KAWASAKI STEEL TECHNICAL REPORT
No.1 ( September 1980 )

# Facilities and Operation of No.6 Blast Furnace at Chiba Works

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Synopsis :
Chiba No.6 blast furnace (4500m3 inner volume and 14.1m hearth diameter), one of the largest furnaces with bell-less top, was blown in on June 17, 1977. It was designed to get a stable yet flexible operation on the basis of iron-making experiences at Chiba and Mizushima Works. Effective control of gas distribution in the furnace by the full use of the bell-less top brought about a successful starting-up and rating-up operations and resulted in attaining high productivity (10 000t/d) and low fuel consumption (418.4kg/t). Design and operation of the furnace are discussed with a particular reference to bell-less top and burden distribution.



The body can be viewed from the next page.

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*Chiba No. 6 blast furnace (4 500 $m^3$ inner volume and 14.1 m hearth diameter), one of the largest furnaces with bell-less top, was blown in on June 17, 1977. It was designed to get a stable yet flexible operation on the basis of iron-making experiences at Chiba and Mizushima Works. Effective control of gas distribution in the furnace by the full use of the bell-less top brought about a successful starting-up and rating-up of operations and resulted in attaining high productivity (10 000 t/d) and low fuel consumption (418.4 kg/t).*

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## 1 Introduction

Completion of the No. 6 blast furnace at Chiba Works integrated West Plant production system. This blast furnace, the construction of which began in April 1975 and which was blown in on June 17, 1977, is the largest of the company's blast furnaces with a hearth diameter of 14.1 m, an inner volume of 4 500 $m^3$ and the capacity to produce 10 000 t/d of pig iron. The No. 6 BF is characterized by Japan's first large furnace with bell-less top charging system. Other advanced technologies have also been introduced in the interests of environmental polution control, energy conservation, cost reduction and safety at the facility. The introduction of bell-less top charging system to blast furnaces has increased in the past few years due to the high flexibility of burden distribution control. Stable operation with a bell-less top charging system is achieved mainly by controlling burden distribution.

This report is intended to give a summary of the No. 6 BF facilities and its operation.

## 2 Summary of the Facility[1)]

The layout of the No. 6 BF is shown in **Fig. 1** and its specifications are given in **Table 1**. The furnace body is a free standing type and is equipped with a PW (Paul Wurth) bell-less top charging system. Four Koppers external combustion type hot stoves have been installed to Ensure a large heating area and thereby restrain NOx generation during combustion. Two energy recovery gas turbines driven by high top pressure gas, an air preheater for combustion air run by exhaust gas from the hot stoves and a humidity control blast facility have been installed for energy conservation. Large capacity dust collectors, silencers and water circulation systems have also been incorporated for environmental protection. The cast houses are laid out in parallelogram for easy transportation of molten iron and slag, which are transported through a passage under the floor. Molten iron is poured into a 350 t torpedo car and slag into a 60 t open ladle.

## 3 Characteristics of the Equipment

### 3.1 Blast Furnace Body

**Fig. 2** shows the profile of the No. 6 BF.

In determining the profile of the No. 6 BF a serious study was done regarding the profile, performance, damage to furnace body brick, operating stability and various other aspects of the giant No. 4 blast furnace at Mizushima Works, which is one of the largest blast furnaces in Japan. The furnace support system is a

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* Rearranged from the following three articles: (1) Kawasaki Steel Technical Report, 10 (1978) 2·3 pp. 25-32 (in Japanese); (2) ibid. pp. 33-46 ; (3) 39th Ironmaking Conference of AIME (The Iron & Steel Society), Mar. 24-26 1980 by the title of "LOW FUEL RATE OPERATION IN A 4500m³ BLAST FURNACE WITH BELL-LESS TOP AT CHIBA WORKS."

** Chiba Works

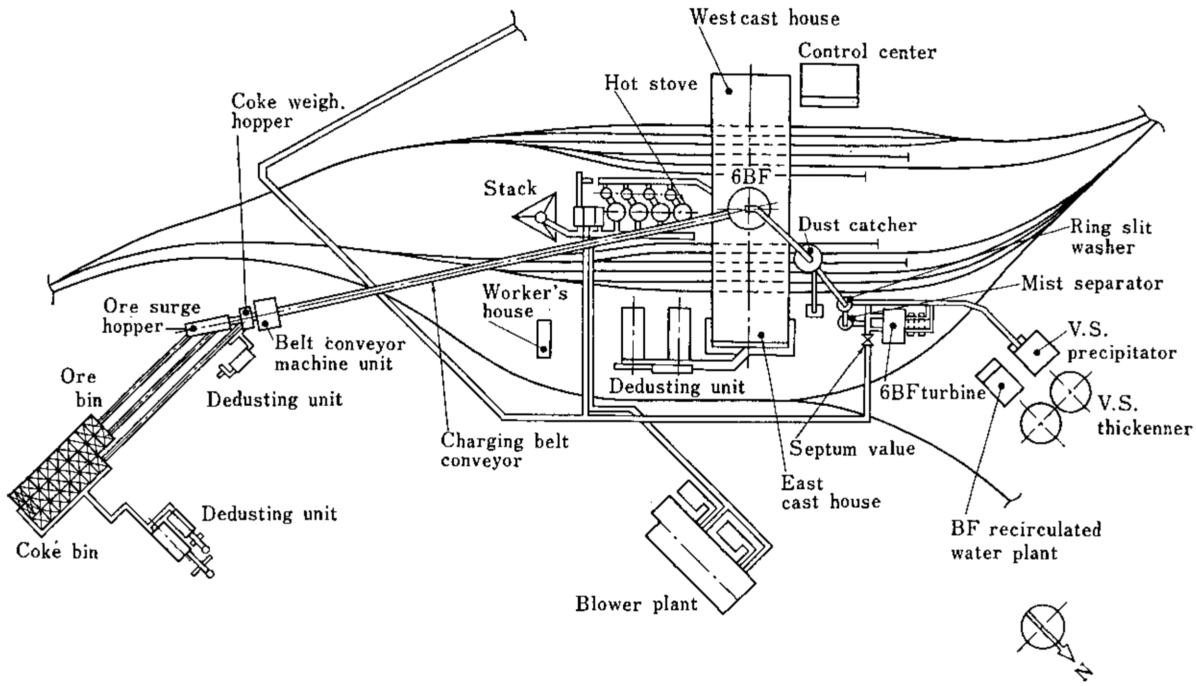


**Fig. 1** Layout of Chiba No.6 blast furnace

free standing type equipped with shaft brackets for emergencies. The bottom of the hearth is made mainly of carbon blocks. There are also a layer of brick for level adjustment, five layers of large carbon blocks and two layers of chamotte bricks. The corner part is protected from corrosion by a reduction in the chamotte brick area and by making the outer carbon blocks thicker. Silicon carbide brick, which has high thermal conductivity and hot bending strength, is used for the bosh, the belly and the lower part of the shaft. For cooling the furnace body, stave coolers, which employ a system of forced boiler water circulation, have been applied. A closed copper cooling boxes were installed as substitute for the Γ type stave coolers in order to reinforce the brick support structure.

Forty tuyeres are used. The tuyeres are a high velocity water cooling type with eccentric spiral water path. In order to improve gas sealing, PW type tuyere connecting pipes, which are far superior to conventional connecting pipes in deformation tolerance, have been used. A forklift was used for replacement of blow pipe and tuyere stock so that repairing work could be done mechanically.

### 3.2 Cast Houses

There are two cast houses, one extending to the east and the other to the west. The floors are perfectly flat to provide optimum work conditions. Floor areas were made as large as possible and trough maintenance stations were built in the cast houses (see **Fig. 3**). There are four tap holes, two in each casting floor, of which three are always in operation. The remaining hole is a spare. A movable tilted trough has been employed for easy ladle alignment and trough replacement. The main trough is one 20 m unit which is equipped with a natural air-cooling system to prevent deformation. The branch trough cover, tilted trough pit cover, etc. were also made flat in order to greatly increase workability.

### 3.3 Hot Stoves

Four Koppers external combustion type hot stoves have been installed. The heating area is a vast 110 000 $m^2$/stove in order to bring down combustion temperature of the stoves and thus reduce NOx generation, preventing pollution. Checker room and combustion chambers are of the independent standing type. The structural steel for the shell in the high temperature zone is SM41C because of its resistance to stress corrosion. At the same time R bending has been applied to all corner sections, annealing to welded sections and acid proof paint to inner surfaces.

New control instrument technologies featured are: control of oxygen concentration in combustion exhaust gas; control of combustion gas calories for each furnace using a two-stage enriching method for coke oven gas; and pressure control system during changing hot stoves.

### 3.4 Charging Equipment

This is the first PW type bell-less top introduced in a large blast furnace in Japan. In designing the

Table 1 General items of Chiba No.6 blast furnace

| | |
|---|---|
| **Blast furnace** | |
| Type | Free standing |
| Inner volume ($m^3$) | 4 500 |
| Hearth dia. (m) | 14.1 |
| Tapholes | 4 |
| Cinder notches | 0 |
| Tuyeres | 40 |
| Tuyere stocks * | PW type |
| Cooling system | |
| Bottom | Cooling tube (recirculated water) |
| Shaft, belly, bosh | Cooling stave (pure water) |
| Hearth | Spray water (recirculated water) |
| **Hot stove** | |
| Type | Koppers external combustion type |
| Blast temperature (°C) | Normal 1 250, Max. 1 300 |
| Hot stoves | 4 |
| Heating area ($m^2$) | $110\,000 \times 4$ |
| Type of burner | Ceramic |
| Dome temperature (°C) | 1 460 |
| Operation mode | Staggered-parallel |
| Air preheater * | Ljungström type |
| **Charging equipment *** | |
| Type | PW-IHI bell-less top |
| Distribution chute | |
| Length (m) | 4.0 |
| Tilting angle (°) | 17~52, 10 setting points |
| Rotation speed (rpm) | 7.97 |
| Flow control gate | |
| Opening angle (°) | 40~47, 8 setting points |
| Charging capacity (ch/d) | Normal 180, Max. 250 |
| **Gas cleaning equipment** | |
| Dust catcher | |
| Capacity ($Nm^3/h$) | $750 \times 10^3$ |
| Venturi scrubber | |
| Type | Kawasaki-Bischoff |
| Outlet dust ($mg/Nm^3$) | Max. 5 |
| Capacity ($Nm^3/h$) | $750 \times 10^3$ |

| | |
|---|---|
| **Blower** | |
| Capacity ($Nm^3/min$) | Max. 9 000 |
| Pressure (atg) | Max. 5.5 |
| **Casting floors** | |
| Cast house area ($m^2$) | 9 000<br>Perfect flat floor * |
| Runner | |
| Hot metal main | |
| Type | Replaceable |
| Size (mm) | $1\,900w \times 20\,000l \times 1\,450h$ |
| Hot metal treatment | Torpedo car (350t) |
| Slag treatment | Open ladle (60t)<br>2 emergency dry pits |
| Cast house crane | $125/20t \times 25m \times 2$<br>$20t \times 9m \times 1$<br>$20t \times 8m \times 2$ |
| Mud guns | 4 |
| Type | Hydraulic |
| Cylinder volume ($m^3$) | 0.3 |
| Cylinder force (t) | Max. 350 |
| Openers | 4 |
| Type | Rotationary post type |
| Jib crane | $10t \times 10.75m \times 4$ |
| **Top pressure control equipment** | |
| Septum valves | |
| Type | Sealing type |
| Dia. (mm) | $600 \times 2$, $850 \times 3$ |
| Gas turbine | |
| Type | 2-stage axial expansion turbine (ГУБТ-12) |
| Output capacity (kW) | $12\,000 \times 2$ |
| Input capacity ($Nm^3/h$) | $340\,000 \times 2$ |
| **Process computer** | |
| Type | YODIC-1000 |
| Capacity | Core 96 kW, drum 1 MW, disk 4.8MW |

* Newly adopted technique, facilities

No. 6 BF, a number of modifications were made on the basis of the performance of and experiences with the No. 2 blast furnace and various model tests with emphasis placed on simplified maintenance. Some examples are: anti-abrasion measures for distributing and vertical chutes, improved reliability of the top bunker scale and introduction of a dust purge system to seal valves. Special consideration is given to exchange and replacement of devices by using a exchange jig. This charging facility is automatically controlled by programmable logical controllers.

Cleaned blast furnace gas is used for cooling the driving unit and thus to keep temperatures below the specified level. Maintenance is normally carried out at three month intervals during scheduled shut downs. The first rotating chute replacement was performed when accumulated iron production reached 4 million tons. The present chute should not require replacement until approximately another 5 million tons of iron have been produced.

### 3.5 Material Weighing Facility

There are 20 ore bins (10 for sinters, 6 for sized ore and 4 for additives) and 6 coke bins. Under-bin screens have been provided to allow for greater control of the fines in sinter and coke.

In view of the special condition presented by the bell-less top charging system, different charging ores are mixed on the ore charging belt conveyor to prevent segregation in the furnace. A special bunker has been installed exclusively for measuring the moisture content of coke with a neutron moisture probe.

### 3.6 Energy Conservation Provisions

The two most significant energy conservation provisions of the No. 6 BF are the hot stove air preheater for combustion air and the energy recovery turbine which is run by furnace top gas. Slightly over 30% of the calories are recovered from combustion gas using the air preheater, contributing to an improvement of approximately 3 ~ 4% in the thermal efficiency of the hot stoves. As for the energy recovery

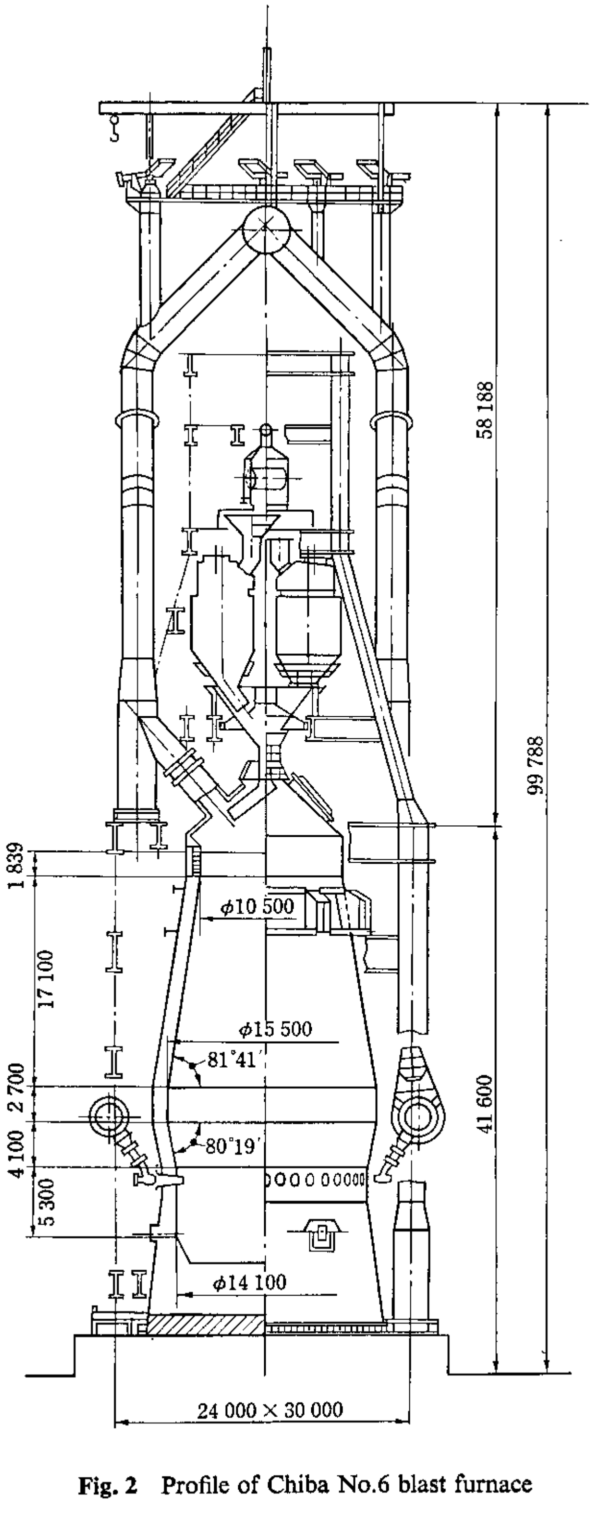


**Fig. 2** Profile of Chiba No.6 blast furnace

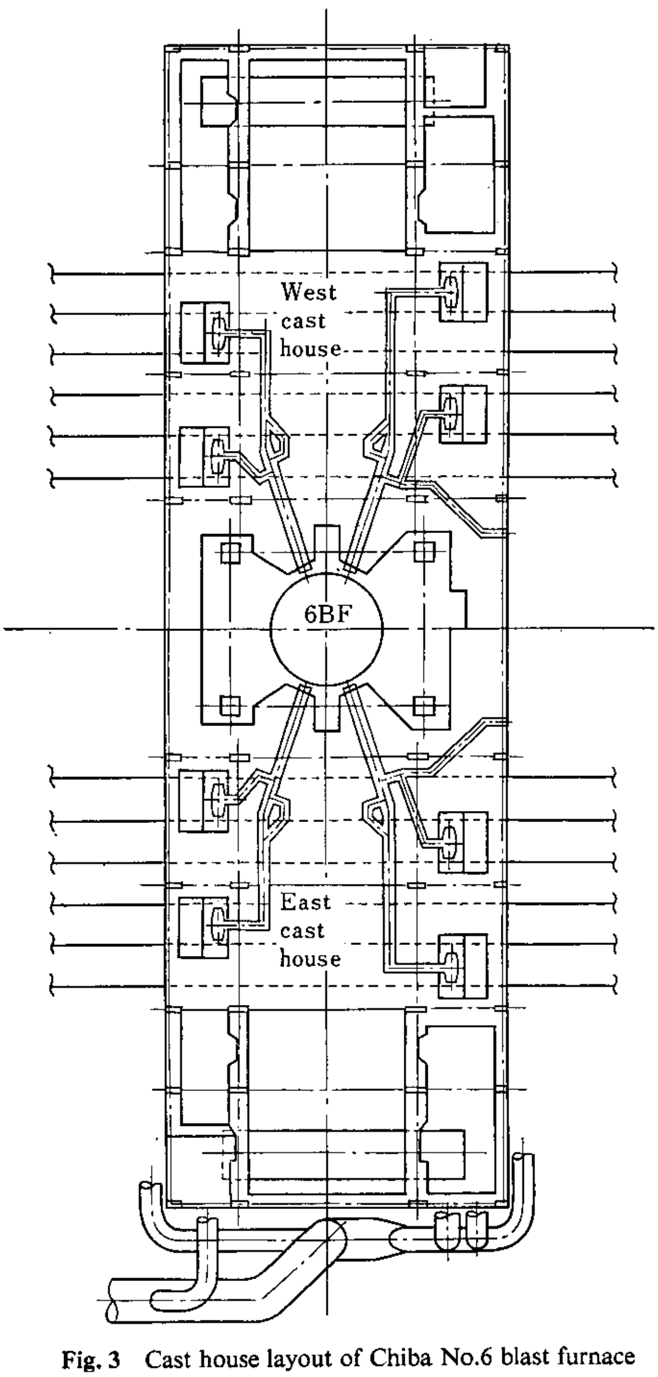


**Fig. 3** Cast house layout of Chiba No.6 blast furnace

turbine, a Russian type was employed. The crude gas which is produced in the furnace flows through the dust catcher to a Bischoff type venturi scrubber which cleans it into high pressure clean gas with a dust content of no more than 5 mg/Nm³. It is then fed to the turbine. With the two turbines installed, output capacity is 12 000 kw each. Top pressure is mainly controlled by turbines and backed-up by septum valves.

### 3.7 Pollution Control Equipment

#### 3.7.1 Dust collecting systems

The cast house dust collecting system is designed to have an overall wind volume of 40 000 m³/min, which consists of wind volume of 10 000 m³/min for suction of iron and slag pit per one tap hole, and wind volume of 17 000 m³/min for suction from top part of the casting house. Maximum volume is determined in consideration of the opening of two tap holes at the same time in one side of the casting house. A variable fluid coupling, which adjusts wind volume, has been installed between the fan and the electric motor as an energy conservation measure. Other dust collectors are located at the material weighing and charging units, and wind volumes of 7 000 m³/min in the ore bin system, 3 000 m³/min in the coke bin system and 2 000 m³/min in the surge hopper system.

#### 3.7.2 Silencer

General noise regulations were first determined in drawing up noise countermeasures. Noise tolerance levels at different parts of the furnace were determined so that they would conform to the general regulations. Silencers were installed and sound arresting laggings were applied to enforce the predetermined levels.

#### 3.7.3 Cooling water

Perfectly closed-loop circulation systems have been set up for furnace cooling water and water for the

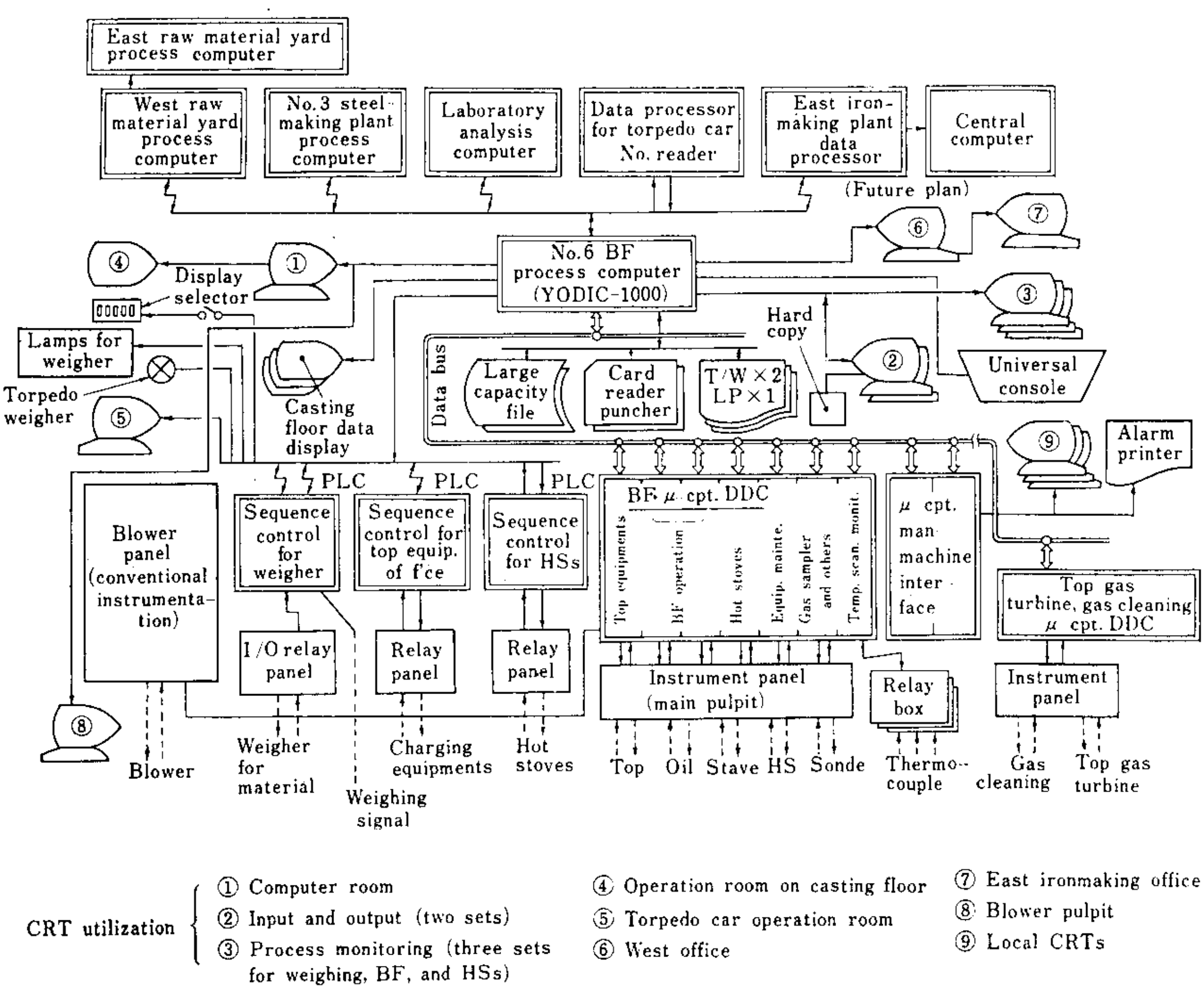


**Fig. 4** Instrumentation and process computer configuration for Chiba No.6 BF (μ-cpt. means "micro-computer")

venturi scrubber. Use of brine is confined to the heat exchangers for furnace cooling water. Stave cooling water is recirculated boiler water to which carefully selected chemicals are added for corrosion prevention.

### 3.8 Instrumentation

Total configuration is shown in **Fig. 4** and main specifications of the principal equipment are described in **Table 2.**

There is a hierarchy of functions as follows:

(1) Field Section
Sensors and manipulating apparatus in the field.

(2) Local Section 1 (Conventional Instrumentation)
This is the operating section with remotely controlled manual operation. Duplicating digital instrumentation, this serves as a backup function.

(3) Local Section 2 (Digital Instrumentation)
Forming the nucleus of this system, this section is

**Table 2** Main specifications of process computer, micro-computers and PLCs

| | Specifications | Function |
|---|---|---|
| Programmable logic controller<br>{Yasukawa}<br>[15] | Model MEMOCON SC 184<br>Memory capacity 4kw×15(core)<br>Memory cycle time 2.0 μs<br>Computer interface 8<br>Remote I/O 7<br>Process I/O (total)<br>A/I 48 points<br>A/O 4 〃<br>D/I 2 560 〃<br>D/O 2 100 〃 | Material weighing control<br>Sequence control for weighing and discharge at bunkers, bell-less charging, hot stove, and dedusting equipment |
| Micro-computer instrumentation system<br>{Yokogawa}<br>[FCC: 8, DFC: 2] | Model CENTUM<br>Memory capacity 16kw×2 (core)<br>32kw×6 (core)<br>48kw×2 (core)<br>Memory cycle time 1.4 μs<br>Process I/O (total)<br>A/I 420 points<br>A/O 90 〃<br>PI 80 〃<br>D/I 680 〃<br>D/O 720 〃<br>CRT color display 3<br>Printer 1 | Measurement and control for blast furnace operation, top equipments, hot stove, gas cleaning, and blast gas furnace turbine<br>Monitoring of temperatures, cooling water leakage, and others |
| Process computer<br>{Yokogawa}<br>[1] | Model YODIC-1000<br>Memory capacity 96kw (core)<br>1 024 kw (drum)<br>4 096 kw (disc)<br>Memory cycle time 0.7 μs<br>Process I/O<br>PI 96 points<br>D/I 256 〃<br>D/O 256 〃<br>Data communication<br>MODEM 3<br>Data bus 2<br>Modified MODEM 8<br>CRT color display 11<br>Printer 2<br>Line printer 1 | Total control of blast furnace. |

A/I Analog Input
A/O Analog Output
D/I Digital Input
D/O Digital Output
PI Process Interrupt

Note : Makers are shown in braces and the number of computers in square brackets composed of many micro-computers and PLCs (Programmable Logical Controllers), and any risk is dispersed. Processing and control on the sensor basis are self-completed. This is also a semi-automatic operating section, in which, once the operator gives a start to a series of operations, the rest of the operation is conducted automatically.

(4) Upper Section (Process Computer)
Information is absorbed from the Local Sections, while various operation indices are calculated, and large capacity data banks also made up. Furthermore, by communicating with the raw material yard and steelmaking plant, it performs total control of the whole blast furnace and gives the information to the operator in an intuitive way after marshalling and consolidating data. For control, it supervises the Local Sections, providing centralized operation[2].

The following are noteworthy features of instrumentation of the No. 6 BF. Comprehensive analyses can be carried out making use of data from such devices as a fixed temperature probe (at 6 points), DDS type horizontal sonde (at 9 points), an infrared camera and an ITV system at the furnace top, all of which contribute to improved burden distribution. The sounding device using micro-wave is a non-contact type, so it is free from inclusion of a sounding rod in the case of slipping. This is extremely useful in emergencies. The blast volume measurement at the tuyere connection pipe is effective for control of blast volume distribution at each tuyere in combination with a heavy oil injection.

Automatic detectors of torpedo car number have been installed in the railway and provide information on every change in torpedo car position. This system makes optimum control of torpedo car number possible.

## 4 Blast Furnace Operation Technology

### 4.1 Burden Distribution Control

Optimum burden distribution is such that it enables the furnace to run at maximum gas utilization while retaining good permeability.

High gas flow is necessary in the very limited central area, to attain good permeability. Moderate gas flow is to be maintained in the periphery because: excessive gas flow causes not only high heat loss but also damage to the furnace lining; too low gas flow can help develop scaffolding and a thick cohesive layer near the wall that on descending into the raceway zone may cause tuyere bending. Gas flow in the intermediate region is controlled so as to obtain maximum gas utilization.

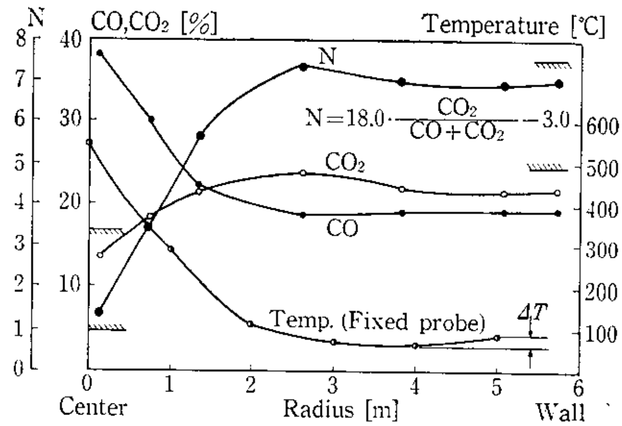


**Fig. 5** Distribution of gas composition and temperature

Gas flow distribution is mainly evaluated by the distribution of temperature and gas composition. **Fig. 5** shows an example of the measured distribution of temperature and gas composition when furnace conditions were thought to be optimal.

Burden distribution is controlled by changing the thickness distribution of ore and coke layers. This is effectively done by using a bell and movable armor charging system or a bell-less charging system. Because of the difference in the burden flow during charging the angle of repose and the degree of size segregation along the radius are greater in the bell-less charging than in the bell and movable armor charging. On the basis of the above consideration, a multi-ring charging was preferred to a single- or dual-ring charging. Apparent angle of repose and size segregation can be decreased by the use of multi-ring charging.

At the No. 6 BF, each of the two top bins is filled with either one layer of ore or coke. Charging rate is so controlled as to charge the material in 13 revolutions of the distributing chute. Burden distribution control is made by changing "charging pattern" which states how many rings are charged at a given tilting position number. Relation between the tilting position number and the tilting angle and an example of a charging pattern are given in **Table 3**. Because of the wide variation in burden distribution obtainable by bell-less charging, the way to obtain optimal burden distribution was the first object. Laboratory tests were carried out to clarify the characteristics of burden distribution by the bell-less charging system. Although the results of the tests helped operators in understanding characteristics, the optimal burden distribution had to be established mainly by various test operations at the blast furnace. The optimal burden distribution was established through a relatively long

Table 3 Typical charging pattern

| Tilting position | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Falling angle (deg.) | | 52.0 | 50.5 | 48.5 | 46.5 | 44.0 | 41.5 | 38.5 | 35.5 | 31.5 | 25.2 |
| Rotating number | Coke | 2 | 2 | 3 | 3 | 1 | 1 | 1 | 0 | 0 | 0 |
| | Ore | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 0 |

Table 4 Control of radial gas distribution

| Index | Range | Remarks |
|---|---|---|
| $CGI=18\times\eta_{CO-center}-3.0$ | 1.0 to 3.5 | Good gas utilization and smooth burden descent |
| $PGI=18\times\eta_{CO-periphery}-3.0$ | 5.0 to 7.5 | Prevent tuyere bending and tuyere burn out |
| $\Delta T=T_{wall}-T_{min}$ | under 30℃ | Control peripheral gas flow |

CGI: Center gas index
PGI: Peripheral gas index
$\eta_{CO}$: CO gas utilization ratio

period of test operation. This long time was necessary because this was our first experience in the operation of a large furnace with a bell-less top and we were short of relevant information. By the experience obtained we would be able to establish the optimal burden distribution in much shorter time for the next blast furnace with a bell-less top.

As a routine practice in daily operation, a fine adjustment of charging pattern is performed on the basis of measured gas distribution, gas utilization ratio and heat loss. The fine adjustment is done by choosing a suitable charging pattern out of seven pre-set standard charging patterns. The standard charging patterns are so determined as to change burden distribution successively from central working to peripheral working. For example, if the gas utilization ratio becomes lower, the operator will change the current pattern to the one a step more towards peripheral working. Furthermore, boundary conditions for gas distribution are set, as shown in **Table 4** to ensure good furnace working.

### 4.2 Properties of Sinters and Coke

Since the ratio of sinters normally amounts to 80 to 85% of the total ores charged, in order to maintain good permeability and reduction condition in the furnace, the properties of the sinter are controlled to keep the following figures: shatter index (S.I.) 89% and over; reduction degradation index (R.D.I.) 40% and under; FeO content between 4.5 and 7.5%. Among these figures, FeO content is kept at as low a level as possible for the attainment of a high utilization ratio of top gas.

In the No. 6 BF, two kinds of sinters are charged: domestic and Philippine sinters. The mean size of Philippine sinter is smaller than that of domestic sinter due to stabilization during the transportation from the Philippines to Japan. This stabilization also makes the shatter index higher than that of domestic sinter[3].

The quality of coke is improved by using a coke

Table 5 Quality of burden materials

| Item | Chiba sinter | Philippine sinter | Algarrobo pellet | Coke | |
|---|---|---|---|---|---|
| T.Fe % | 55.4 | 58.03 | 66.04 | Ash % | 11.0 |
| $SiO_2$ % | 5.90 | 5.85 | 1.81 | Sulfur % | 0.6 |
| CaO % | 9.60 | 8.80 | 2.62 | Moist. % | 0.9 |
| MgO % | 2.20 | 0.60 | 0.36 | | |
| FeO % | 5.23 | 5.17 | 0.66 | | |
| Basicity | 1.62 | 1.50 | 1.45 | $DI^{30}_{15}$ % | 94.5 |
| S.I. % | 89.4 | 93.0 | TI+5mm 97.54 | $TI^{400}_{6}$ % | 84.5 |
| R.D.I. % | 40.5 | 34.7 | C.S* 356.0kg | −25mm % | 1.5 |
| Mean size mm | 12.1 | 10.9 | 12.4 | 25-50 % | 54.0 |
| 5-10 mm % | 32.6 | 24.4 | — | 50-75 % | 42.8 |
| | | | | +75mm % | 1.7 |

* C.S means crushing strength

Table 6 Casting data (Nov. 1979)

| Item | Unit | No.1 TH | No.2 TH | No.3 TH | No.4 TH | Average |
|---|---|---|---|---|---|---|
| Casting time | min | 123 | 120 | 125 | 117 | 121 |
| Quantity: Iron | t | 817 | 837 | 859 | 828 | 836 |
| Slag | t | 254 | 268 | 275 | 251 | 263 |
| Casting speed: Iron | t/min | 6.6 | 7.0 | 6.8 | 7.1 | 6.9 |
| Slag | t/min | 2.3 | 2.5 | 2.5 | 2.5 | 2.5 |
| Drilling Length (L) | mm | 940 | 1 048 | 1 022 | 986 | 993 |
| (S) | mm | 474 | 426 | 487 | 516 | 467 |
| Hammering Length | mm | 2 062 | 2 016 | 1 964 | 1 994 | 1 987 |
| Taphole Length | mm | 3 475 | 3 491 | 473 | 3 497 | 3 447 |
| Quantity of plugging material | kg/tap | 415 | 398 | 394 | 417 | 401 |
| | kg/t | 0.51 | 0.48 | 0.46 | 0.50 | 0.48 |

dry quenching process. The quenching of coke in this process especially enables the attainment of higher drum index, lower reactivity and lower moisture content than those of the conventional wet quenching process. **Table 5** shows the qualities of burden materials used.

### 4.3 Tapping Operation

Stable tapping is indispensable for smooth operation. Tapping of hot metal and slag is controlled on a basis of residual iron and slag in the hearth. Normally, three of four tap holes are used to tap continuously. Sometimes the second tap hole is opened before the end of the tapping from the first tap hole. A 10 000 t-HM/d is tapped in 11 ~ 13 tappings a day. The balance of hot metal and slag tapped is displayed on CRT. **Table 6** shows an example of tapping data. Small differences of the amounts of iron and slag between tap holes, moderate speed of tapping and low consumption of plugging material indicate smooth tapping operation. As a result, molten iron and slag in the hearth are effectively drained.

### 4.4 Improvement in Tuyere Design and Cooling

For stable operation of blast furnaces, the prevention of equipment troubles is an essential factor. For the prevention of tuyere damage which is a major cause of non-scheduled shut-downs, improvements in tuyere design have been continuously made. The design of the tuyeres currently in use is unique in the following points:

(1) The spiral water channel is specially designed so as to strengthen cooling ability at the tip and the upper part of the tuyere barrel. Local velocity of cooling water is as high as 20 m/s.
(2) Two rows of studs are planted at the tip of the tuyere to prevent abrasion by circulating coke.
(3) Durable ceramic coating was applied on the surface to prevent direct attack of molten iron on copper.

It should be noted that smooth operating conditions of the furnace and optimal control of burden distribution, especially in the periphery, are as important as the design of the tuyeres for longer life of the tuyeres.

As the result of the above improvements in design and operation, no tuyere trouble occured from April, 1979 to June, 1980. Currently, the tuyeres are replaced by new ones every 240 days. It is expected to extend the cycle of replacement up to one year in the near future.

### 4.5 GO-STOP System

Blast furnace operation under a low fuel rate has a chance of causing troubles. Preventive technology for such troubles has been developed by Kawasaki Steel Corporation under the name of the GO-STOP system as computer-aided operational guidance. This system is, in its nature, the systematization of the operational experiences of furnace operators with the application of theoretical understanding of the blast furnace process[4].

The principal object of the system is to give the furnace operators a diagnosis of the furnace condition and to give directions for countermeasures to be taken if necessary. By the application of the system, the furnace condition is always categorized as one of the following three states:

(1) GO: The furnace is in good condition.
(2) STOP: The furnace condition needs cautious observation.
(3) BACK: The furnace is in bad condition and the present operation requires change, mainly by decreasing blast volume to some extent.

The blast furnaces with the system at Kawasaki Steel Corporation have not experienced such serious trouble as hearth chilling.

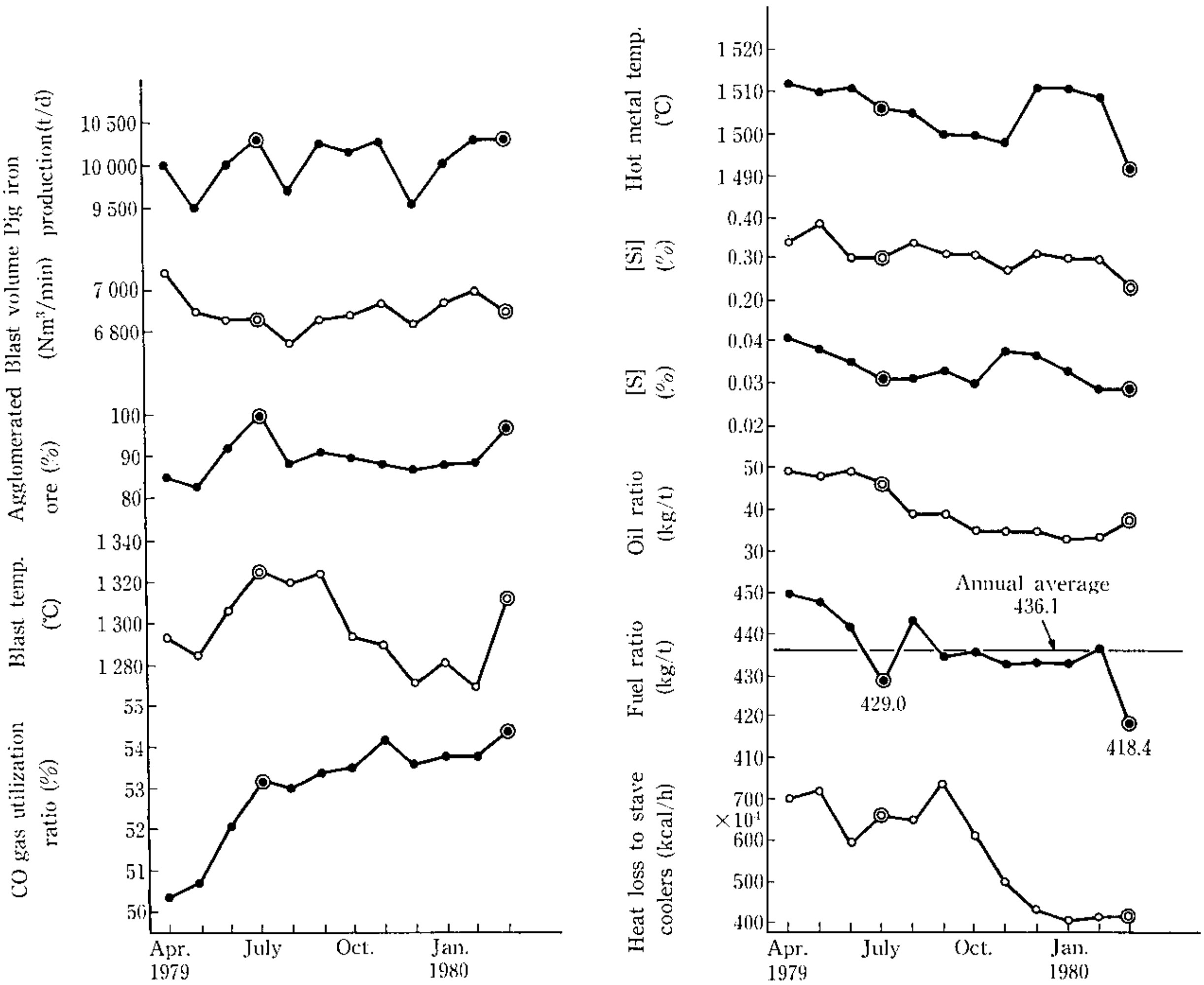


**Fig. 6** Changes in various factors of No. 6 BF operation

## 5 Operating Results

The following depicts the results of operation for a period of one year from April 1979 through March 1980. The changes in major factors of operation during this period are shown in **Fig. 6**. Although the ratio of agglomerated ores in total burden material, which is a crucial factor in blast furnace operation, amounts to 80–85% in normal operation, the ratio was increased to 100% and 97% in July and March, respectively, to investigate its effect on fuel ratio. Mainly the amounts of Philippine sinter and basic pellet were increased. Limestone is not used in the No. 6 BF for slag basicity control. This is performed by controlling the ratio of sinter charged and changing its basicity. The level of FeO content in sinter was kept low in order to improve reducibility which resulted in a slight increase in the reduction degredation index (R.D.I.), but not to the extent it had any major affect on blast furnace operation. Various actions were taken to achieve a low fuel ratio as the agglomerated ore ratio was increased (for example, raising blast temperature, lowering [Si], etc.).

**Fig. 7** shows some of the typical charging patterns.

The figure shows the number of revolution given to coke and ore at each position number. As it can be seen from the figure, charging pattern near the periphery was hardly changed; the change was made mainly in the center to the middle of the furnace.

Gas distribution of the same period are shown in **Fig. 8**.

As the agglomerated ore ratio was increased, central gas flow tended to develop. In order to counteract this tendency and to increase the gas utilization ratio, burden distribution was adjusted to suppress excessive central flow. Generally, gas utilization ratio increases with the decrease in central gas flow while this causes a loss of furnace permeability. Therefore, the central gas flow is kept as low as furnace permeability permits. It can be seen from **Fig. 8** that the central gas flow decreased as the agglomerated ore ratio increased. This fact shows one of the good effects of the sinter on

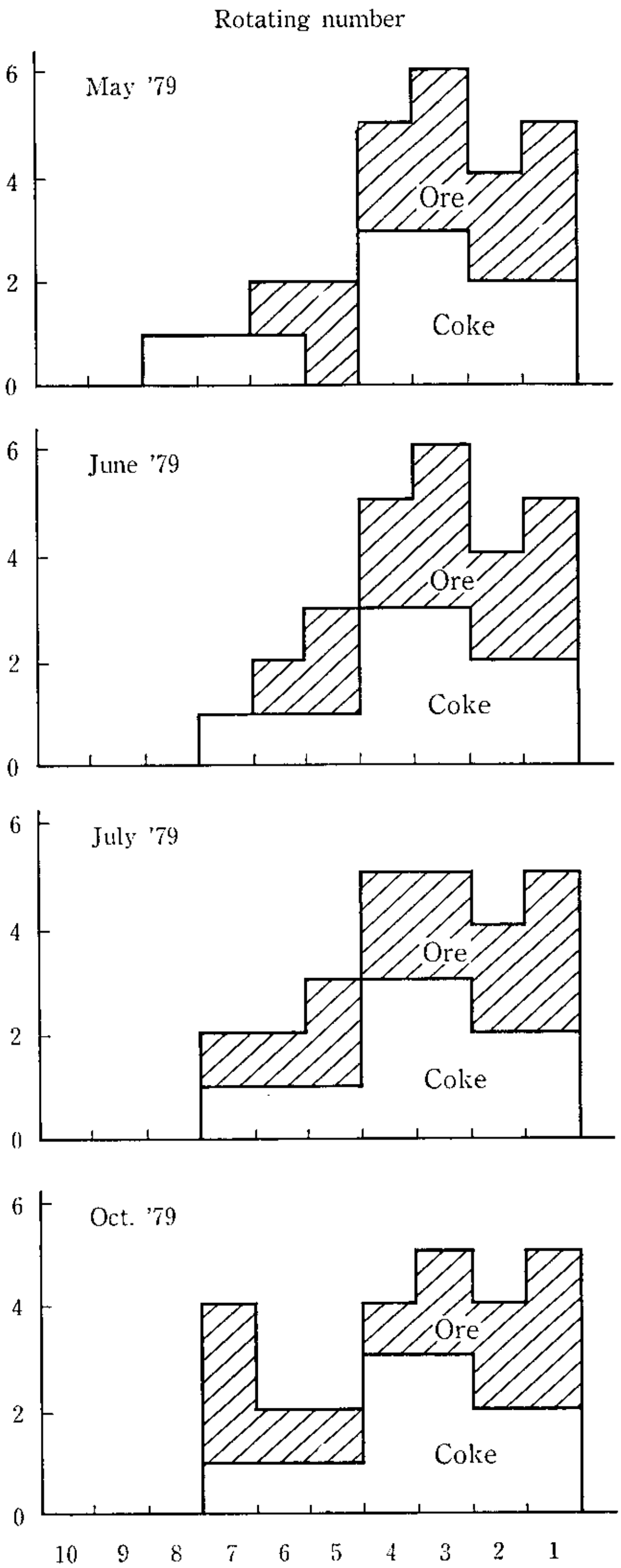


**Fig. 7** Bell-less charging pattern

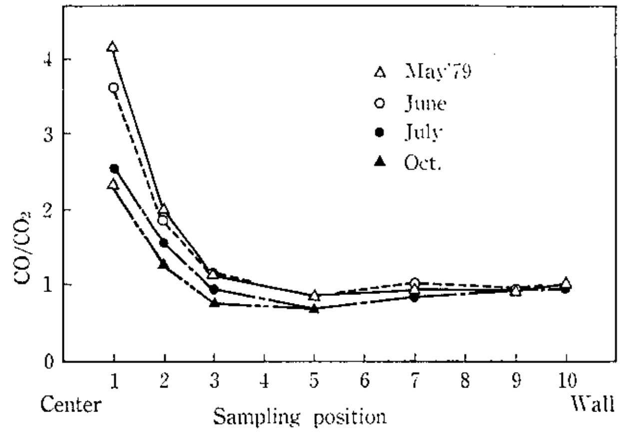


**Fig. 8** Gas distribution in the shaft

furnace operation. The gas utilization ratio increased as a result of improvements in gas distribution and reducibility of the burden materials.

In July 1979, a test operation was carried out with 100% agglomerated ores, and pig iron production of 10 345 t/d and a fuel ratio of 429 kg/t were achieved. Furnace operation was good and furnace permeability improved[5]. Descent of burden material was satisfactory and little blast pressure fluctuation could be observed as shown in **Fig. 9**.

After the test operation with 100% agglomerated ores, the agglomerated ore ratio was decreased to the normal level of about 90%. Good operating performance with a low fuel rate of about 435 kg/t-HM at a production rate of 10 000 t/d has been maintained. This performance is impressive when one notices the decrease in oil rate by about 10 kg/t-HM compared to the test period.

Operating practices in the period following the test period were as follows. Burden distribution was controlled to further suppress the central flow to increase the gas utilization ratio as shown in **Figs. 7** and **8**. The objective of the distribution control at this time was to take maximum advantage of the favourable temperature distribution in the furnace established during the test period. Flow rate of charged material from the top bins was controlled more strictly to decrease fluctuation in the number of revolutions per charge. This contributed to the formation of consistent burden distribution. Stock level was raised by 0.7 m to increase the volume of the indirect reduction zone. Openings of the rubber screens under the coke bins are changed from 35 to 30 mm. By this change, size ratio of coke between 25 and 30 mm increased by a few percent, although overall size distribution remained about the same.

Another test operation was carried out in March 1980 based on the experiences of prior test operation,

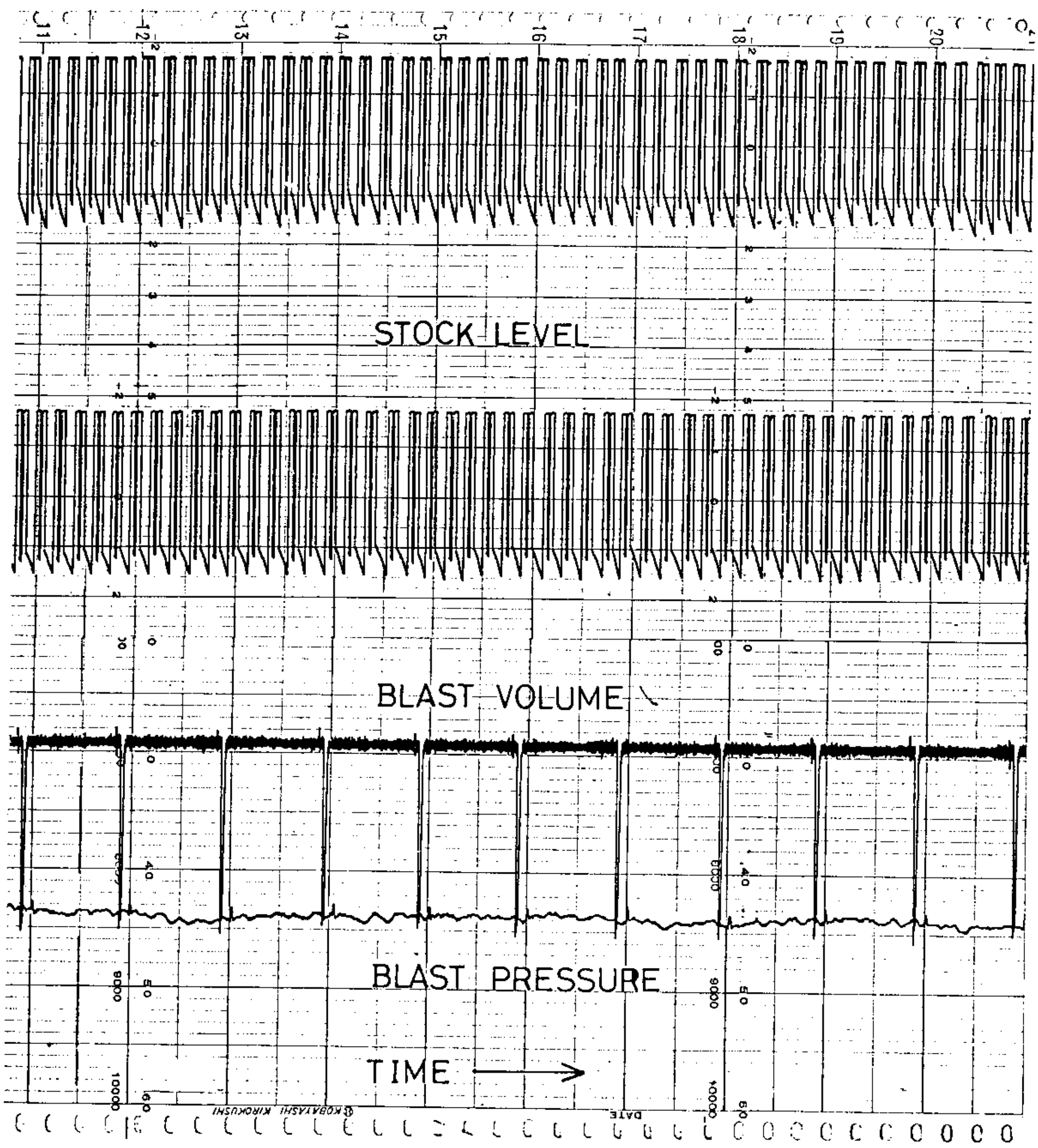


**Fig. 9** Chart for burden descent, blast volume and pressure

this time with 97% agglomerated ores. The results revealed that burden distribution had improved further and performance was good with a pig iron production rate of 10 310 t/d, fuel ratio of 418.4 kg/t, coke ratio of 381 kg/t, oil ratio of 37.4 kg/t and gas utilization ratio of 54.4%. As a result of stable operation during the past year, annual pig iron production average 10 056 t/d, fuel ratio 436.1 kg/t, coke ratio 396.4 kg/t, oil ratio 39.7 kg/t, and operation rate 99.75% (not including scheduled shut-downs). There were no shut-downs due to tuyere failure during this period.

## 6 Conclusion

The No. 6 BF at Chiba Works, which was constructed at West Plant to bring Chiba Works' total annual crude steel production to an 8.5 million tons level, started operation on 17 June, 1977. It is the first large bell-less top blast furnace capable of achieving a daily production level of 10 000 tons in Japan. After a number of modifications, it registered a fuel ratio record of 418.4 kg/t (coke ratio: 381.0 kg/t, oil ratio: 37.4 kg/t) in March 1980. Moreover, the average fuel ratio during the period from April 1979 through

March 1980 reached 436.1 kg/t with no shut-downs due to tuyere failure. The excellent performance which was achieved is attributable to the following factors.

(1) The establishment of technology for fine control of burden distribution using a bell-less top charging system.

(2) Improvement of reducibility and softening-melting properties of sinter, which accounts for a major portion of burden materials.

(3) Stable quality coke obtained by the coke dry quenching process (CDQ).

(4) Furnace condition control by the GO-STOP system.

(5) Introduction of a de-humidifying equipment for blast.

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