

THE ROLE OF THE PILOT PLANT IN IRON ORE SINTERING (*)

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The growing appreciation of the benefits of blast furnace burden preparation in the post-war years had led to a demand by the Iron and Steel Industry for greater Sinter production. This has been the stimulus of process development work and of research into the fundamentals of the sintering process.

The importance of such studies was first realised by the industry in 1952 when B.I.S.R.A., together with the experimental department of one of the large British Iron and Steel manufacturers, undertook a joint programme of laboratory and plant scale experiments which resulted in the elucidation of many physical factors controlling the sintering process. A symposium including this work was held in London in 1953, and interest grew rapidly, until it became of a universal nature. Many of the Iron and Steel manufacturers in Great Britain and abroad now devote a proportion of their research and development resource to further studies in this field, and several national metallurgical organisations of other countries include sintering problems in their research programmes.

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Huntington Heterlein Sintering Research and Development Section:

This section was established in 1953 and is now an integral part of the Simon Carves research department, at Cheadle Heath south of Manchester. This choice of location makes available to us the resources of the research and analytical section of Simon Carves, the parent company. The sintering section consists of a complete pilot sintering plant, housed in the same building as a laboratory type experimental sintering pot unit, and possesses many items of ancillary equipment used in the experimental procedure.

The pilot plant consists of a moving pallet strand-type machine of 12 square feet effective grate area, driven in the same manner as a large scale machine, by means of a reduction geared variable speed drive at the feed end of the machine.

The pallets which each have a grate area of 9 in. by 18 in., have cast steel side plates allowing a maximum bed height of 9 in. They move over grooved wearing strips which, when greased, provide an efficient seal.

The sintering air on leaving the bed, passes down four windboxes to a 10 in. diameter gas main, in which there is an orifice plate and thermocouple for flow measuring purposes, and then to a large suction fan.

The method of feeding the raw mix is by vibrating Velofeeder against a cut off plate so as to simulate large scale plant operation process.

The igniter which was originally a sillimanite brick radiation-type burner supplied by premixed towns gas and air, has been recently replaced by an igniter with concentric tube type burners similar to that which our company installs on its plants.

After the igniter, along the strand, there is a preheater hood which is fitted with four boiler type burners.

The raw mix is supplied to the Velofeeder by conveyor from a large surge hopper, remote from the machine in a separate mixing bay. Beneath this hopper a disc pelletiser of 4'6" diameter, has been installed for use in pelletisation studies. It is also proposed to incorporate in the feed system, a drum pelletiser of 2 ft. diameter. It will then be possible to compare the behaviour of untreated and pelletised mixes on the strand.

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The mixing of raw materials and the addition of water to the mix is done in a cement mixer in batches which are loaded in to the feed hopper prior to a test. The feed from this hopper is controlled by a further Velofeeder.

The end of sintering is measured accurately by means of six Chromel Alumel Thermocouples evenly spaced in the last two wind-boxes, temperatures being measured by a six point temperature indicator-recorder.

The laboratory scale sinter pot unit consists of a 2 ft. square windbox with provision for interchangeable cover plates to accommodate various types of sinter pots. These pots range from 6 in. diameter to 1 ft. diameter, circular, together with 1 ft. square pots and a segregated feed box, the latter being a further attempt to standardise loading, and to simulate strand conditions. All these pots are manufactured from mild steel, but for future work, a refractory concrete lined segregated feed box is being manufactured. If in the manufacture it is possible to pebble-dash the inside faces of the box, perhaps certain edge effects may be minimised. Sintering air is measured by means of an orifice plate and pressure tapings in a 6 inch diameter wind main between the windbox and the fan, bed suction being regulated by means of a bleed-in valve in the line. Waste gas temperatures are measured by a Chromel Alumel thermocouple inserted in the 6 inch main immediately after the windbox.

Other instrumentation includes a suction pyrometer for the measurement of high gas temperatures (during ignition or the use of preheat for example), and a CO/CO₂ meter of the katharometer type for determining the efficiency of fuel combustion in the sinter bed.

Investigation of the Sintering Process:

In practice the sinter mix has a mean particle size below 10 mm and the depth of bed employed is in the range 30-40 cms. This means that a pot test can be made on a vertical section of an actual plant mix so that, in interpreting the results of such tests there are no problems of scaling up involved.

From this aspect of scale there is little advantage in using the experimental strand rather than the pot and the choice between the two test units is generally governed by the quantity of raw material available.

Pot tests are far quicker and require only 90-100 lbs of mix if a 1 ft. diameter pot is used. It is usually preferable to use them for all initial work and to employ the strand to verify the results obtained on a larger scale.

There are the following differences between conditions in pot and strand tests:

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(a) The ratio of bed periphery/bed area is 4 : 1 for a 1' diameter pot and roughly 1.33 for the experimental strand. In consequence there will be a greater peripheral leakage of air in pot tests and, since the strand has an efficient seal between the moving pallets and the windboxes, the measured waste gas volume per ton of raw mix tends to be higher in pot tests, as does the proportion of return fines. This trend becomes more marked as the mix grows coarser in size.

As previously mentioned it may be possible to reduce this edge effect by pebble dashing the interior surface of the pot. Meanwhile an empirical relationship between the waste gas volume recorded in pot tests and the volume to be expected in practice has been established and is sufficiently accurate for the calculation of fan requirements.

(b) The experimental strand gives the same type of bed segregation in terms of particle size and coke content as does a full scale plant charged by a swinging spout or vibratory feeder.

In a normal pot test segregation is largely a function of the method of charging which must be standardised. To eliminate this difficulty BISRA have developed a 2 ft. square segregated feed box, which gives plant type segregation and greatly improves the reproducibility of sinter tests. We have attempted to use a 1 ft. square segregated feed box to lessen the quantity of mix for a test, but we have found that excessive air leakage and cooling at the 4 corners results in low sinter yields. It is hoped that the refractory lined segregated feed box now being made will overcome this difficulty.

(c) Comparative Coke Rates: For a number of mixes coke consumption figures are available for pot tests, experimental strand tests and normal plant operation. When these results are corrected for variations in coke ash and moisture it is found that the coke rate for pot tests is very close to that obtaining in practice, while the experimental strand gives a slightly lower figure.

Sinter Pot Test Procedure

The mix ingredients normally consisting of ore fines, return fines and coke breeze with possibly blast furnace flue dust, mill scale, turnings, etc., are carefully weighed out and hand mixed on the floor in the dry state. Water is sprayed until the mix is of the right consistency (a handful of the mix should adhere when squeezed without any sign of surplus moisture) and a sample is taken to determine % moisture.

The mix is then reweighed and charged into the test pot in a standard manner.

After starting the suction fan a unit pressure gradient is applied to the bed and the air flow is calculated from the pressure drop across the orifice plate. This enables the pre-ignition permeability to be worked out in B.P.U.

If desired the air flow can also be measured at another level of suction and then the average bed particle size can be calculated according to the following equations given by Manson

$$\text{Porosity, } E = 1 - D \left[\frac{100 + m (d-1)}{6250 d} \right]$$

$$\text{Surface Area, } S = 1464 \left(\frac{E^3}{h} \right)^{\frac{1}{2}} \times \left[\frac{P_1 U_2^2 - P_2 U_1^2}{U_1 U_2 (U_2 - U_1)} \right]^{\frac{1}{2}}$$

$$\text{Mean particle diameter, } D_m = \frac{6 (1 - E)}{S}$$

where D = bulk density, lbs/cu.ft. d = Specific gravity of bed material.

S = surface area sq.cms/U. h = bed height in inches

P_1 and P_2 = suction " WG. and U_1, U_2 are the corresponding air flow rates in ft/minute.

Such a measure of particle size and surface area is a useful check on the effectiveness of mix conditioning, for example by pelletising.

The suction is then adjusted so that during ignition the volume of waste gases drawn from the bottom of the bed equals or only slightly exceeds the volume of the combusted ignition gas with the volatiles driven off from the upper part of the bed. This condition of 'neutral' ignition has been shown by BISRA to be the most effective. (Ball, D.F. unpublished paper). Ignition flow is regulated to give a heat input of around 3,000 B.T.U./sq.ft. over a period of one minute.

After ignition the suction is altered to the desired test level and is thereafter kept constant unless bed resistance decreases greatly at the end of sintering when there may be an unavoidable falling off in suction, due to fan limitations.

Throughout the test, readings of air flow and waste gas temperature are taken and the peak value of the latter is adopted as the criterion of the end of sintering.

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After cooling, the sintered charge is dropped from a standard height and screened at 10 mm. and 6 mm. The various size fractions are weighed and the +10 mm. material is tested for strength in a standard shatter drum. Samples may also be sent for chemical analysis of FeO content, etc.

Experimental Design in Sinter Test Work:

The reproducibility of small scale sinter tests has been investigated by BISRA, some of whose results are summarised below.

	Coefficient of Variance = $\frac{\text{Standard Deviation}}{\text{Mean}} \%$		
	<u>Air, ft³/ton mix</u>	<u>Average permeability D.P.U.</u>	<u>Sinter time minutes</u>
Normal bed	6.9	12.7	10.3
Segregated feed bed	4.7	6.9	4.9

These figures illustrate the improved reproducibility obtained with controlled segregated charging particularly in the measurement of permeability and its dependent variable time.

Even with the greatest care there is an inevitable scatter in test results and this fact coupled with the relative speed with which a test can be performed has led to a growing use of statistically planned series of tests. A further advantage of the statistical approach is that there are a large number of variables involved in sintering eg. fuel, moisture and return fines content, bed depth, suction, particle size of mix, additions, ignition, etc., and some of these interact on one another.

A typical investigation might involve say, the effect of 4 variables, bed suction, % return fines, % lime addition and % moisture, on the sintering time. If these variables are each taken at two levels then the full 2^4 factorial design will be as given below:

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	High % Returns		Low % Returns	
	High % H ₂ O	Low % H ₂ O	High % H ₂ O	Low % H ₂ O
High Suction	High % Lime			
	Low % Lime			
Low Suction	High % Lime			
	Low % Lime			

Even with duplication this involves only 32 tests.

Furthermore by selection of the appropriate half of this factorial design it is possible to determine the magnitude of all the chief effects and the more important interactions. The remaining half can then be completed later if the initial results warrant it.

Useful as the statistical approach is, it is necessary to exercise great care in the choice of levels for the variables involved. When the expected relationship is non-linear, it is necessary to choose at least 3 levels of the variable in question. Another danger of the statistical approach, is the tendency to draw the best straight line through the plotted results, when it is obvious on theoretical grounds that the relationship will be non-linear. In a recent example, sinter yield was plotted against fuel content of the mix, in this way up to 6% fuel with a linear extrapolation up to 8% fuel: In fact the yield must increase proportionately less at higher coke contents, since there is always a certain minimum of returns provided in the process of breaking up the cake of sinter.

However, these criticisms apart, the proper design of sinter experiments will yield far more useful information, particularly when one is seeking minor effects only slightly greater than the testing errors. Such minor effects, when applied in practice may make a considerable saving in operating costs; for example on a plant making 500,000 tons of sinter a year a 1% reduction in coke consumption corresponds to an annual coke saving of about 400 tons.

Application of Results:

From a very few tests, properly carried out it is possible to derive much information about the sintering characteristics of the material studied.

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(a) The appropriate proportions of return fines and coke for 'in balance' operation may be determined, together with the optimum moisture content of the raw mix.

(b) The output rate of either +10 mm. or + 6 mm. sinter to be expected on a plant operating at any suction can be calculated. To take the example of a 12" bed of mix weighing 80 lbs., sintered in a 1' diameter pot (cross sectional area, 0.786 sq.ft.) at 12" suction; if the observed sinter time is 15 minutes and the yield of sinter 40 lbs. then the output in tons per 24 hours per square foot of grate area is $\frac{40}{15} \times \frac{60}{2240} \times \frac{24}{0.786} \times 1 = 2.18$

It has been found that the waste gas volume per ton of raw mix is constant for a given mix and that the volume drawn through the bed in unit time is proportional to $\left(\frac{S}{h}\right)^n$ where S is the suction, 'h' the bed height and 'n' is a constant generally about 0.6.

Thus, if a plant has to be designed to produce 60 tons of sinter per hour with a 15" bed at 20" suction, the output per square foot of grate area will be

$$2.18 \times \left(\frac{20}{12} \times \frac{12}{15}\right)^{0.6} = 2.59 \text{ tons/24 hours.}$$

The effective grate area needed for the plant is thus

$$\frac{60 \times 24}{2.59} = 555 \text{ sq.ft.}$$

(c) From the measured waste gas volume, applying a factor for air leakage, the volume of waste gases per minute can be calculated for a given output. This figure, with suction specified, enables the fan dimensions to be fixed.

(d) If the sinter strength and quality do not appear satisfactory, changes in the ore mix, such as lime addition may be recommended.

(e) The permeability of the mix before and after ignition may be poor. This will indicate the need for some conditioning of the mix eg. by pelletising, in order to reduce the size of machine needed to give the desired output.

(f) Lastly, any special peculiarities of the material such as excessive shrinkage may be noted to see if they will require modifications of the sinter plant design.

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The preceding remarks will give some idea of the routine test work for the design of sinter plants. The more interesting type of work is that concerned with new variations of the sintering process or with unusual materials and a few examples will now be discussed.

(A) The Sintering of Fluorspar Fines for use in Steelmaking:

Initial sinter box tests with Fluorspar fines resulted in a low yield of the order 30% + 3/8" of the raw mix input. The main reason for this was the early collapse of the bed of Fluorspar and subsequent loss in permeability. After considering the possible use of cinders, it was decided to add lime to the sinter mix. This proved successful in that the dead fines of the mix were "flocced" and the average particle size of the resulting mix was increased, thus improving the bed permeability. It was also thought that the lime addition contributed to better flame front progress down the bed. The yield of + 3/8" sintered Fluorspar was of the order 53% of the raw mix input, after using as little as 3% lime in the mix. With a 6% lime addition a more "glassy" sinter was obtained. Control of water addition to the mix appeared to be critical. Analysis of samples of sintered Fluorspar showed them to be within the specification required by the Steelmaking Industry. Demonstration tests were then conducted on the Pilot sintering machine with a view to designing a larger scale plant for production purposes.

(B) Sintering Chrome Ore Concentrates:

In this instance the problem was to produce from chrome ore concentrates a strong aggregate which would be transportable without breakdown and be within the specification laid down by the refractories industry.

The concentrates were 80% - 10 mesh and consisted mainly of a chrome rich chrome spinel. Due to the absence of any low melting phases the initial tests gave sinters of poor strength, even when the coke content was raised to 8%.

Pelletising with subsequent heat hardening was considered as an alternative to sintering but the concentrates could not be pelletised without grinding to increase the quantity of -200 mesh material.

Lime additions up to 2% were found to raise the strength to a satisfactory figure but the final solution proved to be the use of coarser coke, namely $-\frac{1}{2}" \frac{1"}{16}$. With this fuel, permeability and output were improved and the fuel consumption per ton of sinter was reduced to 2 cwts. The greater strength obtained was attributed to the higher temperatures attained in the locality of the coarser coke grains and to a better matching of the velocities of the heat front and combustion front.

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(C) Double Layer Sintering:

This patented process is designed to economise in coke when sintering low grade carbonate ores. The sinter mix is charged onto the strand in two layers; the lower consisting of raw low grade ore and possibly flue dust, which is calcined by the waste heat from the upper sintering layer. This upper layer consists of circulating calcined lower layer product together with return fines from the upper layer and fuel.

Sinter pot and experimental strand tests indicated that a fuel saving of about 20% could be achieved, although the high circulating load led to a reduction in output per unit grate area.

The process was incorporated in a scheme for a proposed sinter plant to be located near a low grade ore field. The ore containing 20% iron was limey, with much combined water, and on sintering the loss in weight was of the order of 30-35%. With these conditions the double layer process would save both coke and the cost of transporting the volatiles in the ore.

Incidental advantages of the process are

- (1) a lower average waste gas temperature giving economy of fan power.
- (11) a reduced temperature of finished sinter permitting it to be handled without special cooling equipment.

(D) The Sintering of Preheated Mixes:

Heating the mix to 60-70°C before ignition has been reported to improve the sintering rate by increasing the permeability.

An investigation of this effect was made using a low grade ore which had a poor sintering rate.

The outputs achieved in tons of $\frac{1}{4}$ " sinter per square foot of grate area at 18" suction were as follows :

<u>Cold Hand- mixed Charge</u>	<u>Cold Pelletised Charge</u>	<u>Hot Hand- mixed Charge</u>	<u>Hot Pellet- ised Charge</u>
1.5	1.75	2.2	2.9

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The hot charges were heated by the use of hot return fines and the striking gain in output is due to the effect which heating the charge has on permeability. Permeability collapses after the ignition of cold mixes, but retains a much higher value when a hot mix is used. The reason for this improvement is not fully known, but it is supposed that a higher bed temperature prevents condensation of moisture in the lower part of the bed. The benefits obtained by heating the mix in this way will of course depend on the ore used and will be greatest where a high moisture content is necessary to give a reasonable initial permeability.

(E) Fundamental Research:

Sinter pot tests have been the chief method of investigating the fundamentals of sintering, such as heat transfer. Apart from the work mentioned above, we try to do some more basic investigations after first discussing our ideas with BISRA to ensure that there is no duplication of effort. The aspects of sintering now occupying our attention are as follows:

(1) The role of return fines as they affect permeability and coke consumption. When operating in balance the level of return fines will clearly be a function of the fuel content of the mix and will approach some minimum value asymptotically as the fuel content increases.

Return fines will also affect permeability (and hence at a given suction, the output) by increasing the average particle size of the sinter mix.

Once these relationships have been established by means of pot tests it should be possible to express all the sintering variables in terms of fuel input.

For example the sinter yield Y as a % of the raw mix
 $Y = 100 - R - L$ where $R = \% \text{ returns}$ and $L = \% \text{ sintering loss}$.

$$\text{In turn } L = L_O O + L_C C$$

where O , C and M are the percentages of ore, coke and moisture in the mix and L_O and L_C are the ignition losses for ore and coke respectively.

$$\text{Also } O = 100 - R - C - M.$$

$$\therefore Y = 100 - R - L_O (100 - R - C - M) - L_C C - M$$

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Putting $R = f^1(C)$

$$Y = (1-L_0) (100 - f^1(C)) - C (L_C - L_0) - M(1-L_0)$$

Similarly if permeability, $P = f^2(R) = f^2[f^1(C)]$

$$\text{Sinter time } T, \text{ is proportional to } \frac{1}{P} = \frac{K}{f^2[f^1(C)]}$$

With such equations optimum operating points can be selected according to one of the following criteria.

(a) Minimum fuel consumption : ie. C/Y to be a minimum

(b) Maximum output ie. $\frac{Y}{T} = Y f^2[f^1(C)]$ to be a maximum

(c) Maximum hedony ie. $\frac{\text{Output}}{\text{Fuel consumption}} = Y^2 f^2[f^1(C)]$ to be a maximum.

The application of this work might reveal that many plants were not operating at the best level of return fines to achieve their objectives.

(11) The utilisation of fuel in the sinter mix. Work by I.R.S.I.D. has revealed that there is a significant proportion of CO in the waste gases leaving the sinter bed. The quantity of CO is affected by the suction, the coke size and its reactivity.

We have recently installed a CO/CO₂ meter on the waste gas main from the sinter pot and we intend to follow up this French research by seeking ways of minimising the % CO and thereby increasing the efficiency of fuel utilisation.

(111) The effects of heating a sinter bed either before or after ignition: Supplying hot air or combustion products to the sinter bed after ignition has been shown to save fuel, particularly when sintering low grade ores containing carbonates and combined water. In addition as previously stated, warming the mix to 60°C before ignition increases the sintering rate. We propose to investigate the effect of more intense heating of the bed prior to ignition, using an inert gas to prevent pre-combustion of the coke. We have also studied the results of post ignition heating on both low grade and high grade sinter mixes. Although coke savings are less with rich ores they are still significant and, as with low grade ores the beneficial influence of preheat is not only confined to the upper part of the bed.

CONCLUSION:

The sintering process which at first seems no more complicated than the smoking of a pipe, has yet to be fully elucidated, despite the rapid progress of the last few years. It involves such problems as heat transfer, high temperature reaction kinetics, and resistance to air flow. The purpose of this paper has been to illustrate the usefulness of sinter pot test work, both for achieving a better understanding of the sintering mechanism and for providing the data for the design of sinter plants.

MRK