# A New Technique of Burden Preparation for Ferro-alloy Production

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**SYNOPSIS**

Because suitable lump ore is scarce, fines have to be agglomerated for economic ferro-alloy production, but the classical methods of sintering and pellet-hardening become less economic at smaller scales of production. A new technique of pellet hardening uses a special annular kiln with true countercurrent gas-solids flow. An operating plant is described, together with its economic advantages and the quality of its product. The possibilities of extending the process to the partial prereduction of ferrochromium pellets is mentioned.

## INTRODUCTION

The annular kiln described here represents an interesting example of equipment developed for one particular industry but having a much wider potential application. The original use of the kiln was for the pretreatment of nodular cement raw meal prior to calcination in a rotary kiln; and this application, among others, is described in the relevant patents[1,2] by Associated Portland Cement Manufacturers Limited (A.P.C.M.). Units of up to 10,5 m in diameter are now successfully operating in this way. It was thought that this design of kiln could well offer a number of advantages in the firing of pellets made from iron ore and other minerals when the kiln is used either by itself or in combination with a short rotary kiln.

A programme of development work was therefore initiated in England by Huntington-Heberlein, who held a worldwide licence for the use of the A.P.C.M. patents and designs. This involved the construction of an experimental kiln of capacity 0,5 t/h and a pilot plant of nominal capacity 5 t/h. A wide variety of iron-bearing materials was tested in prepelletized form, as well as pelletized minerals such as phosphate rock. A 5 t/h industrial plant to heat-harden phosphate-rock pellets was built by Huntington-Heberlein as a result of this development work.

In 1969, Kurimoto Ironworks took a licence from Simon Carves' Huntington-Heberlein Division for the manufacture and sale of the annular kiln in Japan, and began their own development programme with a 0,5 t/h experimental kiln.

Two similar experimental kilns were sold to the Japanese National Coal Institute. Interest then centred on the production of ferrochromium in which the shortage of suitable quantities of lump ore necessitated some method of fines agglomeration before electric smelting. Conventional methods of sintering and grate pellet-hardening tend to be uneconomic at the scales of production required, and there is the added problem that high firing temperatures are needed. The annular kiln overcomes both these problems because it is ideally suited to capacities in the range 50 000 to 500 000 tonnes per year and is so constructed that no metallic parts are exposed to the firing temperature.

These considerations led to a 5 t/h pilot unit being supplied to Nippon Kokan for the heat-hardening of ferrochromium pellets. This was so successful that a full-scale industrial kiln and associated pelletizing plant are now under construction by Kurimoto Ironworks for Nippon Kokan to produce 140 000 tonnes of heat-hardened ferrochromium pellets per year.

## DESCRIPTION OF KILN

As shown in Figure 1, the bed of pellets is retained by outer and inner vertical cylindrical walls (1) and (2), and is supported on a flat, circular base (3), with a central discharge opening smaller in diameter than the inner wall. Each surface is refractory-lined. Feed pellets enter through a rotary valve (4) in the stationary hood (5), which is connected to the inner and outer walls by water seals. The base is driven, the inner wall is either separately driven or free to rotate, and the outer wall, which makes a rubbing seal with the base, is free to rotate. The centre of rotation of the base is offset relative to that of the vertical walls, thus causing discharge that is controlled by adjustment of the rotation speed. The discharged pellets fall into a cooler for heat recovery.

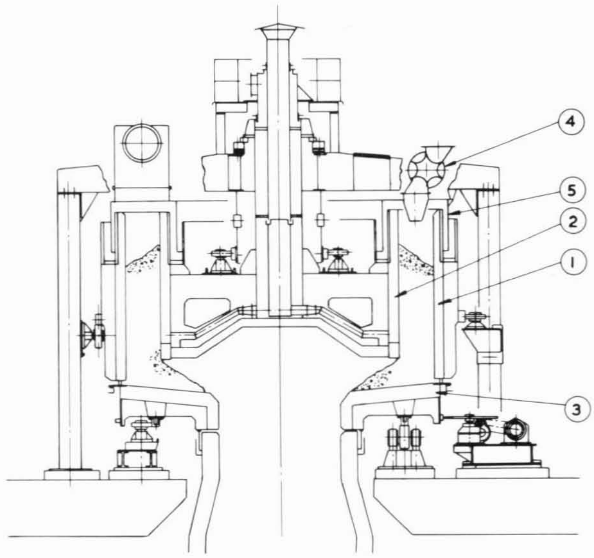


*Figure 1*
*Section through annular kiln*

Air enters through the cooling-air fan, flows through the pellet cooler, and is additionally heated to firing temperature by the fuel burners.

The gases are drawn through the kiln bed by the exhaust fan. A short rotary kiln can be interposed between kiln and cooler.

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## GENERAL CONDITIONS WITHIN KILN

*Thermal Treatment*

The annular kiln has normally been operated at firing temperatures of up to 1350°C and with exhaust gases at temperatures in the range 50 to 200°C. To prevent surface slag formation, the firing of iron-ore pellets requires that a specific heat-soak should be achieved without the use of an excessively high firing temperature. Another critical factor is that the rate of drying must not exceed the rate of steam diffusion from the pellet interior if pellet decrepitation is to be avoided.

This tendency for pellet breakage during drying depends on the size grading of the raw material. Finer materials, while producing more compact pellets, may require a reduction in the rate of steam release, which, in the annular kiln, is achieved by a reduction of the exhaust-gas temperature. The temperature gradient to which the pellet is subjected is dependent both on the solids–gas heat-capacity ratio, $K$, and on any endothermic or exothermic reactions occurring during the firing cycle. The effect on variations in $K$ on gas–solid temperature profiles is shown in Figures 2(A), (B), and (C) for simple heat exchange with fixed solids inlet and outlet temperatures. Figure 2 (D) indicates the effect of exothermic and endothermic reactions on the temperatures of gas and solids. The gas flow through the kiln can therefore be varied so that the solids temperature gradient is that appropriate to the material being treated.

Where the pellets require a long heat-soak to develop strength, or where the firing temperature is critical, this final stage of hardening is best accomplished if the pellets are passed from the annular kiln through a short rotary kiln. The effect of transferring the heat-soak stage to a rotary kiln is to permit operation at a higher value of $K$, with a resultant lowering of the temperature of the waste gases leaving the annular kiln; and, apart from improved thermal efficiency, this may also be helpful with special pellets, in which drying is critical.

The average retention time of material in the annular kiln is about one hour at the rated throughputs, but this is flexible so that the special requirements of some processes can be met.

*Physical Treatment*

If a vertical section through the kiln (Figure 3) is regarded as being fixed with respect to the rotating walls and the base, the discharging action is as follows. During half a revolution of the kiln, pellets in zone A (shaded) are carried towards the centre by the offset rotation of the base, while the space B created is filled by pellets descending down the annulus. The base is then withdrawn during the next half revolution, so that the pellets in zone C are unsupported and are discharged.

If the small amount of random spillage is ignored, the volume discharged per revolution is given by $\pi DHe$, where $D$ is the mean diameter of area B, $H$ is the height of the inner wall above the base, and $e$ is the offset. As the

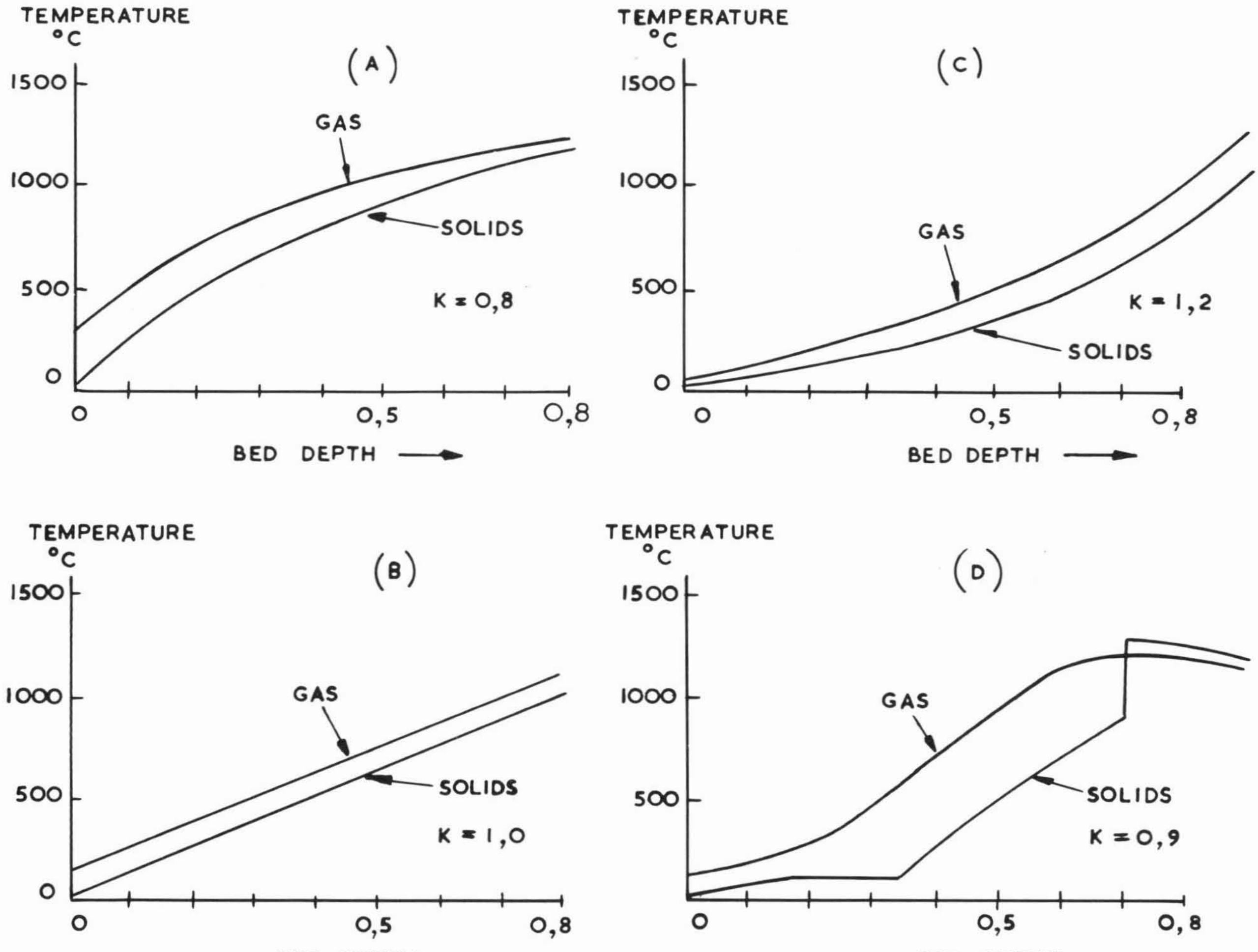


*Figure 2*
*Effect of heat-capacity ratio on temperature profile (bed depth expressed as fraction of total depth)*

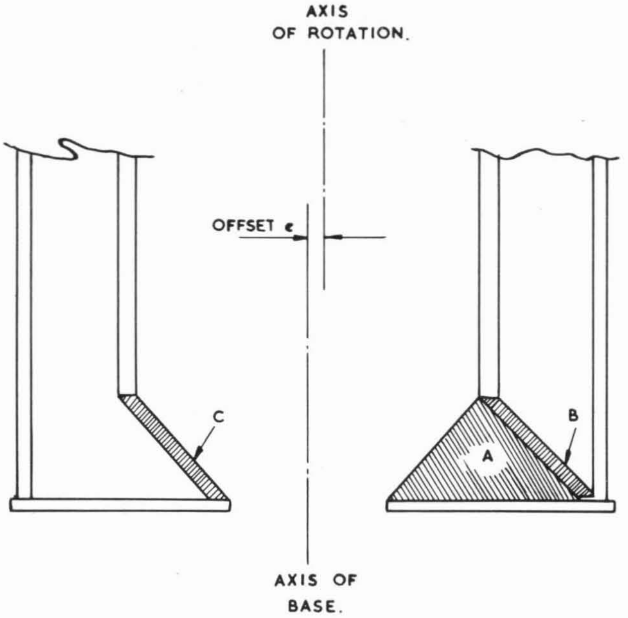


*Figure 3*
*Mode of pellet discharge*

pellets move through the kiln, there is a reduced area available on the horizontal plane. This would generate compressive forces within the bed of pellets in a region where the pellets are not fully fired and could cause breakdown. To overcome this, the base is sloped downwards towards the discharge hole, and the base of the inner wall has an upward inclination, the result being that the volume available for the pellets remains constant. The sloping base has the other advantages of imparting a more positive movement to the pellets on its forward stroke and of creating free space as it is withdrawn. With correct geometry of the kiln, including an appropriate relation between the annular width and the height of the inner wall above the base, the formation of dust is kept to a low level – generally in the range of 3 to 5 per cent.

Very little dust is made in the vertical annulus since, in that region, the pellets are travelling only very slowly downwards between walls that are rotating with the charge. Where dust is produced owing to poor pellet quality, the kiln performance may be affected by disturbance of the gas–solids flow; adequate pellet strength and abrasion resistance are therefore essential.

Results for a wide range of iron ore concentrates show a reasonable correlation between fired pellet strength and the dust formed in the kiln. For example, with pellets having a crushing strength of more than 110 kg, the fraction of material less than 6 mm in the kiln discharge is 3 per cent or less, whereas, for a strength of less than 70 kg, the amount of dust formed rises to 10 per cent or more. This correlation indicates that, provided that green-pellet quality favours an acceptable fired strength, the amount of dust formed within the annular kiln will be less than 3 per cent – an acceptable figure, comparable with that reported for alternative pellet-hardening techniques.

## ANALYSIS OF TEST DATA

*Flow Pattern for Pellets and Gas*

Tests on the large kiln with individually marked pellets have given the retention times of material fed at different positions on the bed top, and use has been made of a change in feed size to determine a distribution of retention times. The best theoretical model to explain the observed data requires that each pellet travels vertically down the annulus to the surface joining the bases of the inner and outer walls, and then moves horizontally towards the discharge hole at the same speed as in the vertical plane. Allowance must also be made for segregation of any smaller material towards the base, where it may exert a retarding effect.

*Temperature Distribution*

The temperature gradients in the kiln have been difficult to measure on account of the combined high temperature and forces on the probes – which must be thin to avoid disturbance of the bed. Isotherms deduced from the flow patterns, on the assumption of a simple heat-transfer operation, are shown in Figure 4. Such experimental data as are available confirm this general pattern of temperature distribution. From the temperature contours and the pattern of pellet flow, the thermal cycles for pellets flowing along different paths within the kiln can be deduced.

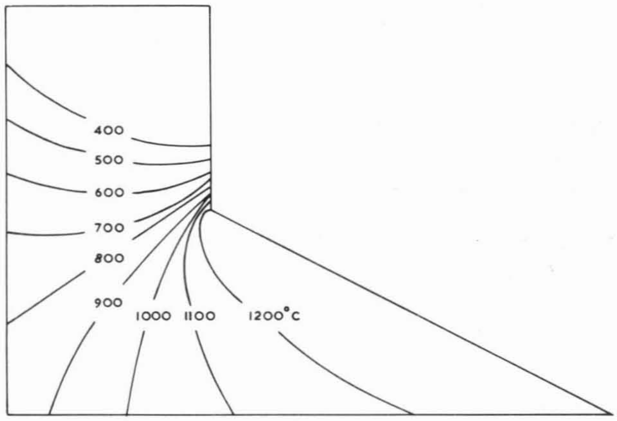


*Figure 4*
*Theoretical isotherms*

Although all pellets are brought to the same final temperature, the rate of heating is highest for pellets adjacent to the inner wall. Pellets in this region may therefore reach the firing zone with a temperature gradient from surface to core. However, these pellets are also subjected to a longer heatsoak at the firing temperature: so the spread of product pellet strength is fairly narrow and comparable with that obtained in a travelling-grate machine.

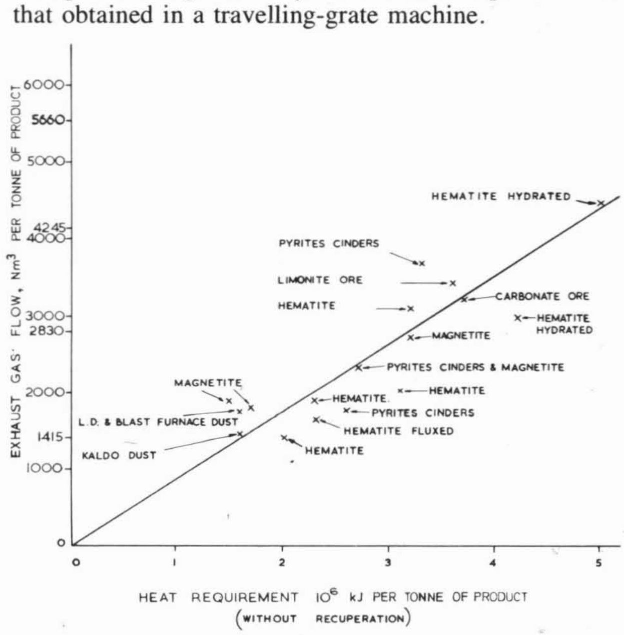


*Figure 5*
*Process requirements for various materials*

*Heat Balance for Various Materials*

The heat requirement is the sum of (1) heat of evaporation of moisture and of chemical reaction, (2) losses by radiation, conduction, and convection, (3) sensible heat in the exhaust gas, and (4) sensible heat in the cooled product pellets. When different materials are compared, the heat requirement is related to (1), i.e., to the exothermic and endothermic reactions occurring as illustrated by the data given in Figure 5.

The inherent compactness of the kiln design minimizes item (2) in comparison with pellet-firing strands. Losses in the exhaust gas depend on exhaust-gas flow and temperature (discussed below), and item (4) depends on efficient cooling by a volume of air not exceeding the requirement of the annular kiln.

*Exhaust-gas Flow*

Since the firing temperature varies over a limited range, the requirement for exhaust-gas flow increases approximately in proportion to the heat requirement, the experimental relation being shown in Figure 5 for a range of iron ores, including those tabulated. Factors such as firing temperature, moisture, and carbonate content cause the deviations from proportionality.

Exhaust-gas flows for magnetites are slightly higher than expected, and it is suspected that the kinetics of the exothermic reaction are such as to cause a temperature peak within the pellet bed and a firing-gas temperature less than the measured pellet temperature (see Figure 2(D)).

Other evidence comes from heat balances – when the firing-gas temperature calculated from the heat input or heat requirement is slightly lower than the measured pellet temperature. Exhaust-gas volume can be varied to give the appropriate temperature profile in the bed, subject to the waste-gas temperature being kept within acceptable limits.

For ferrochromium pellets, the measured heat requirement without heat recuperation is 1 821 000 kJ/t. In a full-scale plant with proper heat recuperation in the cooler, this net consumption is reduced to 984 000 kJ/t. Electric-furnace gas is used for the firing. The products of combustion are drawn through the kiln by a suction fan, and cooling air is passed through the cooler by a separate pressure fan. The total power consumption for the fans at an output rate of 140 000 t/h is approximately 14 kWh/t.

The fired pellets of ferrochromium have a crushing strength of 40 kg per pellet, the total dust produced being less than 0,5 per cent of the product. The pellets remain fully oxidized after firing.

To obtain this quality of pellet it is necessary to make good green pellets from material having at least 60 per cent less than 200 mesh. A small amount of binder is also added. The green pellets are formed on a disc with an appropriate addition of water, and are transferred direct to the kiln annulus.

## FULL-SCALE PLANT DESIGN AND CONTROL

The current trend towards automation makes it necessary to consider the ease with which any new process can be automated. For the annular kiln, control is greatly simplified by two factors: (1) the gas flow through the system involves only two fans – one blowing air through the pellet cooler, and the other drawing exit hot air plus combustion products through the annular kiln, and (2) leakage is almost eliminated.

Given a constant mass of feed material, the regulation of the firing process involves only four controls.

(1) Vertical bed height in the annular kiln is kept constant by short-term adjustment to the rotation or speed of the kiln; bed height in the cooling unit is similarly controlled.

(2) Exhaust-gas temperature is measured and controlled to the desired value by adjustment of the exhaust-gas volume.

(3) The temperature at the firing surface of the annular kiln, or rotary kiln if one is fitted, is measured and controlled by a change in the rate of supply of fuel to the burners.

(4) The pressure or suction at the inlet to the annular kiln is controlled at the correct level by regulation of the volume of cooling air.

## ADVANTAGES OF THE ANNULAR KILN

The advantages of the annular kiln are clear.

(1) It is a highly efficient countercurrent heat exchanger, so that its heat consumption is low.
(2) The prepelletized feed is distributed evenly over the whole area of the annulus, thus ensuring even permeability of the charge.
(3) The fixed discharge is distributed evenly over the whole circumference of the annulus, thus ensuring equal final heat treatment of all pellets.
(4) The pellets are moved downwards through the kiln and discharged by a very gentle action induced by the eccentricity of the discharge hole, so that a high quality of product can be maintained.
(5) Process control is extremely simple and sensitive.
(6) Power requirements for the suction fan are minimal owing to the even, high permeability of the charge and the negligible air leakage.
(7) The mechanical moving parts are simple, slow moving, and well away from high-temperature gases.
(8) At outputs less than about 200 000 tonnes per year, the kiln is cheaper in capital cost than other pellet-hardening machines.
(9) It is a highly flexible apparatus in which the main process parameters such as throughput, firing conditions, and residence time can be easily modified.
(10) The positive gas seals make it possible to operate under neutral or reducing conditions, a fact that may be highly relevant to the treatment of certain chromium ores, where some prereduction of the iron content is desired.

## REFERENCES

1. BEAL, R.V., and BISHOP, L.H. *British Pat. 826, 886,* 1956.
2. DAVIES, G.G.J. *British Pat. 826, 888,* 1957.
3. JENNINGS, R.F., and GRIEVE, A. Le role du four annulaire pour la cuisson des boulettes. *Revue Ind. Miner.*, vol. 48, 1966. pp. 368—378.
4. JENNINGS, R.F., and GRIEVE, A. Developments in pellet hardening. *Steel Times Annual Review*, 1968.

## DISCUSSION

As the conditions obtaining appeared to be conducive to high abrasion, several questions were raised relating to the disintegration of pellets during firing.

*Mr Jennings:*

I refer you to the figures given in the paper for the firing of chromite pellets, which show that the production of fines is small.

*Question from the audience:*

How is a uniform temperature maintained across the annular section? Don't local hot spots lead to sinking and slagging?

*Mr Jennings:*

The forces developed by the eccentricity of the moment of the base strongly counteract any tendency to sinter and also assist in maintaining uniformity of temperature. In addition, the discharge arrangements ensure that the pellets are discharged in a layer only about one pellet deep.