

# Immersion Pyrometry and Open Hearth Furnace Productivity

## FASTER STEELMAKING AT RAVENSCRAIG

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It is nowadays generally accepted that controlling the tapping temperature of steel by immersion pyrometry is an important means of improving steel quality. Broadly speaking, if the steel is too hot when tapped the ingots tend to crack, and if too cool they tend to suffer from "shell" on the surface and non-metallic inclusions beneath.

From this point of view it is now simply a question of establishing the optimum tapping temperature for each quality of steel and for each ingot size, and ensuring that this is regularly attained. This temperature is, of course, closely linked with teeming speed in determining ingot quality. For instance at Ravenscraig, with 250-ton open-hearth furnaces, the same type of steel gives very similar overall results at the rolling mill either by tapping at 1590°C and teeming an 18-ton ingot through a large nozzle in 1½ minutes, or by tapping at 1605°C and teeming this ingot through a small nozzle in 6½ minutes. Intermediate teeming speeds give worse results than either of these. Once the optimum temperature for each quality is established, the aim is to ensure that the last temperature in each charge is taken within ten minutes of tapping, and that it is within 5°C of the specified figure.

Whereas the effect of tapping temperature on steel quality is widely recognised, and sufficient temperatures are usually taken to ensure the correct tapping temperature, the value of taking immersion temperatures during the melting and early refining period is less generally realised.

*The use of platinum thermocouples to measure molten steel temperatures has been well established for many years, and normal steelmaking practice involves the control of tapping temperatures by this means. But in the new melting shop at the Ravenscraig works of Colvilles Limited the author has developed a method of controlling the whole open hearth process on the basis of temperature measurement at fixed intervals of time. The procedure he describes here results in a significant increase in productivity and reduction in cost per ton of steel.*

The higher the temperature of the slag and metal the greater the erosion of the furnace banks and bottom, and the more time and money are expended in repairing them between charges. So the charge must not be allowed to become hotter than is necessary at any stage. At the same time it is desirable to achieve the minimum tap-to-tap time, which means, among other things, operating the furnace as hot as possible.

How are these apparent opposites to be reconciled?

The procedure developed at Ravenscraig involves the measurement of temperature at fixed intervals of time and the use of these determinations, in conjunction with the carbon content of the bath, to control adjustments to the fuel supply and the timing



*Measuring the temperature of the charge with a platinum:rhodium-platinum thermocouple pyrometer in one of the 250-ton open hearth furnaces in the new melting shop at Colvilles' Ravenscraig works. Measurements made at fixed intervals of time are used to control the working of the charge and to increase the speed of reaction*

of additions of ore. In this way as much as an hour can be saved on an eleven hour heat—a significant increase in productivity and reduction in cost.

### **The Thermal and Chemical Processes**

Open-hearth steelmaking may be regarded as a thermal process and a chemical process running concurrently. The thermal process consists in raising the temperature of the scrap, the iron and the fluxes of the charge (whether all solid or partly solid and partly molten) to that required for tapping, besides supplying the heat required for the chemical reactions. The chemical process consists mainly in oxidising the silicon and phosphorus of the charge and eliminating them into the slag, and oxidising enough of the carbon of the charge to reduce it to the required level

at tapping (usually between .10 and .25 per cent C). The oxygen is supplied from the furnace atmosphere and from iron oxides which are charged.

The objective is to “balance” the charge and to operate the furnace so that the thermal and chemical processes are completed at the same time, because if this is done the charge is brought ready for tapping in the minimum time.

The two processes are complementary, because the rate of the chemical reactions depends on the temperature in the bath, and because the absorption of heat by the charge once it is molten depends very largely on the stirring effect of one of the chemical reactions, the carbon-oxygen reaction. If the thermal process is ahead of the chemical process, time and fuel are wasted in maintaining the heat of the charge while the excess carbon is

removed. For the open-hearth process, which thermally is only 20 per cent efficient, this waste of fuel is serious, and the extra wear on the refractories due to the extra furnace time is no less so. If the chemical process is ahead, the carbon is removed before the bath is hot enough, and the consequent stirring action diminishes, thereby preventing the bath from picking up the heat required for tapping. It is necessary to generate a stirring action by adding more iron to the furnace, but this increases the furnace time and adversely affects the steel quality.

In the first two periods of the open-hearth process, during charging (about four hours) and melting (about four hours), the emphasis is on the thermal process, on injecting heat into the charge, since this in turn determines the progress of the chemical reactions. In the third period, the refining period (about two hours), the chemical processes must receive first attention, as sufficient heat for tapping can usually be achieved without difficulty. The change in emphasis from the thermal to the chemical process is usually taken to occur at "clear melt", when the whole charge is completely molten, and when its temperature can rise more rapidly.

### **Balancing the Charge**

However much care is taken in "balancing" the charge, the relative rates of the thermal and chemical processes vary from charge to charge, which results in varying carbon contents at clear melt. Since too low a carbon content at this stage tends to harm the steel quality, while too high a content mainly prolongs the tap-to-tap time, it is normal to balance the charge to give an average melt-out carbon higher than the optimum, and accept the loss in time, and therefore in production.

The charge works fastest if it melts at, say 0.30 per cent C with a temperature of 1530°C, and taps fifty minutes later at 0.15 per cent C and the specified temperature of 1585°C. However, a lower carbon at melt would probably require addition of iron, and to

reduce the chance of this it is normal to aim for a carbon at melt of about .50 per cent C.

This means that in most charges iron ore will require to be fed in order to accelerate the carbon drop. In fact for certain types of steel it is desirable always to feed ore, as this improves the quality. Feeding iron ore enables the chemical process to gain on the thermal process in two ways, both by accelerating oxidation and by retarding the rise in temperature. The temperature is held back directly by the fact that the ore is cold and also by the fact that the reaction between the ore and the carbon is endothermic.

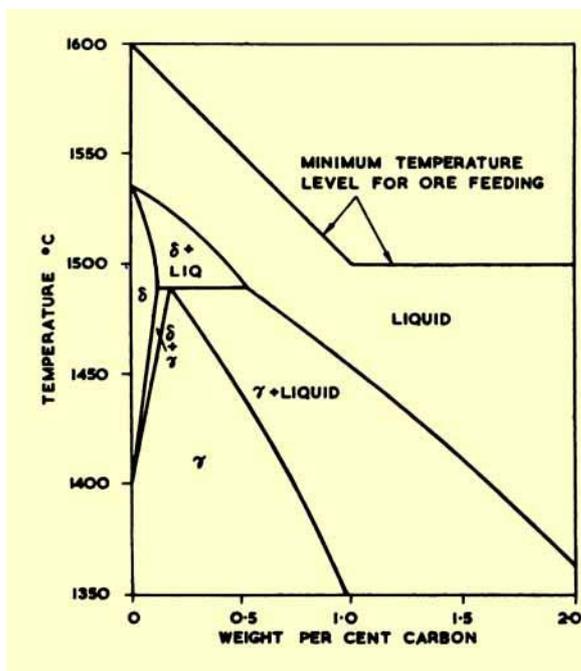
It is therefore important to decide how soon it is possible to determine whether the thermal or the chemical process is ahead, and if the former, how early ore can be added to compensate for this. This must be decided in each melting shop on the basis of experience, but theory can give some guidance.

First consider the portion of the Fe-C equilibrium diagram shown here. The important part of this graph from our point of view is the liquidus curve in the range up to 1.00 per cent C or so. It so happens that the liquidus temperature falls by about 1°C for every .01 per cent carbon content (i.e. for every so-called "point" of carbon).

In deciding at any time whether or not to feed ore, one must consider the amount of superheat in the molten metal, that is, how far its temperature exceeds the liquidus temperature for its existing carbon content.

### **Effect of Feeding Ore**

Consider how the superheat is affected when a box of ore is fed to the bath. At Ravenscraig, with 250-ton furnaces, the rate of carbon drop in the latter stages of the melting period averages 14 points (.14 per cent C) in half an hour. Owing to the slope of the liquidus curve the bath must therefore gain about 14°C in this half-hour in order to maintain the same superheat. On the other hand if a box of ore (weighing three tons) is fed, this reacts over a period of twenty minutes or so, and causes the loss on average of an additional



*The important part of the iron-carbon equilibrium diagram from a steelmaking point of view. Superimposed on the normal diagram is a line showing the minimum temperature, for varying carbon content of the bath, at which ore is fed to the furnace at Ravenscraig*

11 points of carbon, giving a total loss in the half-hour after the ore addition of 25 points. The cooling effect of the ore is 20°C from its thermal capacity and 20°C from the endothermic reaction with the carbon in the bath, a total of 40°C. If the superheat at the end of the half-hour is to be maintained, the bath must absorb heat equivalent to a gain of 65°C in temperature, that is 25°C to compensate for the loss of 25 points of carbon, and 40°C for the cooling effect of the ore. In fact, if ore is fed, the bath must gain heat 4 to 5 times as fast as if not. This is possible. When ore is not fed, the fuel burned in the furnace must be limited to avoid overheating the roof; when ore is fed, the bath is strongly agitated, and can therefore absorb a larger proportion of the heat of the flame, so that the fuel flow can be increased without damaging the roof.

### Application of the Method

Thus, at Ravenscraig, if the superheat is high enough to feed a box of ore, then half an hour later it should again be high enough to feed a second box, and so on. In another

melting shop this time interval might be either longer or shorter, depending on many factors. What superheat then is sufficient for feeding ore? At Ravenscraig this is found by experience to be about 50°C before clear melt, and 30°C when the charge is fully molten. So if before clear melt the sum of the temperature at any time and the number of points of carbon at the same time exceeds 1600 it is safe to feed a box of ore. Thus if the bath is at .50 per cent C (50 points of carbon) and the temperature 1560°C, the sum of 1610 justifies a box of ore being fed. Once the bath is clear the sum of carbon and temperature requires to be only 1580 for a box of ore to be fed, so that at .50 per cent C any temperature over 1530°C would be high enough for a box of ore. The only exception to these rules is that no ore is fed until the temperature exceeds 1500°C, whatever the carbon content.

It is found in practice that below 1500°C the temperature recovers very slowly after a box of ore, possibly because the melting of the solid materials still lying on the furnace bottom is delayed excessively. Even above this

temperature feeding ore tends to delay clear melt, but this is no disadvantage. Provided the bath is hot enough before clear melt to accept a box of ore, it pays to accelerate the carbon drop because it is this, and not the bath temperature, which will be the factor deciding when the furnace will tap.

### Method of Taking Temperatures

It may seem surprising that it is possible to take temperatures below 1500°C in a bath which is not fully molten. At Ravenscraig the standard practice is to take the first temperature three hours after the furnace is fully charged, when it is usually below 1500°C. This is to make sure of catching those charges which at this time are above 1500°C and which provided they contain enough carbon, are ready for ore. At times the silica tube and thermocouple wire are damaged by such early "dips", either because the operator has failed to avoid the lumps of lime floating on the surface, or because the solid material on the bottom just inside the middle door is too near the surface of the bath. However, this risk is accepted in order to learn as early as possible if ore can be fed. The metal in the bath is prevented from adhering to the graphite end-block by heating it in the furnace before immersion until the recorded temperature of the thermocouple exceeds 1500°C or so. It should be mentioned that the temperatures are taken by a single "dipperman" on each shift; this man maintains the pyrometers and also has duties apart from immersion pyrometry. If the temperatures were taken by too many different men the frequency of damage to the pyrometers would possibly preclude their use at such low temperatures.

### Cost of Immersions

This practice, including taking frequent temperatures before the bath is melted, is not considered extravagant since the average cost for materials is exactly 2s per dip. This figure includes the cost of silica sheaths, platinum and rhodium-platinum wire and all other equipment for the pyrometers. The

labour cost has been excluded because the operator spends only part of his time on immersion pyrometry and because the labour cost per dip varies considerably according to the number of furnaces operating and therefore the number of dips which are taken in a shift.

### Timing of Samples and Immersions

In order to operate the above system for deciding whether or not to feed ore one must know the temperature and carbon content at successive stages of the charge. The temperature can be measured in less than a minute, but the result of a sample drawn from the bath for carbon analysis is received fifteen to twenty minutes later; so the carbon content at any time can only be estimated by extrapolating from earlier results. It is therefore specified that samples should be drawn regularly every thirty minutes starting two and a half hours after the furnace is charged. An immersion temperature should be drawn immediately after each sample from three hours after the

The Working of a Typical Charge at Ravenscraig			
Target Specification 0.18 per cent C, 0.045 per cent max. P & S, 0.75 per cent Mn. 1585°C			
Time		Per cent carbon	Temperature °C
3.15	Furnace charged		
3.45	Slag flushed		
5.45		.97	
6.15		.82	1490
6.45		.67	1510
7.15	Clear melt	.57	1530
7.20	3 Tons of ore fed		
7.45		.42	1540
7.50	3 Tons of ore fed		
8.15		.23	1550
8.20	1½ Tons of ore fed		
8.30		.16	
8.40			1580
8.45		.105	
8.55			1590
9.00		.08	
9.10	Furnace tapped		



*Charging a box of iron ore to an open hearth furnace. The method of timed temperature measurements, in conjunction with rapid checks on the carbon content of the bath, makes it possible to decide on the exact moment when ore should be charged, so reducing the overall operating time*

furnace is charged. This means that at the time the first temperature is taken the carbon content can be estimated from the known content half an hour earlier.

### **Example of Operation**

The actual method of operation is best illustrated by an example. If a furnace is charged at 10.00 a.m. a sample is drawn at 12.30 p.m. The carbon content of this sample is reported at 12.45 p.m.—suppose it is 1.00 per cent C. The melter estimates that by 1.00 p.m., when the first temperature check is due, the bath will contain about .85 per cent C. So before the temperature is taken he knows that provided it is over  $1515^{\circ}\text{C}$  (i.e.  $1600-85$ ) it should be safe to feed a box of ore. If so, it is fed at once. (Whether his estimate of the carbon content at 1.00 p.m. was correct is known later from the sample drawn at this time, immediately before the temperature check.) If ore is fed just after 1.00 p.m., its reaction will be complete by about 1.20 p.m., that is before the next sample

and temperature are due at 1.30 p.m. The same procedure for deciding whether to feed ore is followed after each temperature determination.

For various reasons it is not always possible to take samples and temperatures exactly every thirty minutes or to follow them immediately with a box of ore. This can make the calculations more difficult, particularly if a sample is drawn within twenty minutes of a box of ore being fed, before its reaction is complete. One advantage of the above method is that it can be operated by melters who are not familiar with the use of graphs, such as are used in other similar systems.

An example of the working of an actual charge is given in the table.

It may be added that it has been found to be harmful to feed two boxes of ore in quick succession, however hot the metal in the bath may be; otherwise there is excessive delay before the metal is hot enough to feed a further box. This is understandable from a

knowledge of the cooling effect of ore. However, it has been found that if the "sum of carbon plus temperature" exceeds 1620 (instead of the usual 1600) then it is possible to feed a box of ore, and a second box fifteen minutes later, before the effect of the first is complete.

The method of applying immersion pyrometry is different again in a furnace recently built in the melting shop referred to, where the roof is of basic bricks instead of the silica bricks of the other three furnaces. The higher temperatures which the basic bricks can withstand allow a higher fuel rate, and consequently a higher production rate. In this furnace the oxidation rate can be controlled much more than is possible with a silica roof, not only by feeding ore but also by varying the ratio of "atomising" steam to oil. Again, whether oxidation requires to be

accelerated depends on the temperature of the bath, which must be measured.

## Conclusion

It is hoped that enough has been written to indicate the advantages of immersion pyrometry in improving productivity. Certainly it is possible to estimate visually the temperature of the steel in the furnace by observing the overlying slags and thereby to decide whether or not to feed ore. However, the inaccuracy of this estimate is such that in many cases the steelmaking process will be delayed by ore being fed either too early or too late. Immersion pyrometry is justified in the interests of faster production and consequently cheaper production.

The writer wishes to thank the directors of Colvilles Ltd. for permission to publish this article.

# Platinum Catalysts in Fuel Cells

## ADVANTAGES OF LOW TEMPERATURE OPERATION

The immense amount of research now being carried out on the development of fuel cells is directed towards a considerable variety of devices. The possible combinations of fuels, electrodes and electrolytes are obviously very numerous, even within the limits of potential practicability, and the range covered by both industrial and government sponsored research programmes is extremely wide. Naturally there is no expectation of the development of one all-purpose fuel cell, and it is likely that a number of differing types, each with its own particular advantages and shortcomings, will emerge within the next few years to meet the varied requirements of vehicular propulsion, communications, auxiliary power sources in aircraft and specialised military applications. The day of the fuel cell as a means of primary power generation is certainly farther away.

While research on cells aimed at central station generation is generally based upon operation at more or less elevated temperatures, there is an obvious advantage in the achievement of low temperature operation for cells designed to provide auxiliary power or to operate in locations remote from sources of heat. This lies in the ease of starting-up at

normal temperature. Now in most types of fuel cell it is essential to incorporate a catalyst in the electrodes to achieve a high rate of reaction. In cells operating at elevated temperatures a catalyst of only moderate activity is adequate to ensure rapid reaction, depending, of course, upon the particular fuel employed and upon the structure of the electrodes. With lower temperatures of operation a more highly active catalyst – and one resistant to poisoning by impurities in the fuel – must be chosen.

An increasing number of fuel cell designs currently being investigated employ platinum, or sometimes another member of the platinum group, dispersed on or in the structure of the electrode in conjunction with one or other of a variety of fuels such as hydrogen, hydrocarbons and alcohols. Although in some cases precise details of the catalyst are not disclosed, a trend clearly discernible in the vast amount of research now in progress is towards the high degree of acceleration of the electrode reaction that can be provided by a platinum catalyst, operating at ambient temperature and with an organic fuel that can be made available cheaply in a state of high purity. L. B. H.