A Completely Closed Electric Furnace for the Production of 75 per cent Ferrosilicon

by K. HORIBE* (presented by Mr Horibe)

SYNOPSIS

There has been a worldwide urgent demand for many of the difficulties in the production of 75 per cent ferrosilicon by a closed furnace to be overcome from the points of view of pollution control, better working atmosphere, and others.

The following are the reported causes of the difficulties:

(1) characteristic dust formation,
(2) formation of hard crust round the electrodes, which may bring about sudden and sporadic mix descents,
(3) frequent fluctuation of the furnace pressure in a wide range, and
(4) high temperature by blowing.

The above obstacles have been overcome with our newly developed installations, and since April 1971 we have been successfully operating a 15 000 kVA closed furnace for the commercial production of 75 per cent ferrosilicon. The raw materials are not specially prepared as they are for the open furnaces.

From our experiences, the closed furnace will pay for itself in the production of 75 per cent ferrosilicon. Some of the results we found are as follows.

(1) The dust particles are larger than those in open furnaces and they are fibrous.
(2) For that reason, dust collecting is easier. The waste water from the wet dust collector is almost neutral.
(3) The temperature in the furnace is far lower than expected.
(4) The fluctuation of furnace pressure could be kept similar to that in other ferro-alloy furnaces.
(5) The consumption of specific power and material is lower than it is in open-type furnaces.

INTRODUCTION

In the history of smelting furnaces, open furnaces have been replaced gradually by closed ones because they have certain advantages: better working atmosphere, production of byproduct gas, protection of furnace parts from heat, and so on. In recent years, strict anti-air-pollution regulations have been imposed on the ferro-alloy plants in Japan as well as in other countries. From the point of view of pollution control, most of the big ferro-alloy furnaces tend to be closed, except those used in the production of 75 per cent ferrosilicon and metallic silicon.

Many trials of furnaces used in the production of 75 per cent ferrosilicon have been carried out on an industrial scale in the U.S.A., the U.S.S.R., and other countries; but no operation on a commercial scale has been reported for a considerable period, perhaps for the following reasons.

(1) Dust clogged the gas-outlet pipes and accumulated under the cover.
(2) Hard crust was built around the electrodes, and sudden mix descents occurred.
(3) Furnace gas pressure fluctuated over a wide range.
(4) The intense heat of the blowing gas damaged the accessories under the cover.

To what extent is it possible to close a 75 per cent ferrosilicon furnace? This question was answered by the Electric Furnace Research Group of the Japan Ferro-alloy Association in its intermediate report published in 1969. The report stated in its conclusion:

> A closed operation will be achieved only when the yield of silicon metal is kept above 95 per cent without poking the mix surface. To realize such an excellent furnace condition, the research should be concentrated on a furnace design and raw material treatment. This will bring a success in closing the furnace for 75 per cent ferrosilicon manufacture . . .

We agree completely with that conclusion. However, it was felt that specially treated raw materials may be too expensive. So we planned to use the same raw materials in a closed furnace under the normal conditions of an open furnace. In January 1971, we began to convert a 15 000 kVA calcium carbide furnace of closed type to a 75 per cent ferrosilicon furnace, and we started to operate the furnace in April 1971. Since then, we have continued closed operation without serious troubles with the design and method of operation stated below.

*Joetsu Electric Furnace Industry Co. Ltd, Japan.

DESIGN

Most of the existing parts of the calcium carbide furnace are used except the cover, mix-feeding equipment, and gas-cleaning equipment.

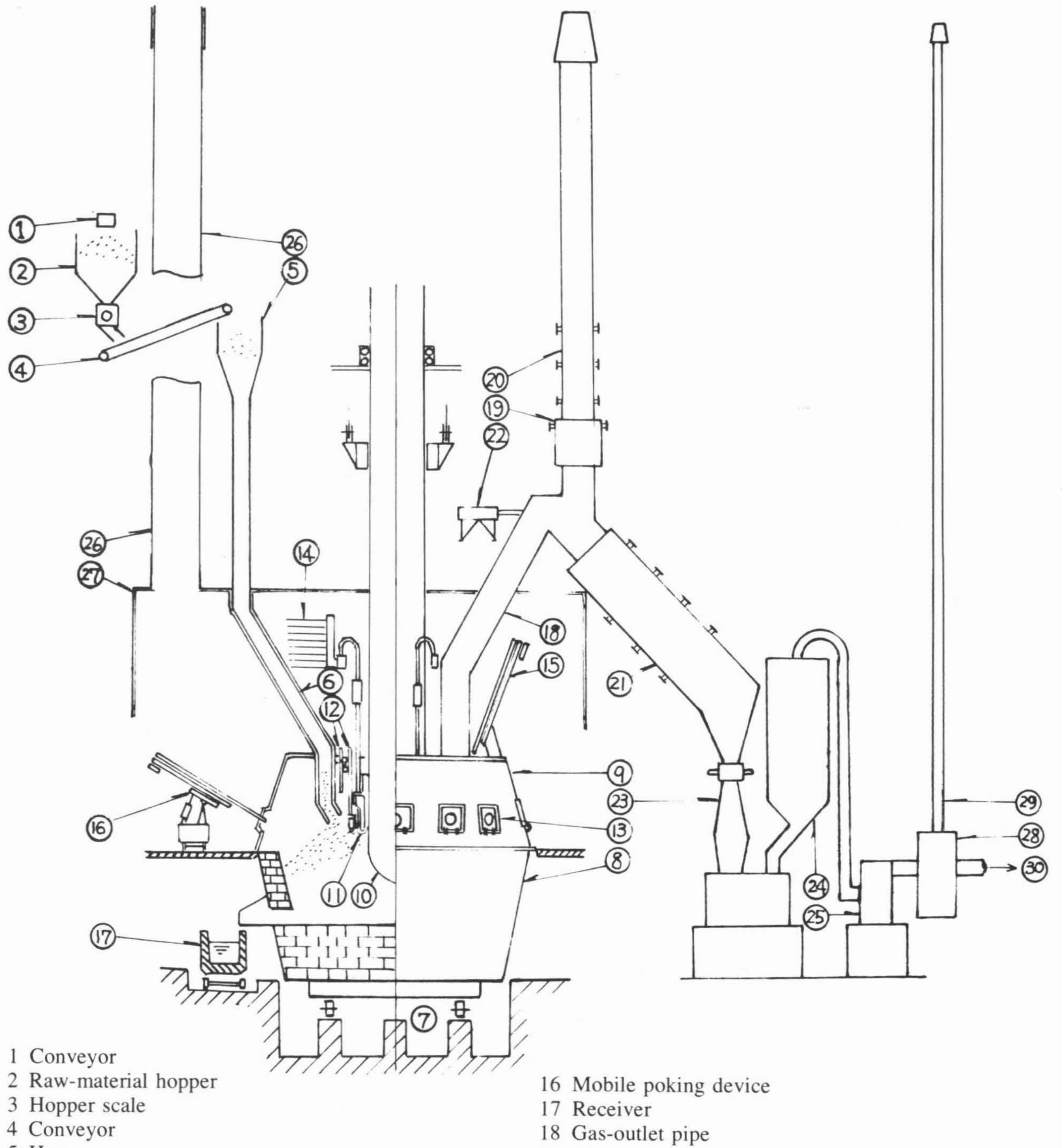
The major dimensions are shown in Table 1, and the diagram of the furnace in Figure 1.

Table 1
Major dimensions

Transformer	Furnace
Capacity 15 000 kVA Current 59 900A	Dia. of electrode 1050mm Inner dia. of hearth 6460mm
Primary voltage 63 000 V	Outer dia. of hearth 8100mm
Secondary voltage 80 to 170V	Height of cover 2300 mm
Tap setting, on-load adjustment 33 taps	Number of gas take-off pipes 4
Connection Δ—Y	Number of side ports 18

Mix Feeding

The raw materials—quartzite, coke, coal, and mill scale—are weighed on separate hopper scales. They are



1 Conveyor
2 Raw-material hopper
3 Hopper scale
4 Conveyor
5 Hopper
6 Charging chute
7 Rotating equipment
8 Furnace shell
9 Cover
10 Electrode
11 Clamp shoe
12 Electrode mantle
13 Inspection shutter and explosion valve
14 Bus bar
15 Fixed poking device
16 Mobile poking device
17 Receiver
18 Gas-outlet pipe
19 Water-sealed damper
20 Flare stack
21 Inclined washing pipe
22 Dust remover
23 Venturi scrubber
24 Mist separator
25 Gas blower
26 Stack
27 Hood
28 Water-sealed valve
29 Second flare stack
30 To steam boiler

Figure 1

Diagram of a 15 000 kVA completely closed electric furnace

blended on a belt conveyor and stocked in furnace hoppers, which are joined to separate feeding pipes. The mix comes out of the separate feeding pipes continuously onto the surface of the raw materials inside the furnace.

The mix has a large angle of repose, which requires special care in the placing of the feeding pipes to distribute raw materials equally round the electrodes. The distances between the electrodes, the mix-feeding pipes, the gas take-off pipes, and the level of the mix surface are carefully determined.

Accessories Round the Electrodes

The following items should be considered when the accessories round the electrodes are designed.

(1) The distance should be as short as possible from the bottom of the clamp shoes to the surface of the mix.
(2) Maintenance and repair round the electrodes should be easy to carry out.
(3) The electrodes must be slipped smoothly by a remote-control system.
(4) The accessories under the cover must be protected from heat.

We have encountered a few minor failures in the accessories round the electrodes since our start-up.

Cover

The cover should be higher above the mix level than it is in other ferro-alloy furnaces. The cover consists of steel or stainless-steel water-jackets. The inner surface of the cover is lined with a castable refractory. The side wall of the cover is provided with eighteen side ports, which will act as safety valves in case of an explosion.

Gas Take-Off and Gas Cleaning

The following points should be taken into account to prevent dust collection under the cover and in the gas take-off pipes:

(1) a suitable configuration of the mix-feeding pipes and the gas take-off pipes round the electrodes, and
(2) a suitable arrangement of the poking devices to improve the furnace condition.

The gas take-off pipes are kept clear by dust removers mounted on the horizontal parts and with a water stream employed in the descending parts.

The gas take-off pipes lead the byproduct gas containing dust particles to a one-stage venturi scrubber, which removes solid substances easily and efficiently from the gas stream. This is because of the relatively large size of the dust particles formed in the closed furnace. The cleaned gas is used as fuel in a steam boiler at a neighbouring chemical plant.

OPERATION

Raw Materials

As mentioned before, the raw materials—quartzite, coke, coal, and mill scale—are not treated specially, as is the practice in open furnaces. If the raw materials are further screened and dried, the furnace conditions will be considerably improved. Moisture in the mix (usually 5 to 7 per cent) increases the hydrogen content in the collected gas.

Operation

The closed furnace is operated almost in the same way as other closed ferro-alloy furnaces. However, operators must be trained specially. They should watch out for clogging of the gas take-off pipes by dust, hard crust formations round the electrodes, abnormal mix descents, and large gas blows round the electrodes. The furnace pressure chart is shown in Figure 2.

The gas temperature under the cover varies in the range of 400 to 500°C and is lower than expected. Of course, the temperature will be much higher where radiated heat from the electrodes or gas blows impinges on a part of the cover.

The gas temperatures in various parts are as follows:

Under the cover	400 to 500°C
Top of the gas take-off pipes	200 to 300°C
Outlet of the venturi scrubber	30 to 40°C.

The gas temperature at the top of the gas take-off pipes is shown in Figure 3.

Byproduct Gas

Gas Volume. Depending upon the furnace conditions and the mix, the rate of evolution of gas varies considerably. The higher the specific power consumption, the larger the volume of gas per tonne of alloy. One of the reasons probably is the reaction

$$SiO + H_2O \rightarrow SiO_2 + H_2.$$

Usually the volume of gas evolved will be 1600 to 1900 Nm^3 per tonne of alloy when the moisture content of the mix is 5 to 7 per cent.

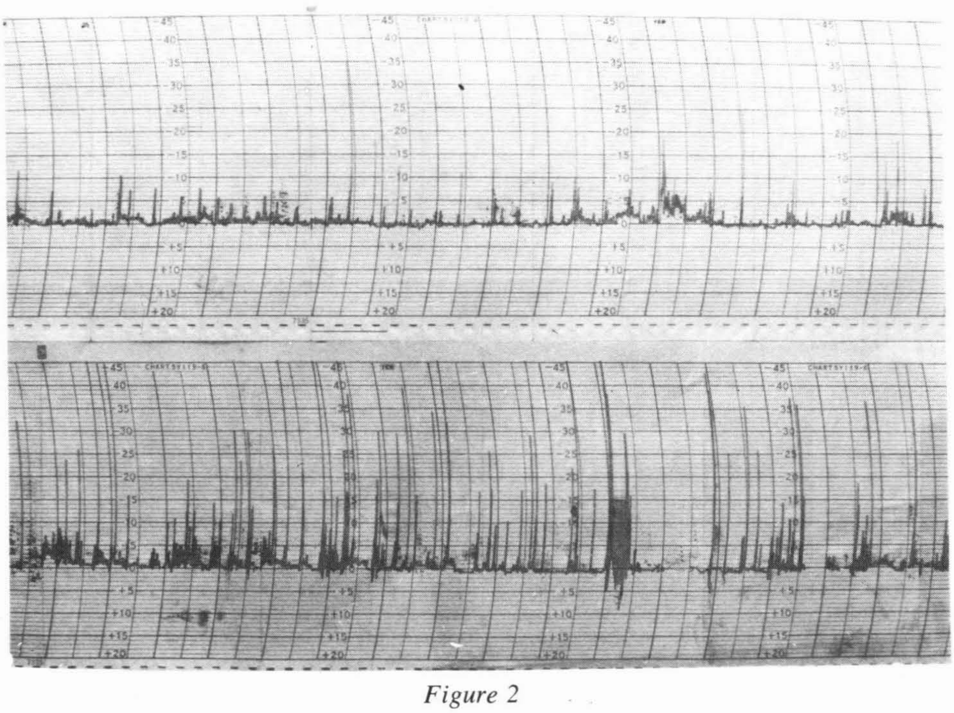


Figure 2
Furnace pressure chart

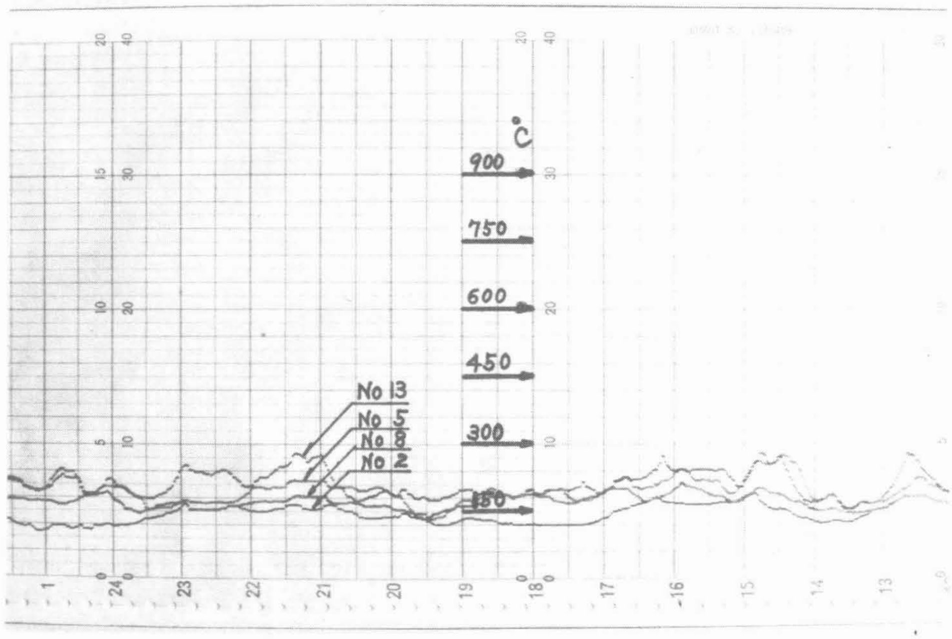


Figure 3
Chart of gas temperature on top of the gas off-take pipes

Gas Composition. Table 2 shows the composition of byproduct gas.

*Table 2**
Gas composition

CO	H_2	CO_2	O_2+N_2	CH_4 + hydrocarbons
80,7	14,5	1,9	2,3	0,6

The calorific value of the gas is about 3000 kcal/Nm^3. The hydrogen content increases up to about 20 per cent when a fresh mix is fed, and decreases gradually down to about 10 per cent. In an open furnace, sulphur in the mix is oxidized by air to sulphur dioxide; in a closed furnace, most of the sulphur is free and is deposited as dust, and most of the remainder is converted to hydrogen sulphide. Insufficient sulphur dioxide is formed to make the waste water acidic.

Dust Formation

A characteristic dust is formed in the closed furnace. This was examined both chemically and with an electron microscope.

The dust sampled under the cover was analysed, and the results are shown in Table 3. As a comparison, the analysis of a dust sampled from an open furnace is shown in the same table. The solid substances in the waste water were also analysed, as shown in Table 4.

*Table 3**
Dust analysis

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	C
Closed	84,86	2,74	0,91	0,39	1,21	9,90
Open	87,51	4,45	0,77	0,86	1,58	4,83

Tables 3 and 4 both show that the percentage of carbon in the dust from the closed furnace is higher. This is probably because carbon is not oxidized by air, and the equation

$$SiO+CO \rightarrow SiO_2+C$$

is a reaction of dust formation in the closed furnace.

*Table 4**
Analysis of solid material in waste water, %

Closed	85,47	3,28	0,88	1,77	1,08	7,52
Open	86,64	3,96	2,26	1,84	1,39	3,91

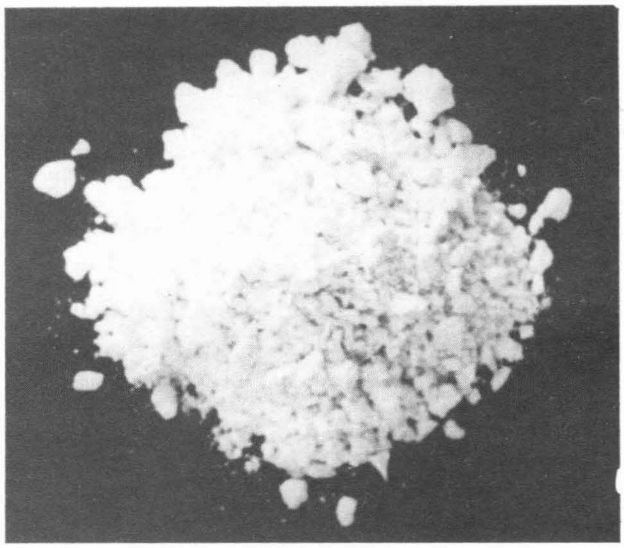


Figure 4
Dust from an open furnace

To the naked eye, the dust of an open furnace is a white, fine powder, as shown in Figure 4. On the other hand, the dust of the closed furnace is black or grey, asbestos-like, fibrous, and soft, as shown in Figure 5. It accumulates easily in the closed furnace and is very adhesive to the furnace accessories. Other photographs show the dust observed through a scanning electron microscope (Hitachi HSM-2B), as shown in Figures 6 to 9. Large particles will be formed in an atmosphere of highly concentrated carbon monoxide and silicon monoxide under the cover. The formation takes place according to the following reactions:

*See amendments on pp. 97 and 98.

$$SiO + CO \rightarrow SiO_2 + C$$
$$SiO + H_2O \rightarrow SiO_2 + H_2$$
$$3SiO + CO \rightarrow 2SiO_2 + SiC.$$

The mean diameter of the particles is about $1 \mu m$, ten times that of the particles formed in an open furnace. The particles are sometimes joined to one another by thread-like strings.

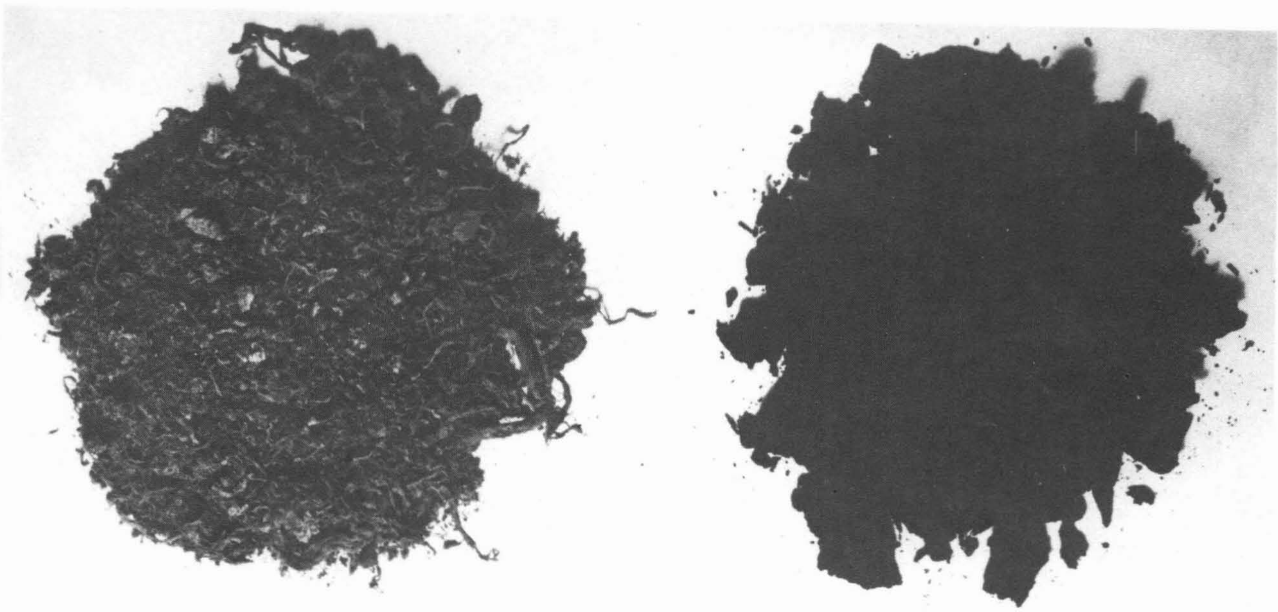


Figure 5
Dust from a closed furnace

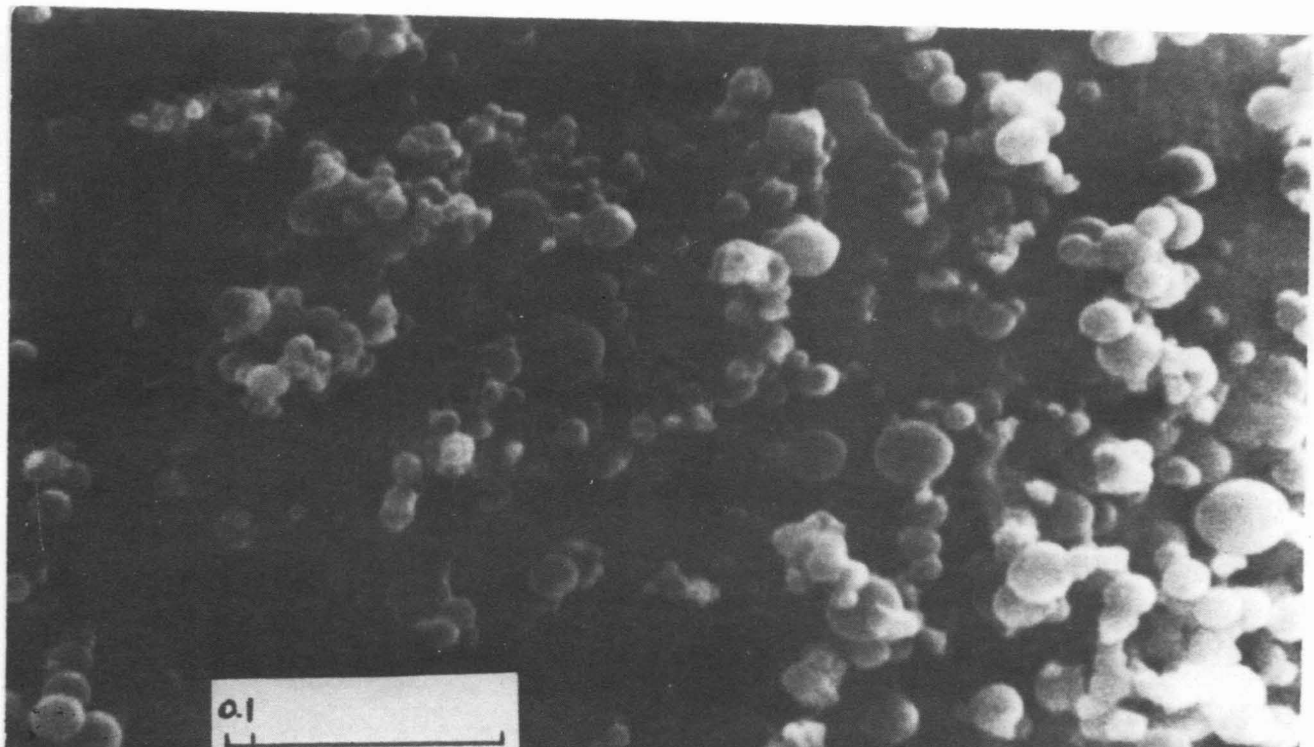


Figure 6
Photomicrograph of dust particles in an open furnace

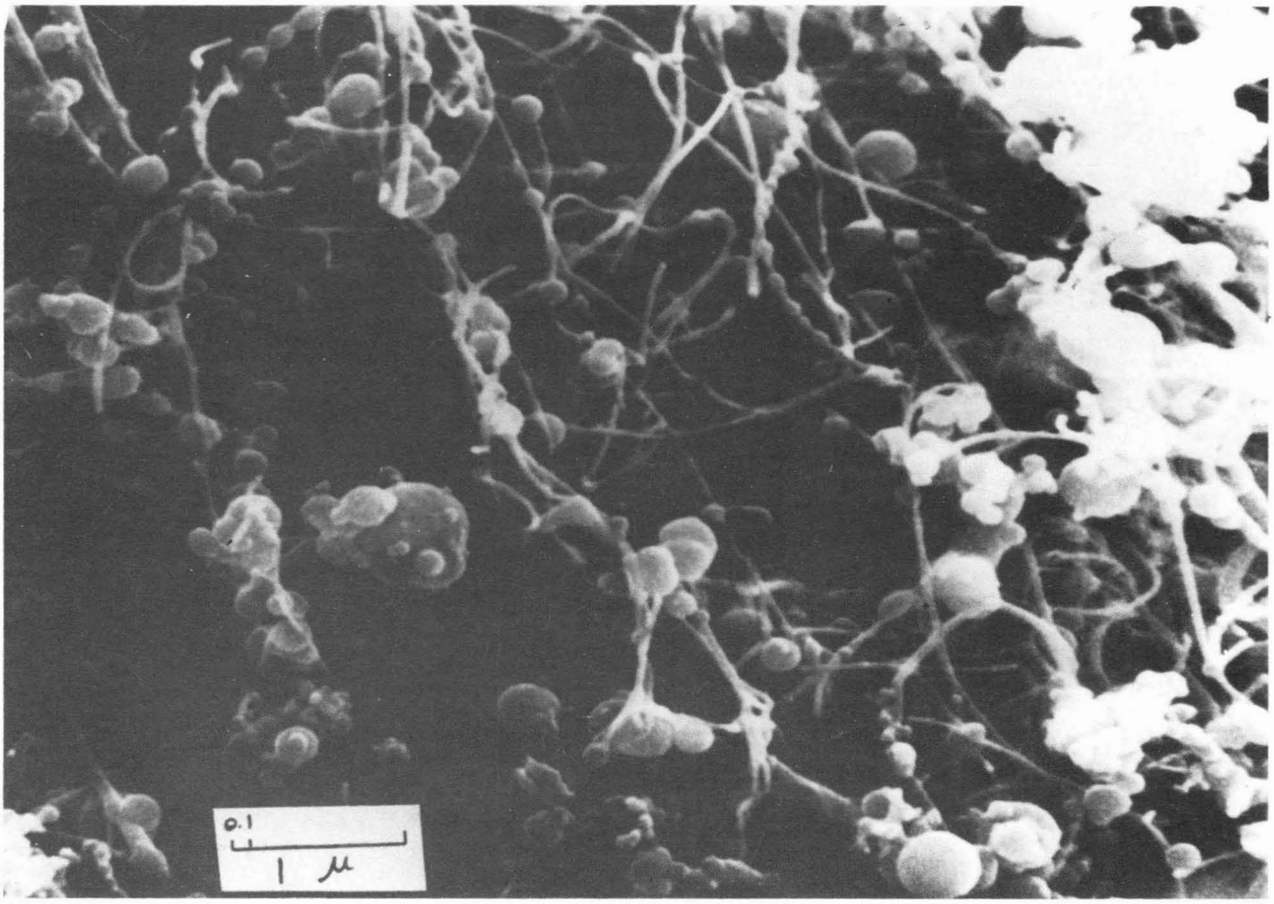


Figure 7
Photomicrograph of dust particles in a closed furnace

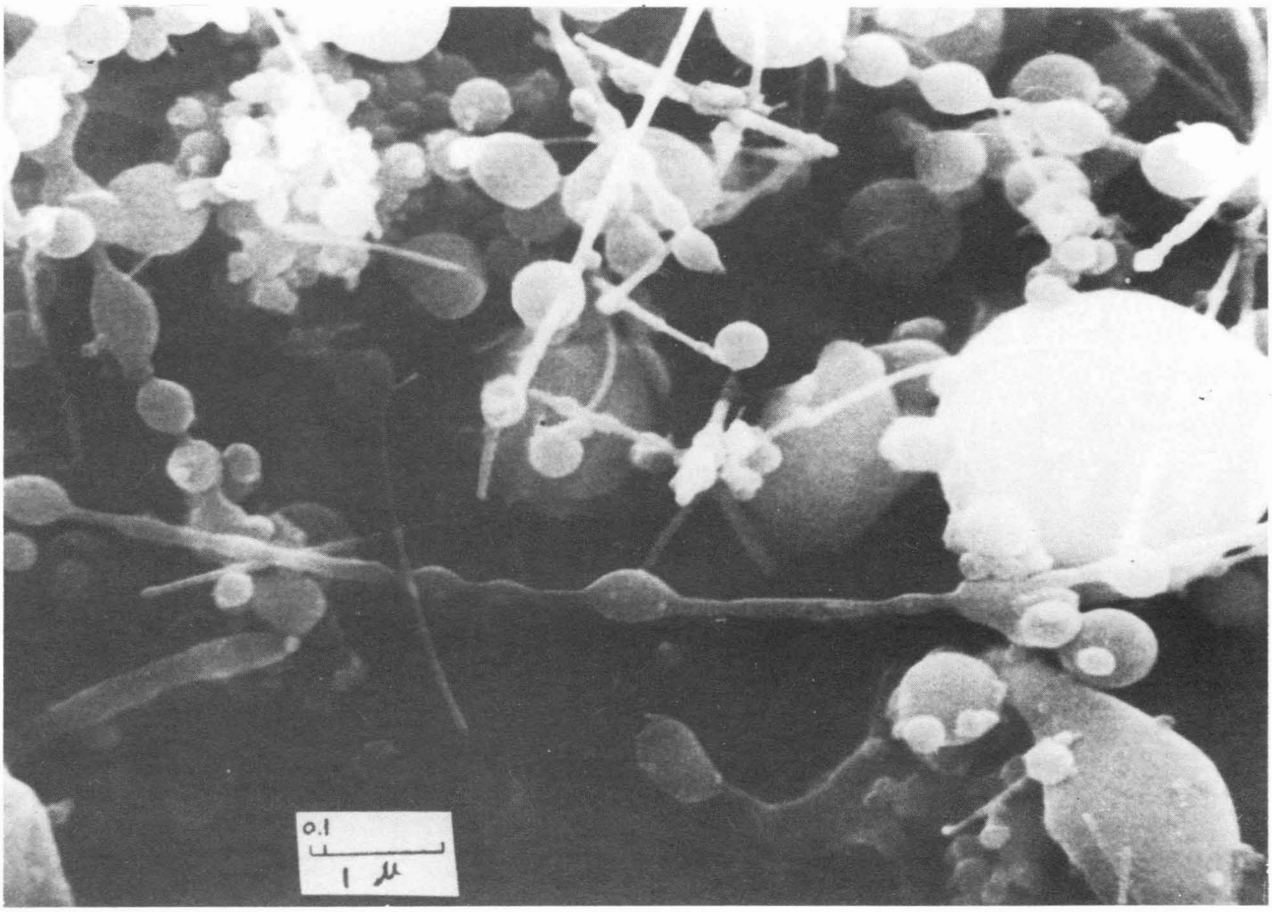


Figure 8
Photomicrograph of dust particles in a closed furnace

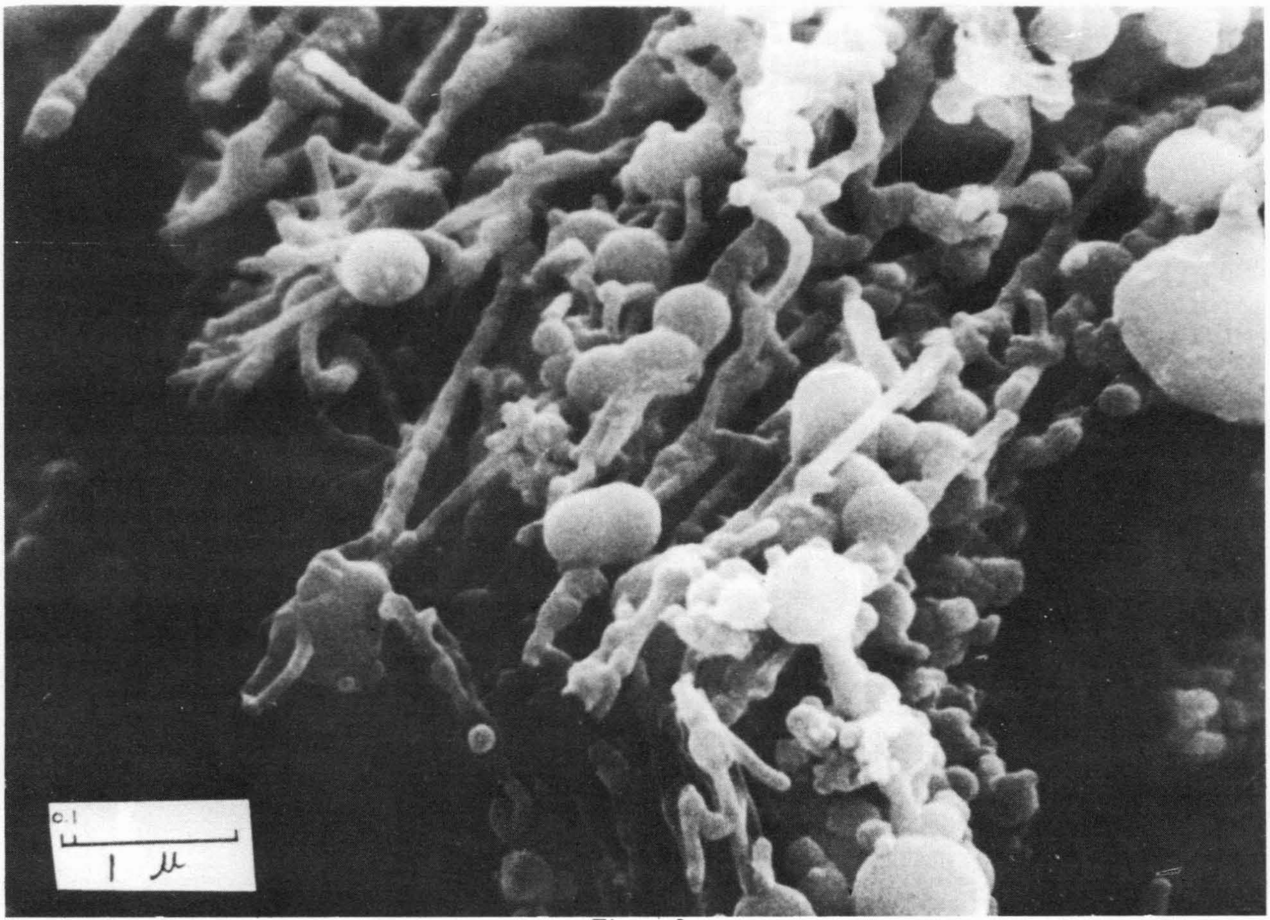


Figure 9

Photomicrograph of dust particles in a closed furnace

Capital Cost and Operation Cost

Compared with an open furnace equipped with a dust collector, a smaller gas volume (generally one-fiftieth to one-seventieth) is treated for a closed furnace. Further, the closed furnace is free from corrosion problems in wet installations because the pH value of the waste water is between 6 and 7, which is similar to that of the feed water. These could be merits in the capital cost of a closed furnace, which will be less expensive than an open furnace with a dust collector.

When compared with closed furnaces for ferro-alloys other than 75 per cent ferrosilicon, the capital cost of a closed 75 per cent ferrosilicon furnace will be a little higher, because a 75 per cent ferrosilicon furnace should be provided with poking devices and dust removers, which are probably not installed in other alloy furnaces. The operating cost of a closed furnace could be far lower than that of an open furnace, as is the case with other closed ferro-alloy furnaces. The waste water does not contain poisonous heavy metals or toxic substances and is almost neutral, as mentioned before, and special procedures to dispose of the waste water are not necessary. The byproduct gas can be recovered to the extent of 1500 to 1800 Nm^3 per tonne of alloy, and it can be used as fuel, raw material for synthetic products, and so on. This will reduce the operational cost to a large extent.

CONCLUSIONS

From our experience, it is economical to produce 75 per cent ferrosilicon in a closed furnace. We have found the following points important and interesting.

(1) A closed furnace can be operated with comparative ease by operators with some previous experience.

(2) A stable gas pressure can easily be achieved.

(3) The gas temperature is lower than expected.

(4) The collected gas volume is larger than expected.

(5) The waste water is neutral, and so there is no corrosion problem.

(6) A lower specific power consumption results.

At present, we are certain that a closed furnace has big advantages in coping with pollution control. Closed types will thus replace conventional open types in the near future.

ACKNOWLEDGMENT

We thank the Tanabe Co. and others for their cooperation in developing our closed furnace.

In his presentation, **Mr Horibe** indicated some corrections and additions to the published paper. Tables 2, 3, and 4 were changed as follows.

Table 2

Gas composition, %

CO	H_2	CO_2	O_2+N_2	CH_4+hydrocarbons
79,5	15,6	1,3	1,9	1,7

Table 3

Dust analysis, %

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	C
Closed furnace	86,67	2,03	0,19	0,81	1,14	8,53
Open furnace	82,26	4,90	0,71	0,88	1,60	4,68

Table 4

Analysis of solid material in waste water, %

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	C
Closed furnace	84,96	3,63	1,01	1,98	1,19	6,48
Open furnace	85,85	3,99	2,36	1,86	1,49	3,49

The following table gave an energy comparison between open and closed furnaces:

Energy Comparison

	Open	Closed
Specific power consumption	9 000 kWh	9 000 kWh
Power as utility		
Pollution control	500	80
General use	100	100
Subtotal	9 600 kWh	9 180 kWh
	>8 256 000 kcal	>7 894 800 kcal
Recovered gas 1500 Nm^3	0	<4 500 000
Total	8 256 000 kcal	3 394 800 kcal

The gas volume per 10 Mwh is given in Figure 10.

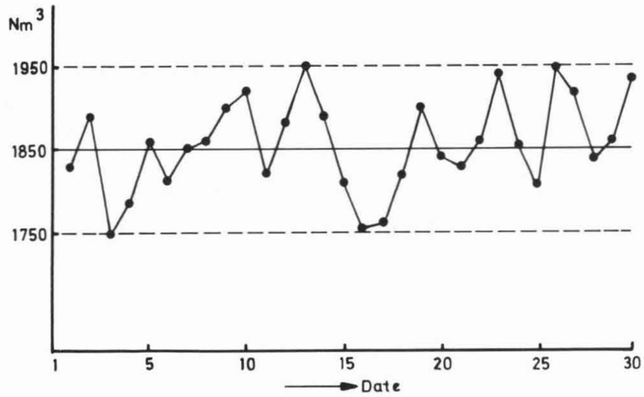


Figure 10

Gas volume per 10 MWh

DISCUSSION

Dr Person:*

My comment is chiefly concerned with the discussion on particle size. Our own investigations of material collected in bag collectors from both covered and open 75 per cent ferrosilicon operations would generally tend to the conclusion that fume characteristics are really fairly similar. Electron micrographs of the fume from both sources seem to indicate that most particles are less than 0,1 μm, and these particles, and even the larger particles, are similar whether they are from a closed or an open furnace. The other evidence we have that supports this contention is that our surface-area measurements for fume from a covered furnace are about 37 m/g as against 20 to 30 m/g from an open furnace. Perhaps this difference is due to a difference in sampling techniques or sample preparation; but from a practical standpoint perhaps the natural agglomeration in the closed furnace makes it more readily collectable from a wet scrubber.

Mr Horibe:

We sampled from under the furnace cover during shut-down with a special sampler. We observed the collected particles under a microscope, and we do not think the size of the dust particles is the same. To the naked eye, they have an asbestos-like appearance.

Mr Streicher†:

May I, from the chair, ask one last question—whether these gentlemen think that the type of gas-washing plant (venturi) that they have is entirely suitable for ferrosilicon furnaces? Is it as effective as a bag filter in cleaning gas from a furnace?

Mr Horibe:

The efficiency of a venturi scrubber can be estimated from the following.

The gas contains 100 to 150 g/Nm^3 from the furnace, and the dust cleaned after the venturi scrubber contains 0,05 to 0,1 g/Nm^3.

*Union Carbide Corporation, U.S.A.

†Amcor Management Services (Pty) Ltd, South Africa.