Developments in Blast Furnace Practice

T. P. Colclough

IT WILL be generally accepted that the principal factors in the economy of the blast furnace are productivity and the coke rate. With the ever increasing demand for iron, attention was focussed in the inter-war period, and since the last war, on increasing productivity by building larger furnaces which were, by virtue of their size, able to burn more coke and smelt more ore per hour with relatively small additions to the labour force, therefore giving much higher productivity in terms of tons of iron per hour and tons per men employed.

It was soon found that the rate of increase of the coke burnt and of iron production was not proportionate to the increase in the hearth diameter of the furnace but showed a regular, positive fall. This arises from the fact that the penetration of the air blast into the hearth of the furnace is limited and that the combustion of coke is confined to an annular ring close to the periphery of the hearth.

This is well expressed in the formula proposed by Rice of the U.S.A. which may be written in the simple form :

$$W = 50\,(D - 7{\cdot}5)$$

where "W" is the tons of carbon burnt per day in a furnace with a hearth diameter of "D" feet. This means that the amount of coke burnt per day will increase proportionally as the hearth diameter increases up to 15 feet, but beyond this size there is a definite fall in the rate of increase of production.

This furnishes a reason why for many years the optimum size of the blast furnace was taken to be about 15/17 feet hearth diameter.

It also indicates that there is an economic upper limit to the size of the furnace, depending upon the relative cost of building the furnace as compared with the tons of iron produced. While this may vary under different local conditions, this upper limit is, today, taken to be about 30 feet hearth diameter.

With these considerations in mind, there has been a difinite trend to increase the size and limit the number of furnaces, installed to produce a given tonnage of iron.

In consequence, the old type of blast furnaoe plants consisting of five or more furnaces of 15/17 feet hearth diameter have been displaced by plants of two or three or more furnaces with hearth diameters between 25 and 30 feet.

Coke rate

It is generally accepted that the blast furnace regarded as equipment for the reduction of iron ore has a very high degree of efficiency—97% being accepted as standard practice. On the other hand, when examined from the thermal aspect and a comparison is made of the heat usefully employed in the furnace against the thermal value of the fuel consumed, the thermal efficiency of the furnace in normal practice must be regarded as unsatisfactory.

In normal good practice, operating on rich ore burdens, the heat usefully employed in the furnace rarely exceeded 50% of the intrinsic heat of the coke burnt and supplied in the air blast. Approximately 50% of the heat value of the coke escaped from the furnace in the form of unburnt CO in the furnace gas.

It is quite true that in efficient integrated plants this gas was used externally for heating purposes but it is obvious that these same heat requirements could be met by using fuel of lower cost than blast furnace coke. Attention has therefore been focussed during the last 25 years on securing a more efficient use of the coke in the blast furnace, thereby reducing both the cost of the coke consumed and the heavy demand for the scarce commodity, coking coal of good quality.

Burden distribution

The reasons underlying the inefficient use of coke were first demonstrated by S. P. Kinney[1] in 1927 in his investigation of a model blast furnace. These results were confirmed by Bone[2] and his colleagues in 1937 in their field tests, and the principles underlying the methods to be applied to secure higher efficiency were outlined by the present author[3] in 1936. Today, these principles are being widely applied and their study intensified.

The coke burnt at the tuyeres can only burn to CO and liberate some 30% of its intrinsic heat value. The inefficiency arises from the failure to utilise the reducing power and heat generating potential of this gas in its passage from the tuyeres to the throat of

---

[1] S. P. Kinney, P. H. Royster and T Joseph—U. S. Bur. Mines Tech-Publ. No. 391, 1937.

[2] "Reports on Blast-furnace Field Trials", Iron and Steel Inst. Spec Rep. No. 18, 1937.

[3] T. P. Colclough—J. I. S. I., 1936, No. 11.

Dr. T. P. Colclough, C.B.E., D.Sc., Technical Adviser, British Iron and Steel Federation, London, United Kingdom.

the furnace. This failure, in turn, arises from the lack of uniformity, both physical and chemical, in the materials charged into the furnace.

It will be accepted that to secure chemical uniformity the ores could and should be thoroughly mixed before charging and not, as in normal practice, charged as individual ores. That is the first essential for uniformity.

It is well known that in most cases the ores received at the blast furnaces show a wide variation in physical size, from fine dust to large pieces. It has been demonstrated that when the ores fall from the charging bell into the throat of the furnace there is a segregation pattern by size, with the larger pieces on the wall and in the centre, with an intermediate annular zone of fine material. This pattern persists throughout the height of the furnace stack.

As a result, the zones on the wall and central vertical axis of the stack offer less resistance to gas flow than the more densely packed annular zone of fine material.

The ascending gases from the hearth, seeking the path of least resistance, travel through the zones in the central axis and up the walls at such high velocity that they escape before their sensible heat and reducing power can be effectively utilised.

The solution of the problem is obviously to remove the cause of the physical segregation—the large variation of size in the ore pieces.

Modern techniques

(*a*) *Crushing and sintering*: The first and most important principle in the modern blast furnace is that the ores, as received, shall be crushed to such a maximum size as will permit the penetration of heat and gas to the centre of the piece during its transit time down the stack. This size generally ranges from 2″ to 4″.

The crushed ores are then screened to remove all fines below, say, 1/2″ so as to take out all the fine material which would occupy the interstices between the larger pieces and impede gas flow. These fines are then sintered or agglomerated into pieces and this sinter should preferably be screened to remove all material below 1/2″ dimensions.

By this operation, the ores charged into the furnace lie within a size range of 4″ to 1/2″ relative uniformity and, most important, freedom from dust and fines.

It has been shown[4] that the loss in permeability of a mixture of materials with a variation of size of 3 : 1 is very small as compared with material of uniform size. It is therefore recommended that the crushed, screened ore should be further screened to give two fractions conforming to roughly this size range i.e. ½″ to 1½″ and 1½″ to 4″ and that these fractions should be charged separately into the furnace.

It is to be noted that this physical preparation of the ore involves a considerable degree of mixing, thereby promoting chemical uniformity. In many cases this is supplemented by a thorough mixing of the ores in "beds" either before or after crushing to ensure uniformity of composition. Having established a uniform supply of raw materials, it is then practical to apply further developments of technique.

The progressive improvement in blast furnace practice, as regards both the production per day and the coke rate, by increasing the proportion of the ore sintered up to the maximum of 100% has been clearly demonstrated by the pioneer work of Elliot[5] and his colleagues, and others, in the U.K.

This experience has been confirmed[6] by the practice in other countries, particularly Sweden, U.S.A. and U.S.S.R.

(*b*) *High top pressure*: As indicated above, one of the reasons for low thermal efficiency lies in the high velocity of the ascending gases in certain zones. With high rates of blowing, these velocities become so high that, particularly with fine ores as in U.S.A., a large proportion of the ore fines is blown out of the furnace stack. This loss of ejected fines-flue dust losses-imposes an economic limit on the rate of blowing and therefore productivity. This loss is minimised by the sintering operation which, by removing fines, reduces automatically the tendency for the ore to be blown out.

Alternatively, the furnace may be operated under higher pressures. On first principles, the volume of a given weight of air blown varies inversely with its pressure and consequently the velocity of the gases passing up the furnace stack must fall as the pressure rises, given the same weight of air per minute. This lower velocity has a two-fold effect—it reduces the tendency for the ejection of fine ore, which was the primary reason for its adoption in the U.S.A. Further, by giving a longer "residence" time for the gas in stack, it promotes the transfer of sensible heat from the gas to the descending solids and more effective use of the reducing power of the CO in the gas.

In practice, it has been found that with furnaces operating with top pressures of 0·7 atm. (10 psi); flue dust losses show a substantial reduction and productivity may be raised by about 9%. This has been found of particular value in the U.S.S.R. where the sinter is charged in the unscreened condition.

Other techniques are employed to reduce the thermal load or coke demand.

(*c*) *Self-fluxing sinter*: In normal practice, it has been customary to charge as a separate material the limestone or magnesium carbonate required to flux the acid constituents of the burden as slag.

It is well known that these fluxes—carbonates—require heat for their decomposition in the stack and that the CO_2 liberated reacts with carbon to form CO, thereby absorbing more heat and using coke in the stack.

---

[4] C. C. Furnas—U. S. Bur. Mines Bull, No. 307, 1929.

[5] G. D. Elliot and others—Iron and Steel Inst. Sepc. Rep. No. 30, 1944, and later papers.

[6] J. I. S. I., 1958.

In the modern practice, the necessary fluxes are added to the ore mix in the sinter machine and this has a multiple effect. The calcination operation is carried out in the sinter machine more efficiently and reduces the heat requirement in the furnace. Further the CaO and MgO liberated flux the SiO_2 of the ore in the sinter mix, giving a stronger sinter and generally leaving the iron-oxide of the ore in a more readily reducible form. It has also been found that the addition of the fluxes leads to a higher rate of production on the sinter machine.

In addition, the elimination of the fluxes from the furnace charge is another step towards ensuring the desired charge of uniform composition. Also, with the use of self-fluxing sinter, the slag is already formed and the slag melting operation is conducted in a much more limited temperature range and tends to give smoother and more regular operation of the furnace.

(*d*) *Higher blast temperatures*: The use of hot blast instead of cold blast is now traditional and by supplying heat in the "sensible" form has reduced the requirement of coke. Theoretically, this principle is capable of further application and is the basis of the proposals to raise blast temperatures and to inject additional external fuels.

The advent of prepared burdens and higher proportions of sinter has made possible the use of higher than traditional blast heats. There is, however, a limit in practice. It is well known that with the additional sensible heat in the blast there is a raising of the combustion temperature and it is not so well known that there is a correlative contraction of the zone of activity. (See Korevaar, Leyden, 1924).

As a result, the point is inevitably reached at which the raising of the blast heat leads to stickiness in the lower bosh zone and consequent fall in production and increased coke rate. When these conditions arise, the modern practice is to make an addition of steam to the air blast.

(*e*) *Steam additions*: The principles underlying the use of steam for this purpose are well known. The water in the blast reacts with the carbon in the coke to form CO and H_2 and heat is absorbed. The quantity of steam to be added can be calculated so that the heat absorbed balances the increase arising from the planned raising of the blast heat. This restores the thermal conditions in the tuyere zone to the optimum which had been already attained and re-establishes smooth operation.

It is to be noted that this water gas reaction generates twice the volume of CO and H_2 per lb of carbon as compared with the CO generated by carbon/air reaction and there is no diluting nitrogen. The ascending gases are therefore enriched in reducing agents and this stimulates the reduction of ore and generation of heat in the upper zones of the furnace.

The overall effect of the steam additions is therefore to promote smooth operation of the furnace; to increase the rate of burning coke at the tuyeres; and, by reducing ore in the stack, to lower the coke rate.

It can be calculated that for the same overall heat supply, the raising of blast heat from 800°C to 1,000°C is counterbalanced by the addition of 12·5 grains of steam to the blast and the rate of coke combustion is raised by about 5%. There is a further benefit to be derived from the fact that the moisture content of the blast is stabilised instead of being subject to the wide variations in the ordinary atmospheric air, particularly in tropical climates.

(*f*) *Oxygen additions*: Similarly, the enrichment of the blast by oxygen additions stimulates the rate of combustion of coke at the tuyeres and intensifies the temperature conditions. In consequence, the enrichment by oxygen demands concomitant additions of steam to maintain smooth working.

It can be demonstrated[7] that the enrichment of the air blast to 24·5% O_2 requires approximately 19·5 grains of water vapour per cubic foot of blast. It is estimated that the enrichment of the blast to 24·5% with its concomitant 19·5 grains/ft³ of blast at 800°C will give an increase of production of about 12½%.

This application is of special value where increased production of iron is desired without the building of further furnace capacity. At the present time, a large tonnage oxygen plant is being installed in the blast furnace section of the National Steel Corporation at Weirton, U.S.A.

Summary

The improvements in blast furnace economy which are to be achieved by the application of complete ore preparation, the use of 100% self-fluxing sinter, and high blast heat with steam addition can be judged from the comparison given in Tables I and II of the modern practice with the normal practice using unprepared burdens. In addition, the uniformity of materials used and operations gives a quality of pig iron which is much superior to that made by the normal varying conditions.

Application to Indian conditions

With the large tonnage of pig iron capacity under construction in India at the present time, it may be of interest to indicate how far these principles are applicable, in particular to the Durgapur plant.

(*i*) *Furnaces*: In planning a new steel plant, it is vital that the basic tonnage must be adequate to carry the capital charges arising from the heavy capital expenditure involved. Today, a production of one million tons of steel is regarded as the minimum initial tonnage and the installation should be planned to permit substantial expansion at minimum further expenditure.

The production of pig iron must be determined

---

[7] T. P. Colclough—J. I. S. I., 1958.
J. H. Strassburger—J. I. I. S., 1958.

TABLE I

Heat requirements in blast furnace comparison of typical practices.

Heat required per ton of metal	PRACTICE "A" Unprepared burden			PRACTICE "B" 100% Sinter	
	Heat of reaction B.T.U./lb	No. of lb	B.T.U × 10^3	No. of lb	B.T.U. × 10^3
A. Metal					
Reduction:					
Fe from Fe_2O ...	3,191	2,091	6,672·4		
Si from SiO_2 ...	12,176	17·9	217·9		
Mn from MnO ...	3,158	22·4	70·7		
P from P_2O_5 ...	10,843	14·5	157·2		
			7,118·2		7,118·2
Decomposition of phosphate ...	925·5	72·5	67·1		
Sensible heat of metal ...			1,142·0		1,209·1
Total for metal ...			8,327·3		8,327·3
B. Slag					
Decomposition of:					
$CaCO_3$	769	805	619·0	135	103·8
$MgCO_3$	551	92	50·7		
CO_2 liberated	402·4 lb or 3,460 ft^3			59·4 lb or 510 ft^3	
Reduction of CO_2 ...	1,595	241·4	385·0	25·6	40·8
Sensible heat	750	1,100	825·0	1,000	750·0
Total for slag			1,879·7		894·6
C. Water					
Evaporation	1,151	185	213·0	75	86·3
Decomposition	5,810	43·25	251·3	88	511·3
Total for water			464·3		597·6
D. Sensible heat of gas					
Gas	6·84 (@2,20°C)	12,200 ft^3	834·9	79,500 ft^3 (4·7 @ 150°C)	370·0
Water vapour ...	8·0	4,000 ft^3	32·0	2,315 ft^3	12·3
Total			866·9		382·3
E. Heat losses, etc. ...	(4·7%)		564·2	(4·5%)	477·9
Total heat requirement ...			12,102·4		10,679·7

by the process adopted for steel-making and the availability of other steel-making materials such as scrap. Since steels of all commercial qualities and some special steels are to be made at Durgapur, the steel is to be made by the open hearth method with prerefining of the hot metal by oxygen-blowing. The only scrap available will be that arising from the steel-making and rolling operation.

It is therefore essential that the pig iron must form the major part of the steel-making materials and will be of the order of 85% of the ingot weight.

In addition, Durgapur plant is designed to furnish a substantial tonnage of foundry iron for the iron castings industry.

The blast furnace plant therefore consists of three furnaces each of 27′-6″ hearth diameter—the middle of the modern size range—and with nominal capacity of 1,200 tons of liquid iron per day when operating on an unprepared burden of the quality delivered from Noamundi. The combination of two furnaces on basic iron and one on foundry iron will ensure that the liquid iron required in the steelworks will always be available even when any one furnace is off for repairs or relining.

The furnaces are designed for the installation of the valves necessary for high top pressures and the stoves have a capacity adequate to supply hot bast at a temperature of 800°C.

The equipment for steam additions to the air blast can be readily applied.

TABLE II

Heat balance. (Per ton of pig iron/2,240 lb).

		PRACTICE "A" Unprepared Burden B.T.U. × 10³		PRACTICE "B" Prepared Burden B.T.U. × 10³
Heat required				
Metal		8,327·3		8,327·3
Slag		1,879·7		894·6
Water-evaporation		213·0		86·3
Water-decomposition		251·3		511·3
Sensible heat of gas		866·9		382·3
Losses, etc.		564·2		477·9
Total		12,102·4		10,679·7
Heat generated				
Combustion of:				
C to CO_2	369·2 lb	5,371·9	423·6 lb	6,163·5
C to CO	1,136·8 ,,	4,945·0	636·3 lb	2,767·5
H_2 to H_2O	1·2 ,,	62·5	3·91 lb	203·5
Sensible heat:				
Blast temperature		600°C	56,000 ft³	800°C
Air 86,500 ft³		1,701·4	1,850 ft³	1,484·0
Water vapour 910 ft³		21·6		61·0
Total heat		12,102·4		10,679·5

TABLE III

New and existing blast furnace plants in India

	BUILDING			OPERATING	
	Bhilai	Durgapur	Rourkela	Indian Iron and Steel	Tata
A. *Ore Preparation at Works*					
Crushers	2	4	4	4	
Screening plant	Yes	Yes	Yes	Yes	Yes
Sintering:					
No. of machines	2	Provision for installation	Provision	Provision	
Capacity (tons/day)	3,000				5,000
B. *Blast Furnaces*					
No. and Hearth Diam.	3 at 23′8″	3 at 27′6″	3 at 24′3″	2 at 17′0″ 2 at 25′0″	6 at 17′6″ to 28′0″
Designed for High Top Pressure	3	3		2 at 25′0″	28′ only
Nominal capacity tons/furnace day	1,135	1,200	1,000	700 to 1,200	650 to 1,650/2,000
Coke rate lb/ton	2,040	1,900	1,940	2,200 to 1,900	2,000 to 1,900

(*ii*) *Ore preparation*: India is extremely fortunate in its enormous reserves of rich iron ore. With the abundant supply of labour and the methods of mining employed at Noamundi, it is not necessary for the initial levels of pig iron production to install ore preparation plant.

The ore storage and handling plant under installation at present is designed to give ample capacity for further expansion and adequate mixing of supplies from different sources.

It is accepted that the growth of iron production in India will necessitate the installation of mechanical diggers and it will be increasingly difficult to maintain the present high standard of small size clean ore free from clay.

At this stage, or when increased production is required at Durgapur, it will be desirable to install ore crushing and screening plant, either at Durgapur or at the mines, and sinter plant for self-fluxing sinter at Durgapur. The layout is specially designed for this development.

It is estimated that with the full preparation of the ore, use of self-fluxing sinter and other techniques, the capacity of the furnaces can be increased by at least 35%.

For purposes of reference, the information available as regards the provision made or equipment installed for ore preparation and the size of furnaces in use or being built in India, is given in Table III. It will be apparent that given the application of the modern techniques to these new furnaces, there is a substantial latent capacity, and that the production of iron can be expanded to a considerable extent, without the building of further furnaces, as the demand increases.

DISCUSSIONS

Mr. B. L. Sen, N.M.L., Jamshedpur: Humidification of the blast has been referred to in the paper. At the temperature prevailing at the top of the blast furnace, this will result in the generation of a practically equivalent amount of steam that is introduced through the blast. I would like to ask Dr. Colclough if this additional quantity of steam will have any effect on the refractory lining of the furnace near about the top of the furnace where this is not utilised for any reduction purpose. My second question is regarding enrichment of the blast by oxygen alone. There is likelihood of a steep temperature gradient resulting in the concentration of a very high temperature reaction zone in case of O_2 injection alone. In view of the high alumina and silica contents of our raw materials, is there any possibility of the Si content rising still higher in the pig iron because of the oxygen addition alone to the blast accompanied by change in viscosity of the slag?

Dr. T. P. Colclough (Author): My answer to your first question is definitely—No. The reason is that with the full preparation of the burden, passing all the fines through the sinter plant, the amount of steam added to the blast is probably less than the quantity of water introduced in the furnace by using wet ores, for example. In this process, you just reduce the quantity of water involved and add some of it at a more appropriate place where it can do useful work.

As regards your second question, I would say that oxygen enrichment does not automatically mean any change in Si content. I indicated that as you raise the temperature of the blast, you go beyond the optimum working point of the furnace and you then have to add steam to restore optimum conditions. The same thing exactly applies in case of O_2 enrichment. As you have mentioned, oxygen addition intensifies the combustion conditions beyond the optimum and steam must be added in order to bring us back to this optimum, because smooth working gives much lower coke rate than any other factor. One very important point, to be borne in mind, is that when you are operating with high blast temperature or with O_2 enrichment, and you have the inevitable addition of steam to make to the blast, you then have in hand the most powerful weapon for the control of silicon. It should be remembered that if you want to change the thermal conditions in the blast furnace hearth, by present methods, you alter your ratio of ore to coke. If the furnace is too hot you do reduce the blast temperature temporarily but you alter your charge and it might take 6 to 12 hours to produce the required effect, by which time your coke is altered and you are ultimately not in a position to check upon the change. Now if on the other hand you regulate the steam by merely turning the regulator, you can within 10 minutes change the temperature conditions at the tuyeres, which control the Si content. Briefly, the enrichment with oxygen does not automatically effect any change in Si. You must control the conditions by steam addition, and suitably varying it you can counteract some of the evils caused by changes in the quality of coke or ore.

Dr. B. R. Nijhawan, Director, N.M.L.: From some of my observations in Russia, the net effect of a 26% enrichment is a considerable decrease in the temperature of the shaft. Moisture addition lifts up the temperature zones so that advantages of both O_2 enrichment and blast humidification are combined. 10 grains of moisture are added per cft., raising the temperature to about 200°C. For an addition of 30 gr. moisture per cft. the working temperature is round about 1,000°C and it is proposed to raise this to about 1,200°C. It thus appears that oxygen injection is damaging so far as it relates to lowering of temperature in the upper regions of the blast furnace but it intensifies the combustion zone and extends it considerably, which improves the annular condition for the purpose of rise of gases through the furnace.

Dr. Colclough (Author): I am particularly interested and stimulated by your comments and I agree entirely with what you have said. In fact we do not have enough knowledge of what happens in the stacks of the blast furnace, and at the British Iron and Steel Research Association where I happen to be the Chairman of the Iron Making Division, we shall be starting a series of tests to simulate the conditions of a blast furnace temperature and ascending gas—and we hope to obtain some information on that before very long. The point in my mind is that when you enrich with oxygen you must also add steam and it is inevitable that the first effect is that the isotherms will form somewhat lower in the blast furnace. On the other hand, the ascending gases enriched by H and CO from the water gas reaction cause an increase of iron oxide reduction in the stack, and the liberation of heat of oxidation of CO to CO_2, makes it quite possible, in fact probable, that these isotherms will be raised. We shall thus have the two conflicting elements and we shall be highly interested in the U.K. to know the results of the experiments you are carrying out here in India and we will naturally communicate with you about our own work which I hope will be started by March or April this year.

Dr. M. N. Dastur, Messrs Dastur and Co., Calcutta: The author has given an excellent review of developments in blast furnace practice. In this connection a slide was projected showing different sizes of furnaces correlated to the size of the "dead man" in the centre of the furnace for each size. In a 13′ hearth diameter furnace the active zone spread across the entire hearth—there was no "dead man" in the centre, and it progressively increased with the size of the furnace. I would like to ask the author if there is an optimum size (35′ or 40′ or more) beyond which it will become impossible to operate the furnace due to too big and inactive a zone in the centre.

Dr. Colclough (Author): There obviously is an optimum size for a blast furnace but it cannot possibly be laid down from theoretical grounds. Every case must be examined on its own merits and in determining the size of a blast furnace there are many other factors to be considered besides the size of the dead man in relation to the total hearth area and it has been proved by a matter of long experience that a furnace in the neighbourhood of 27′-30′ gives a good operating productivity. Another factor to be kept in mind is that you might make all the iron you want by going to a 34-foot furnace, but there will be an element of uncertainty in its operation and as a blast furnace must come off from time to time, say for relining, it is not practical to lay down a theoretical optimum for its size.