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.

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.

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

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

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

\[ \text{SiO} + \text{H}_2\text{O} \rightarrow \text{SiO}_2 + \text{H}_2. \]

Usually the volume of gas evolved will be 1600 to 1900 Nm³ per tonne of alloy when the moisture content of the mix is 5 to 7 per cent.

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

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>H₂</th>
<th>CO₂</th>
<th>O₂ + N₂</th>
<th>CH₄ + hydrocarbons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed</td>
<td>80.7</td>
<td>14.5</td>
<td>1.9</td>
<td>2.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Open</td>
<td>86.4</td>
<td>3.96</td>
<td>2.26</td>
<td>1.84</td>
<td>1.39</td>
</tr>
</tbody>
</table>

The calorific value of the gas is about 3000 kcal/Nm³. 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.

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:

\[
\text{SiO} + \text{CO} \rightarrow \text{SiO}_2 + \text{C}
\]
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.

\[
\begin{align*}
\text{SiO} + \text{CO} & \rightarrow \text{SiO}_2 + \text{C} \\
\text{SiO} + \text{H}_2\text{O} & \rightarrow \text{SiO}_2 + \text{H}_2 \\
3\text{SiO} + \text{CO} & \rightarrow 2\text{SiO}_2 + \text{SiC}.
\end{align*}
\]

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
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 Nm³ 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, %

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>H₂</th>
<th>CO₂</th>
<th>O₂+N₂</th>
<th>CH₄ + hydrocarbons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>79,5</td>
<td>15,6</td>
<td>1,3</td>
<td>1,9</td>
<td>1,7</td>
</tr>
</tbody>
</table>

Table 3
Dust analysis, %

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed furnace</td>
<td>86,67</td>
<td>2,03</td>
<td>0,19</td>
<td>0,81</td>
<td>1,14</td>
<td>8,53</td>
</tr>
<tr>
<td>Open furnace</td>
<td>82,26</td>
<td>4,90</td>
<td>0,71</td>
<td>0,88</td>
<td>1,60</td>
<td>4,68</td>
</tr>
</tbody>
</table>

Figure 9
Photomicrograph of dust particles in a closed furnace

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Table 4

Analysis of solid material in waste water, %

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed furnace</td>
<td>84.96</td>
<td>3.63</td>
<td>1.01</td>
<td>1.98</td>
<td>1.19</td>
<td>6.48</td>
</tr>
<tr>
<td>Open furnace</td>
<td>85.85</td>
<td>3.99</td>
<td>2.36</td>
<td>1.86</td>
<td>1.49</td>
<td>3.49</td>
</tr>
</tbody>
</table>

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

Energy Comparison

<table>
<thead>
<tr>
<th></th>
<th>Open</th>
<th>Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific power consumption</td>
<td>9 000 kWh</td>
<td>9 000 kWh</td>
</tr>
<tr>
<td>Power as utility</td>
<td>500</td>
<td>80</td>
</tr>
<tr>
<td>Pollution control</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>General use</td>
<td>9 600 kWh</td>
<td>9 180 kWh</td>
</tr>
<tr>
<td>Subtotal</td>
<td>&gt;8 256 000 kcal</td>
<td>&gt;7 894 800 kcal</td>
</tr>
<tr>
<td>Recovered gas</td>
<td>1500 Nm³</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>8 256 000 kcal</td>
<td>3 394 800 kcal</td>
</tr>
</tbody>
</table>

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

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 m² as against 20 to 30 m² 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/Nm³ from the furnace, and the dust cleaned after the venturi scrubber contains 0.05 to 0.1 g/Nm³.

*S*Union Carbide Corporation, U.S.A.
†Amcor Management Services (Pty) Ltd, South Africa.