The Smelting of 50 per cent Ferrosilicon in a Large, Closed Electric Furnace

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SYNOPSIS

To rationalize the smelting of ferrosilicon, we attempted to develop a process in which siliceous iron ore is used as the source of both Fe and Si (instead of the conventional process using scrap or scale as the source of iron) in the production of eutectic ferrosilicon with a silicon content of 50 per cent.

The good results of a laboratory study of a small-scale furnace led to a study, on an industrial scale, of the raw materials, electric-loading characteristics, etc., in an open electric furnace with a 10 000 kVA transformer.
We succeeded in developing a technique for the economical production of ferrosilicon of excellent quality. The ferrosilicon does not disintegrate and contains few impurities. Furnace operation is smooth and stable, without any trouble such as 'hanging', which often occurs in the conventional process of ferrosilicon smelting. The production costs are low, and the reduction of silicon is high. The furnace conditions in the test clearly showed the possibility of operation in a closed furnace. However, there were many problems to be solved in the construction of a closed furnace of large capacity.
We developed our own special designs for the furnace, which incorporate the following main points:
(1) a 'bus-conductor system' to give a well-balanced electric load to each electrode phase, which is necessary for stable smelting conditions and easy electrical control, to increase the power factor, and to make it easy for the electrode to be removed even in the worst case of breakage; and
(2) a 'charge-pipe system' for each electrode, which supplies mixed charge materials round each electrode with no segregation, and accurately measures and observes the mass decrease of the charge in accordance with the progress of smelting.

In July 1968, we started production of 50 per cent ferrosilicon in the Yahagi closed electric furnace with a 45 000 kVA transformer designed according to the above-mentioned system, and in July 1972 we added an improved, larger furnace with a 60 000 kVA transfer.

The gas from the furnaces is cleaned thoroughly by a wet process with water in closed circuit, and is utilized as raw material for chemical synthesis, etc.
These furnaces run smoothly and efficiently without any pollution problem.

DEVELOPMENT OF THE TECHNIQUE

During the smelting of ferrosilicon in the primitive open electric furnaces generally used, the high-calorific gas that is evolved is not recovered but burns on the furnace top. The working conditions are extremely unhealthy on account of the high temperature. Extensive equipment, which often gives trouble and is very expensive, is required for the prevention of air pollution.

Yahagi, after lengthy studies and experience in electric iron-making, has succeeded in developing a rationalized technique of ferrosilicon smelting in a fully closed electric furnace of large capacity.

In the first experimental study, an open electric furnace was used in the determination of conditions for the satisfactory smelting of the materials charged to the furnace, which was operating smoothly without any tending such as stoking or poking.

For the following reasons, it was aimed to make 50 per cent ferrosilicon from siliceous iron ore, which is used mainly as a source of both iron and silicon, quartzite being added to supply the additional Si required.

(1) For the production of 50 per cent ferrosilicon having a eutectic composition and a low melting-point, low-temperature smelting under stable furnace conditions is expected.

(2) The following improvements are expected by the use of sized siliceous iron ores as the source of iron, instead of steel scrap, turnings, scales, etc:
   (a) good gas permeability in the mixed charge,
   (b) decreased segregation of the mixed raw materials as they move downward in the furnace,
   (c) increased electrical resistance of the mixed charge,
   (d) smaller additions of quartzite, which would prevent the hanging of the mixed charge in the smelting zone as the result of softening and sticking together of the constituents,
   (e) the easy digestion of sublimated SiO in the smelting zone by the good gas-flow, resulting from the reduction and melting of the iron ore at a decreased volume,
   (f) the avoidance of gas absorption by the ferrosilicon and of contamination by such material as rusty steel turnings, and
   (g) lower costs because of lower consumptions of electric power and reducing agent, resulting from the indirect reduction of iron oxide by the large quantity of reducing gas evolved during the reduction of SiO_2.

A series of experiments was conducted on various types, qualities, and sizes of raw materials, as well as their mix ratios, the dimensions of the smelting furnace, and the electrical loading characteristics.

From the results, it was found that the smelting of 50 per cent ferrosilicon containing few impurities and absorbed gases, and non-disintegrating and homogeneous in quality, is industrially possible when the conditions are selected so that there is a high yield, the furnace conditions are stable, and the charge travels smoothly downwards without the need for any troublesome stoking or poking, even in a stationary hearth furnace[1].

Industrial operation was then begun with a 10 000 kVA open electric furnace. Technical expertise in the practical operation and a deep self-confidence in its applicability to closed-furnace operation have been obtained.

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DEVELOPMENT OF FURNACE DESIGN

Smelting in a closed electric furnace involves many difficulties that are related to the sealing of the furnace and to many other points involved in the enlargement of the furnace. But, we ultimately succeeded in smelting ferrosilicon in a large closed electric furnace to which we applied our own special design and construction as outlined in this paper.

In a three-phase electric smelting furnace, if there is to be a balance between the electrical-loading characteristics of each electrode, stable furnace operation, and high smelting efficiency, it is a fundamental condition that the 'bus-conductor system' should be incorporated to minimize and equalize the reactance of each phase.

Conventional design and construction cannot satisfy this requirement. Furthermore, when an electric furnace is enlarged, the load resistance tends to decrease, but the increase in reactance lowers the power factor. Our bus-conductor system was developed to solve these problems.

With this system, even if the electrode breaks, it is possible to remove the broken part or to replace the electrode.

This bus-conductor system, which takes up an exceedingly small space, leaves a wide space above the furnace. This remaining space is now occupied by a new charge-pipe system[3]. In this system, many charge pipes, which exclusively serve one particular electrode, are disposed symmetrically, and as perpendicularly as possible, round that electrode. These charge-pipes permit the uniform feeding of mixed raw materials round each electrode with the minimum of segregation. By the use of the weighers and recorders for each charge-pipe, the mass change of the raw materials stored there in accordance with the progress of smelting and the supply to the hearth can be observed continuously for each charge-pipe or each electrode independently.

Thus, when there is any trouble such as hanging in the smelting zone, it is possible to find it and deal with it immediately, which is important to the control of furnace operation, especially in closed-furnace smelting.

PRACTICAL OPERATION

According to our design described above, a furnace with a 45 000 kVA transformer (No. 4 furnace) was constructed in July 1968, and a better and larger one with a 60 000 kVA transformer (No. 5 furnace) in July 1972. Both furnaces are satisfactorily smelting ferrosilicon in closed-furnace operation.

Specifications and Electrical Characteristics

The main items of these furnaces are shown in Table 1.

In this process, smelting is conducted at a lower temperature. So that the smelting characteristics are stabilized, the smelting zone between the electrodes and the hearth bottom, and the electrical-loading resistance, must basically be held within a certain range. The values of the electrical-loading resistance and the reactance are indicative of the smelting condition, and those values, together with stability, are therefore used as important guides to the furnace operation.

Table 2 shows typical examples of electrical-loading characteristics in operation.

The resistance values and the other electrical loading characteristics in each phase are all well balanced. At the same time, because the geometrical space of the smelting zone is also good, the smelting is smooth and efficient.

Raw Materials

Siliceous iron ores containing a suitable quantity of

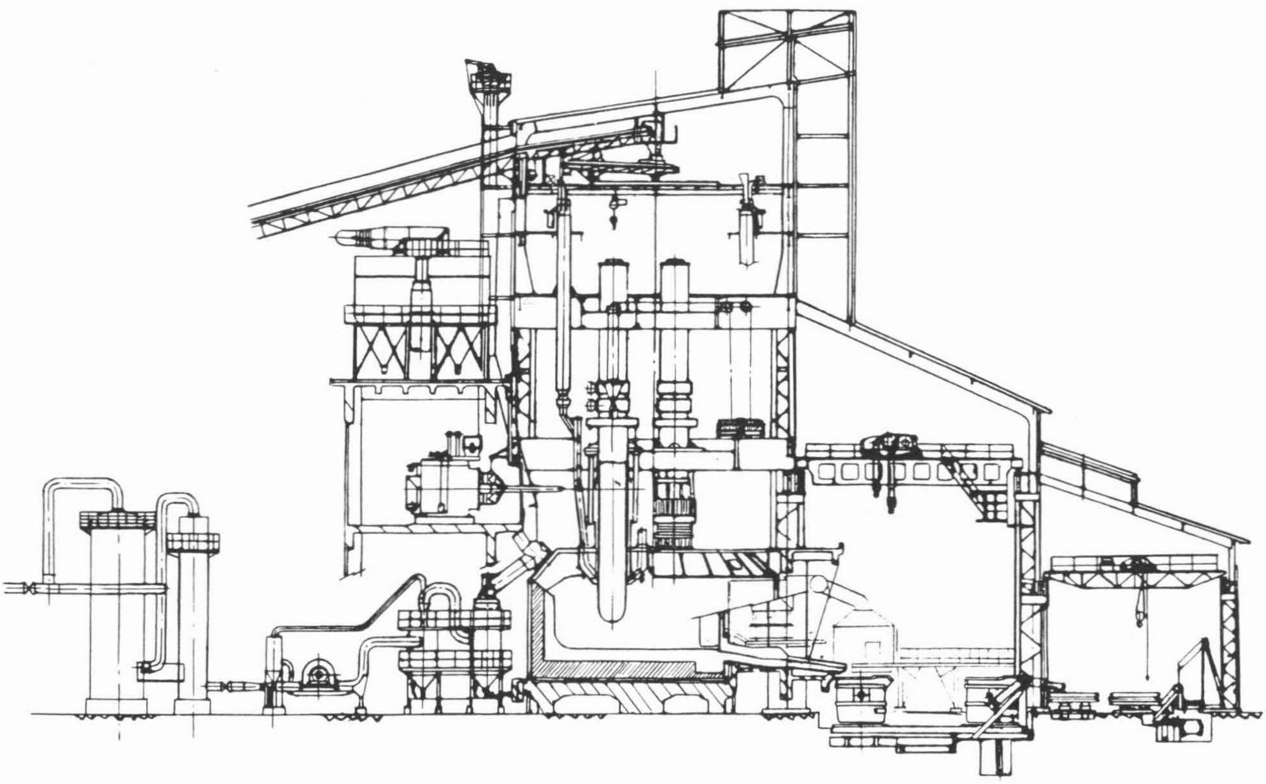


Figure 1
An elevation of the Yahagi completely closed, electric smelting furnace

Table 1

General data on large, closed electric furnaces for smelting 50 per cent ferrosilicon

Furnace No.	No. 4	No. 5	Remarks
Type	Yahagi type, perfectly closed stationary hearth	Yahagi type, perfectly closed stationary hearth	
Transformer			
Capacity max.	45 000 kVA	72 000 kVA	
continuous	40 000 kVA	60 000 kVA	
Frequency	60 Hz	60 Hz	
Input line voltage	77 000 kVA	77 000 kVA	
Output line voltage	154—77,5 V	193,4—95,3V	
Secondary taps	35 taps	35 taps	Changeable on load
Max. output current	90 000 A	130 000 A	
Secondary bus-bars			
Bus-bars	Multiple plates, air cooling	Multiple pipes, water cooling	
Connection	Open delta — delta	Open delta — delta	
Electrode			
Type	Söderberg type, self-baking	Soderberg type, self-baking	
Diameter	1400 mm	1750 mm	
Disposition	Regular triangle's apex	Regular triangle's apex	
Max. stroke	4000 mm	4000 mm	For emergency
Stroke in operation	850 mm	900 mm	For gas sealing
Charge pipes (Regular)	6 pipes per electrode	7 pipes per electrode	
(Auxiliary)	—	3 pipes	
Shell			
Diameter	10 500 mm	15 300 mm	
Depth	6000 mm	7500 mm	

Table 2

Typical electrical loading characteristics

Furnace No.	No. 4	No. 5	Remarks
Total input of transformer	27 700 kW	42 800 kW	Gauge indication
Terminal phase voltage	135 V	173 V	On no load
Each phase loading current	86 kA	106 kA	Gauge indication
Each phase loading voltage	117 V	145 V	Gauge indication
Each phase loading resistance	1200 $\mu\Omega$	1200μV	Gauge indication
Each phase loading reactance	650 $\mu\Omega$	690 $\mu\Omega$	Gauge indication
Each phase loading power	8860 kW	13 500 kW	Gauge indication
Each phase cos θ	88,2 %	86,7 %	Calculation
Total circuit resistance	1250 $\mu\Omega$	1270 $\mu\Omega$	Calculation
Total circuit reactance	950 $\mu\Omega$	1020 $\mu\Omega$	Calculation
Total circuit cos θ	79,6 %	78,0 %	Calculation
Average power in operation	about 25 MW	about 40 MW	Except power cut

silica and few impurities, or acidic hematite pellets made from pyrite cinder, are mainly used as raw materials.

As a supplementary source of silicon, quartzite that is about 96 per cent SiO_2 is used. The same kind of coke as that used in a blast furnace, having a fixed carbon content of about 88 per cent, and coal specially selected for its qualities of 'hot swelling', volatile matter, etc., are used.

These raw materials are properly sized and should preferably be poor in alumina and phosphate compounds.

Operating Conditions and Results

Figure 2 is a typical recorder chart showing the rates of consumption of the raw materials stored in one group of the charge-pipes serving an electrode exclusively, and indicate the smelting condition and efficiency. This chart consists of six curves, showing the mass change applicable to six main charge-pipes. The rapid rise of the curve shows that the raw materials are received into the charge-pipes, and the mass after receipt is not usually equal to that of the other pipes.

The smooth downward inclination in parallel of each curve shows clearly and definitely that smelting progresses smoothly all round the electrode.

As the amount of the charge consumed in a certain time can be obtained from the downward inclination of these curves, the amount of product (or the productivity) and the power consumed per unit of the product can easily be calculated for any time.

According to the calculation of the materials, all the silica charged, except that used in the formation of slag, is reduced, and more than 95 per cent of it goes into the product as silicon; very little is lost to the furnace gas.

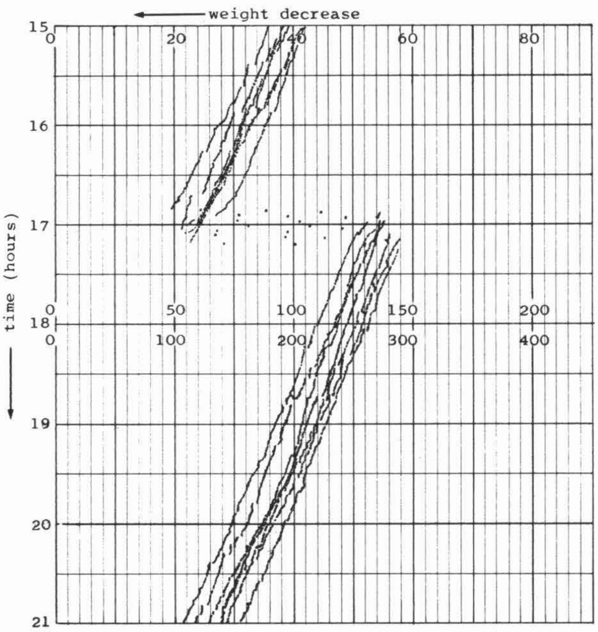


Figure 2
Recording chart of decrease in mass of stored materials in six charge pipes belonging exclusively to an electrode

Table 3 shows examples of the materials balance for 1000 kg of ferrosilicon.

It is estimated, from the CO_2 content of the recovered furnace gas, that the iron oxide in the iron ore is indirectly reduced by CO gas by about 50 per cent. The amount of coke to be mixed must be adjusted according to the CO_2 content of the gas.

The furnace gas, about 1150 Nm^3 per 1000 kg of ferrosilicon, which is increased in pressure with a blower, and which has been cleaned of less than 0,01 g/Nm^3 of dust through two stages of venturi scrubber and electrostatic precipitator, is stored in the gas holder. It is transported to an adjacent chemical plant, where it is used mainly for the raw gas of ammonia or other synthetic chemical products and for fuel.

The dirty water discharged from the gas-cleaning system is thickened, and the overflow is recirculated after being cooled. It never leaves the plant.

In smelting, about 100 kg of slag is formed, mainly consisting of SiO_2, CaO, Al_2O_3, MgO, silicon carbide, etc. Proper adjustment of the slag so that it has a low melting-point and can be discharged smoothly from the furnace, is required to keep the furnace conditions stable.

Product

Molten ferrosilicon tapped from the furnace is received by a ladle and is cast to the desired thickness by a special, automatic casting machine of our own design.

Solid ferrosilicon is sent on conveyors to the sizing plant, where it is crushed, sieved, separated according to the appropriate size and quality, and stored in bins for shipment. Fine ferrosilicon is packed into bags by an automatic packing machine.

The chemical analysis of the product is as follows: Si 50,65 per cent; Mn 0,19 per cent; C 0,03 per cent; P 0,025 per cent; S 0,003 per cent; Al 0,75 per cent; Ca 0,08 per cent; O_2 80 p.p.m.; H_2 2,5 cm^3 per kilogram of ferrosilicon.

The ferrosilicon is favoured for steel-making and iron-casting because it contains few impurities and gases, it does not disintegrate, and it is homogeneous in nature with a eutectic composition, being smelted at a relatively low temperature.

CONCLUSION

Generally, in the smelting of ferro-alloys in an open electric furnace, the gas evolved burns on the surface of the furnace, producing a large amount of smoke and dust. This makes working conditions very unpleasant and pollutes the air. Pollution control, which recently became very important, requires large equipment and considerably increases operating costs.

On the other hand, although closed-furnace smelting requires a high degree of design for equipment, metallurgical technique, and furnace operation, any special consideration for operation and design with high-temperature gas is unnecessary, and the volume of gas to be treated is relatively small because it is unburnt.

Therefore, it can be treated with a small-scale cleaning system, and it is economically possible to improve working and smelting conditions and air pollution. The recovered high-calorific gas, which is free from sulphur, can be utilized.

This kind of closed electric smelting furnace will contribute greatly to the production of ferrosilicon. Furthermore, the results obtained in the abovementioned processes are applicable to the efficient production of other ferro-alloys.

Table 3
Rough results of 50 per cent ferrosilicon smelting

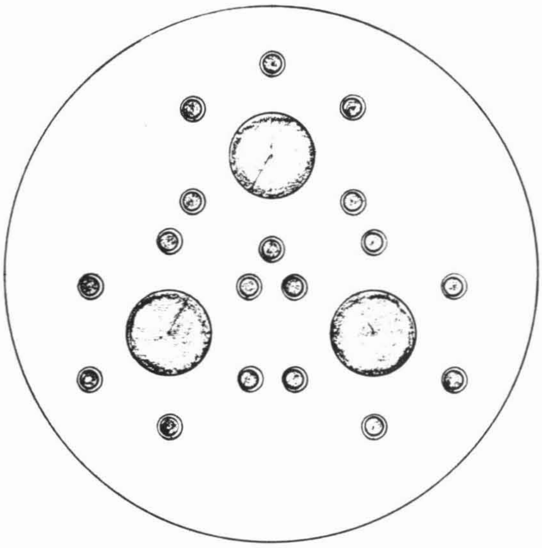
	A	B
Raw Materials		
(A) Hematite pellet (Fe 61,1%; SiO_2 7,91%)	773 kg	—
(B) Siliceous iron ore (Fe 46,7%; SiO_2 30,7%)	—	1012 kg
Quartzite (SiO_2 97,5%)	1108 kg	852 kg
Reducing agent (Coke, Coal)	674	
Electrode (paste for Söderberg)	16—20 kg	
Electric power	Av. 5800 kg	
Ferrosilicon produced	1000 kg	
Slag	100 kg	
Recovered gas	1150 Nm^3	
Sludge or dust from the gas	75 kg	
(Si in ferrosilicon)/(Si in total material — Si in slag)	95 %	

REFERENCES

1. TADA, Y., *et al.* Electric smelting method of eutectic Fe-Si. *Japanese Pat. 603955.*
2. TADA, Y., *et al.* Bus conductor system for a three-phase electric furnace, etc. *U.S.A. Pat. 3499970.*
3. TADA, Y., *et al.* Electric smelting furnace, etc. *U.S.A. Pat. 3598888.*

In his presentation, **Mr Hosoi** showed some slides that presented new information. The first (Figure 3 below) indicates that No. 4 furnace has six feed chutes per electrode, and No. 5 furnace has seven feed chutes per electrode. Whereas Figure 2 of his paper was a recording of the decrease in mass of stored material in six charge pipes belonging exclusively to an electrode, Figures 4 and 5 below show the same thing for six charge pipes under normal and abnormal conditions. Finally, a special conductor system was developed so that a minimum of space was occupied. It also ensured a balanced loading under all conditions, together with the lowest possible reactance. Figure 6 below shows the layout of the conductor system.

No. 4 Furnace



No. 5 Furnace

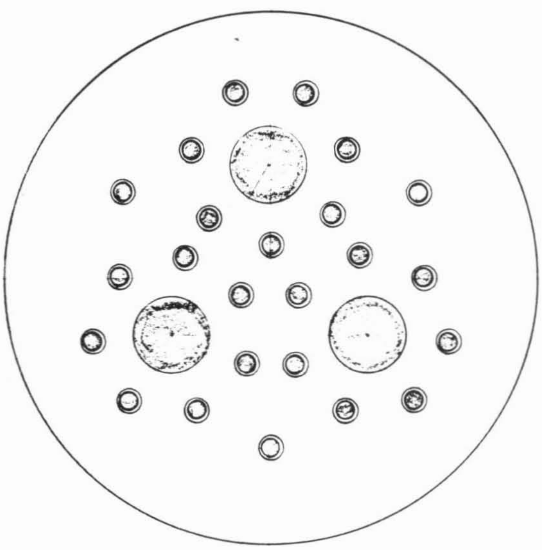


Figure 3
Disposition of material-charging pipes

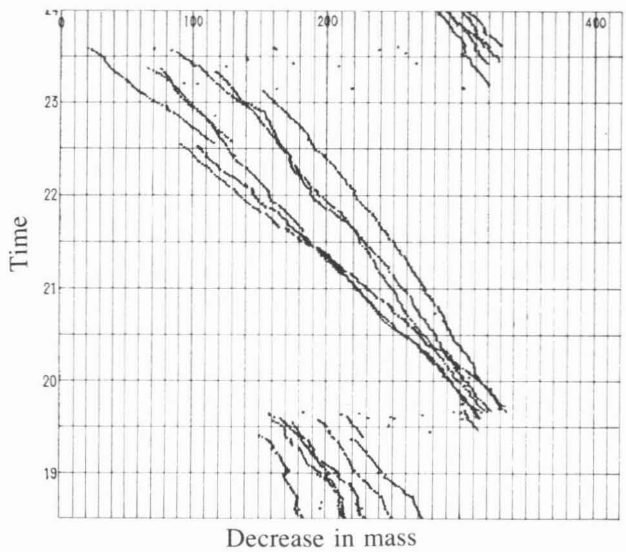


Figure 4
Recording chart of decrease in mass of stored material in six charge pipes belonging exclusively to an electrode under normal conditions

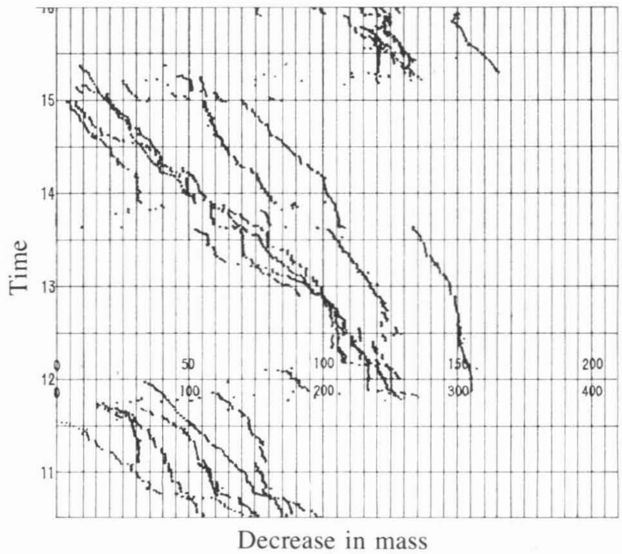


Figure 5
Recording chart of decrease in mass of stored material in six pipes belonging exclusively to an electrode in abnormal conditions

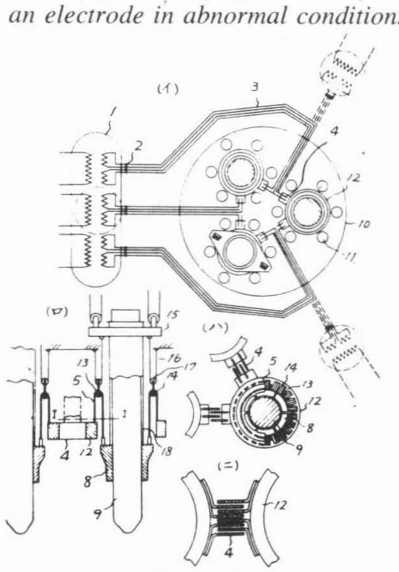


Figure 6
Bus-conductor system (Yahagi type)

DISCUSSION

Questions from the audience:

(1) What is the furnace availability, i.e., the days operated per month?

(2) What quantity of 50 per cent ferrosilicon is produced per month in each furnace?

(3) What is the power consumption per tonne of ferrosilicon produced?

(4) Have the authors any experience with other iron ores, and does the process depend on the type of iron ore used?

(5) Is the small quantity of slag produced conditioned by the addition of flux?

Mr Hosoi:

(1) Shutdown is half a day per month.

(2) No. 4 2500 tonnes
No. 5 3500 tonnes

These are the figures within the power consumption under special contract between the electric power company and us. These will increase during continuous full-power loading.

(3) 5800 kW ± 5 per cent; we expect to make less in the future.

(4) We had experience with other types of iron ores, and the process is adaptable to various natural acidic iron ores, such as hematite.

(5) No flux is ordinarily added. The slag with low melting-point and good fluidity is controlled by adjustment of the composition and mixing ratio of the charge. Besides that, smooth low-temperature smelting and high quality of product are attained by careful daily operation control, such as that of electrode, power-loading characteristics, size distribution of the charge, and so on.