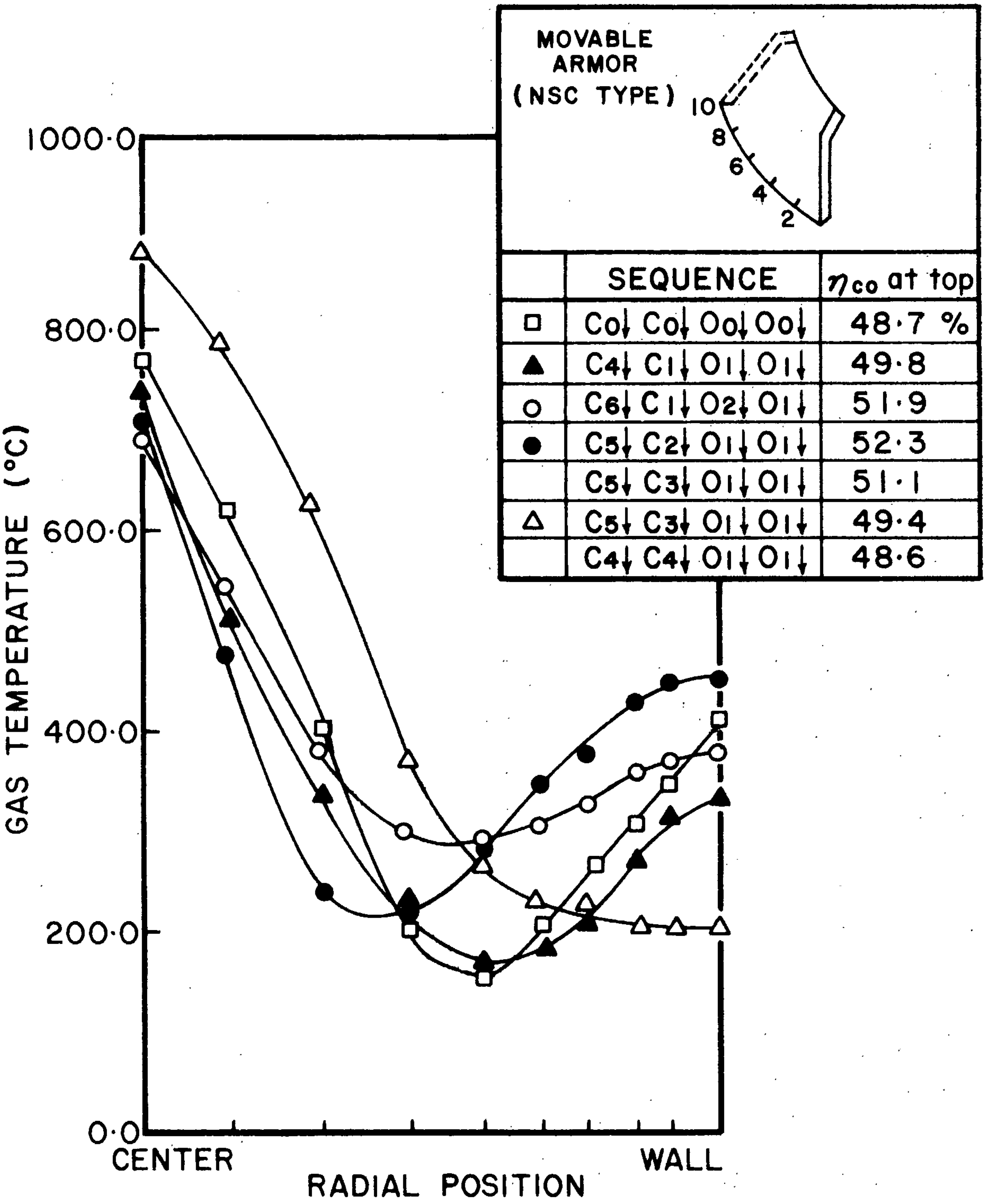


Fig. 4. Influence of distribution and high temperature properties of burden on gas permeability of furnace.

and the inverted V structure when coke layers are thicker. V or W shaped melting zones result in higher blast pressures, increased hangings and slips and increased temperature at the walls of the blast furnace when compared with the inverted V melting zones. Thus it was concluded that the softening-melting zone of the inverted V shape is desirable for high productivity with steady and safe blast furnace operation. The top of the inverted V-shaped melting zone should not be too high in the furnace because it would decrease gas utilization. The sharper the inverted V-shape of the softening zone, the greater was the amount of gas deflected toward the walls of the furnace and the better was the gas utilization in the blast furnace stack. As a result the temperature profile at the stock-line characteristic of the best furnace operation is that pattern in which the high temperature gas region is kept narrow to obtain a high gas utilization rate while maintaining a central gas flow. In order to obtain this profile on Kimitzu No. 3 blast furnace (inner volume 4063 m^3) which has moveable armour the charging sequence $C_5C_2O_1O_1$ was found best (see Figure 5). For Muroran No. 1 blast furnace (inner volume 1245 m^3) equipped with a bell-less top, making the coke layer progressively thicker from the wall toward the center of the furnace by spiral charging achieved the best central gas flow.

Kawasaki Steel Corporation (4) have more fully described the operation of their Paul Wurth top on their Chiba No. 2 blast furnace. This furnace is equipped with an ITV system capable of observing the motion and piling behaviour of burden at the stockline and has a horizontal gas and temperature probe at the throat of the furnace that can also mechanically measure the profile of the stockline. Results from tests on a model of Chiba No. 2 indicate blast furnace operation changes from peripheral gas flow through uniform gas distribution to central gas flow by increasing the rotating speed of the chute, allowing the stockline to descend, increasing the tilting angle of the chute for charging ore, and by decreasing the tilting angle for coke charging. Spiral charging is used at Chiba No. 2 to achieve the desired charge distribution, a CO gas utilization of 50% and a fuel rate of 467 kg/tonne iron.



	SEQUENCE	η_{co} at top
□	$C_0{\downarrow}\ C_0{\downarrow}\ O_0{\downarrow}\ O_0{\downarrow}$	48·7 %
▲	$C_4{\downarrow}\ C_1{\downarrow}\ O_1{\downarrow}\ O_1{\downarrow}$	49·8
○	$C_6{\downarrow}\ C_1{\downarrow}\ O_2{\downarrow}\ O_1{\downarrow}$	51·9
●	$C_5{\downarrow}\ C_2{\downarrow}\ O_1{\downarrow}\ O_1{\downarrow}$	52·3
	$C_5{\downarrow}\ C_3{\downarrow}\ O_1{\downarrow}\ O_1{\downarrow}$	51·1
△	$C_5{\downarrow}\ C_3{\downarrow}\ O_1{\downarrow}\ O_1{\downarrow}$	49·4
	$C_4{\downarrow}\ C_4{\downarrow}\ O_1{\downarrow}\ O_1{\downarrow}$	48·6

Fig. 5. Shaft gas temperature distribution and top gas utilization rate under different charging methods (Kimitsu No. 3 BF)

Papers from Italsider (5) describing operation of Taranto No. 1 blast furnace and Hoogovens (6) describing blast furnaces No. 4, 6, and 7 indicated these furnaces use central gas flow primarily to minimize heat losses through their losses. Hoogovens found, however, that excessive central gas flow reduced gas utilization efficiency and increased tuyere loss probably because of a decreased distance from the melting zone to the tuyeres. Fuel rates of 477 kg/tonne were achieved by Taranto No. 1 furnace. The possibility of further lowering the fuel rate by a more uniform gas distribution over the cross-section of the blast furnace was counteracted by decreased permeability and uneven operation. Twin medium sized blast furnaces (2175 m^3) at Solmer France (7), however, improved their fuel ratios to 460 kg/tonne of iron by changing from heavy central gas flow burdening to a more moderate central working. Although burden permeability decreased, the reduction efficiency and the standard deviation of silicon in the metal improved while heat losses through the wall and operational problems remained the same.

Koverhar Iron and Steel Works in Southam, Finland were required to reline their 6.5 m (hearth dia.) blast furnace in 1973 and 1974 (8) because of an unsuitable burden distribution which led to a strong gas stream along the walls. In 1974, moveable armour was installed and subsequent burdening practise resulted in more control gas flow which decreased heat losses and lining wear, and improved the fuel rate. The central flow was not as great however as that recommended by the Japanese. The content of CO_2 with the strong central gas flow would fall below 10% and in cases of high alkali loading KCN in the central gas will not be reoxidized and may appear in the gas cleaning water.

The carbon consumption versus direct reduction rate diagram (Figure 6) indicates that fuel efficiency is not only regulated by the $FeO + CO \longrightarrow Fe + CO_2$ reduction efficiency but also by heat requirements of the furnace. Minimum fuel consumption occurs at the intersection of the boundary of chemical equilibrium and boundary for the heat balance. Thus a low fuel consumption requires not only an efficient reduction but also small heat losses and a great heat load on the furnace walls is not only a cooling problem but a matter of fuel economy. Figure 7 has specific blast amounts drawn on the coke rate vs DRR diagram and shows two extreme alternatives.

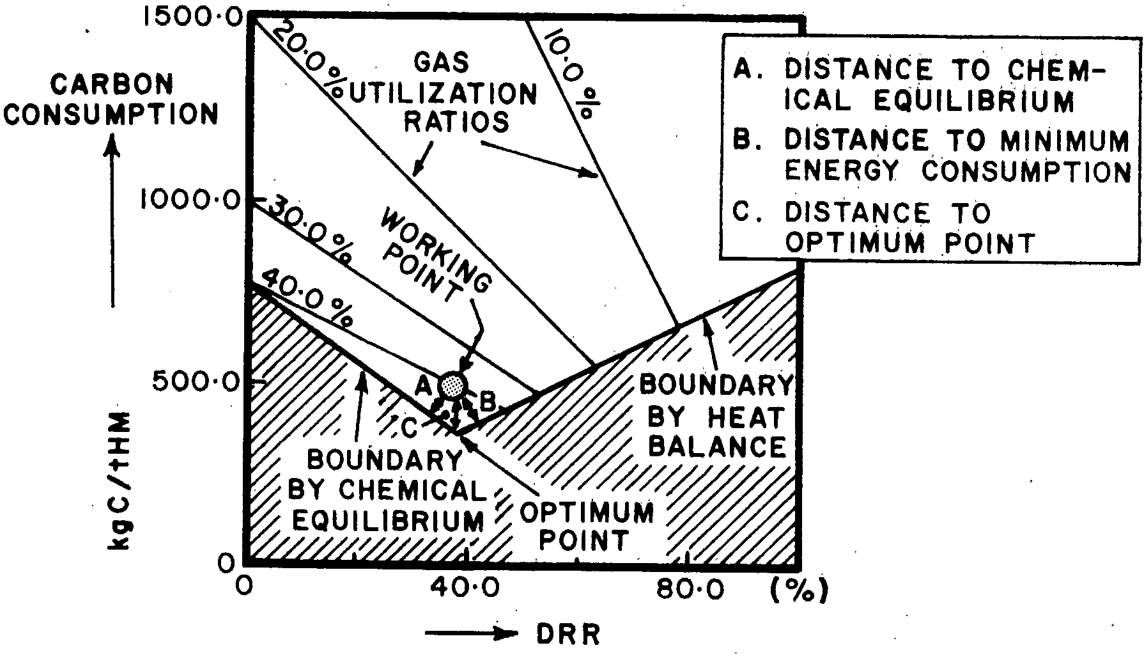


FIG. 6. Principles of the C-DRR Diagram

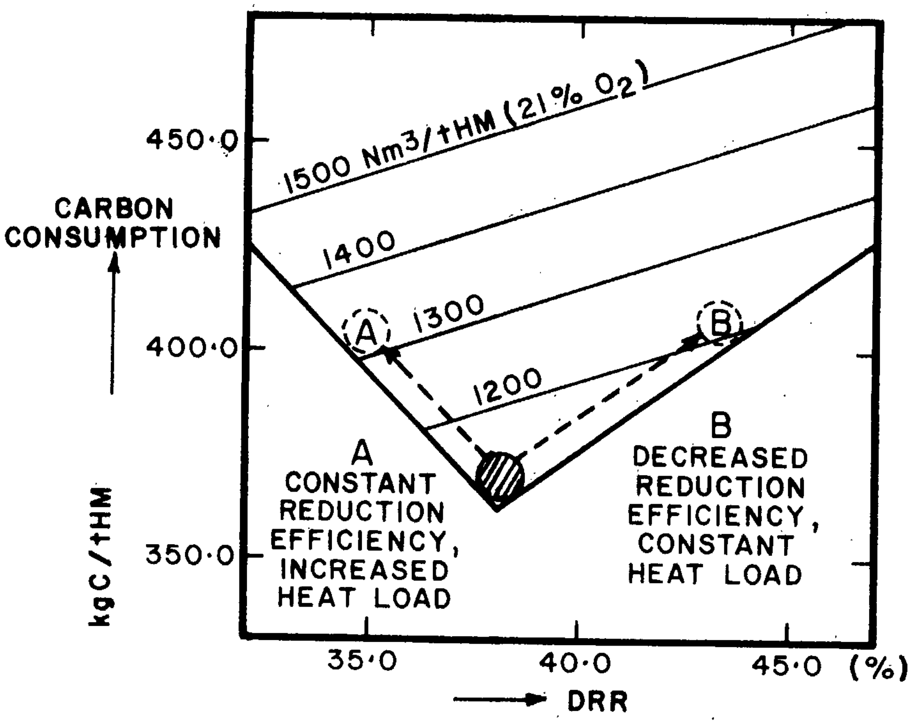


FIG. 7. Specific Blast Amount in the C-DRR Diagram

A and B both having a coke ratio of 400 kg/tonne. Point B having decreased reduction efficiency from the optimum but constant heat load requires less blast than a system A having constant reduction efficiency but increased heat load. This can partly explain why a central flow is considered favourable at high production rates.

REFERENCES

1. Standish, N. "Optimum burden distribution in the blast furnace".
2. Fukushima, T., Nishio, H., Ohno, Y., Furukawa, T., Izawa, T. "Importance of burden distribution control and inner state of the blast furnace"; Nippon Kokan K.K., Kawasaki, Japan.
3. Wahazama, S., Kanazama, Y., Okuno, Y. "The characteristics and control of burden distribution in the blast furnace"; Nippon Steel Corporation, Tokyo, Japan.
4. Nazai, T., Kurihara, J., Takahashi, H., Okumura, K. "Control of burden distribution by bell-less top at Chiba Works, Kawasaki Steel Corporation"; Kawasaki Steel Corporation, Chiba, Japan.
5. Guili, M., Palchetti, M., Gandolfi, G., Federiko, G., Staffelini, A., Donnini, G. "Burden distribution in no. 1 blast furnace of Italsider Taranto Works"; Italsider, Taranto, Italy.
6. Vogel, R., van der Vliet, C., Flurman, G., Toxopeus, H. "Control of the gas and burden distribution at the Ijmuiden blast furnaces"; Hoogovens Ijmuiden B.U.
7. Jusseau, N., Bouget, J., Annichini, A., Thirion, C. "Gas distribution control in Salmer blast furnaces"; Solmer, Fos-Sur-Mer; France.
8. Lundqvist, G., Moliis Mellberg, A., Eriksson, K-G. "The use of a charging model - A key to good results in small blast furnaces"; Oy Koverhar Ab, Lappokja, Finland.