1. Blast Furnaces

C. General
The Future of Ironmaking

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Four years ago, at the meeting of the Blast Furnace, Coke Oven and Raw Materials Committee in Cleveland, in a paper entitled Ironmaking—Past Achievements, Present Limitations and Future Prospects, J. M. Stapleton and his associates made a prediction that within a few years some of the furnaces then operating would produce 3000 tpd and that not too many years later, with the aid of beneficiated materials, oxygen and very high top pressures, production rates of 4000 thm per day could be foreseen.

Today, we plan to be a little more specific in showing how and when the second portion of this prediction will come true, using as a basis for this forecast the average operating statistics for the 10 American iron and steel industry blast furnaces that are topmost in production rate.

Table I shows the operating statistics for the 10 leading furnaces for 1957 (the year used in the previous paper) and for last year, 1961. In this four-year interval, the average production rate increased from 1729 to 2190 thm per day and the coke rate decreased from 1484 to 1248 lb of coke per thm. However, in 1961, 32 lb of tuyere injected hydrocarbon fuels per thm were used in addition to the coke. Other changes within the four years were an increase in hot blast temperature from 1177°F to 1590°F, in top pressure from 3.9 to 6.2 psig, and in wind rate from 93.8 to 100.1 Mscfm. Another significant change was a drop from 527 to 361 lb per thm in the amount of raw flux used.

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TABLE I
Average Annual Operating Statistics

<table>
<thead>
<tr>
<th></th>
<th>1957</th>
<th>1961</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production rate, NTHM per day</td>
<td>1729</td>
<td>2190</td>
</tr>
<tr>
<td>Coke rate, lb, per NTHM</td>
<td>1484</td>
<td>1248</td>
</tr>
<tr>
<td>Tuyere injected fuel, lb per NTHM</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Hot blast temperature, °F</td>
<td>1177</td>
<td>1590</td>
</tr>
<tr>
<td>Top pressure, psig</td>
<td>3.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Wind rate, Mcfpm</td>
<td>93.8</td>
<td>100.1</td>
</tr>
<tr>
<td>Raw flux rate, lb per NTHM</td>
<td>527</td>
<td>357</td>
</tr>
</tbody>
</table>

Offhand, one might attribute a large portion of the production rate increase to furnace enlargements, but the average for the 10 leading furnaces given in Table II shows an increase of only 3 in. in the hearth diam, from 28 ft 4 in. to 28 ft 7 in. The average working volume increased from 48,129 to 48,738 cu ft, only 609 cu ft. Although the hearth diameter and working volume increased slightly, the working volume to hearth area ratio decreased from 76.4 to 76.0. These dimension changes are small and one can safely say that the gains achieved are caused by other factors.

TABLE II
Average Furnace Size

<table>
<thead>
<tr>
<th></th>
<th>1957</th>
<th>1961</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearth diameter, ft-in.</td>
<td>28 ft 4 in.</td>
<td>28 ft 7 in.</td>
</tr>
<tr>
<td>Hearth area, sq ft</td>
<td>629.6</td>
<td>641.5</td>
</tr>
<tr>
<td>Working volume, cu ft</td>
<td>48,129</td>
<td>48,738</td>
</tr>
<tr>
<td>Working volume per hearth area ratio</td>
<td>76.4</td>
<td>76.0</td>
</tr>
</tbody>
</table>

As a matter of interest, Table III shows the average daily production rate per sq ft of hearth area and per cu ft of working volume. The net thm per day per sq ft of hearth area increased from 2.75 to 3.41 and the tons per 100 cu ft of working volume from 3.6 to 4.5.

TABLE III
Daily Production Rate vs. Hearth Area and Working Volume

<table>
<thead>
<tr>
<th></th>
<th>1957</th>
<th>1961</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTHM per day per SFHA</td>
<td>2.75</td>
<td>3.41</td>
</tr>
<tr>
<td>NTHM per day per 100 CFWV</td>
<td>3.6</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Between 1957 and 1961 the increase in production rate was 6 pct per yr compounded annually, or 27 pct for the four-year period. If this rate of increase continues, the average production rate for the 10 leading furnaces should reach 4,000 tpd by 1972 without a drastic change in furnace size. Figure 1 is a graphical plot showing the effect of the 6 pct per yr increase on the average daily production rate.

To reach the predicted goal of 4000 tpd, several operating improvements will have to be made during the next 10 years. Actually, some plants are already making plans for installing the equipment required to effect these improvements. The most important of these are as follows:

1. Increase in hot blast temperature.
2. Incorporation of more of the flux in the agglomerates.
3. Greater uniformity in the chemistry and size consist of the coke and iron bearing materials.
4. Increase in top pressure.
5. Oxygen enrichment of the blast.

These changes will not take place to the same extent at each of the 10 leading furnaces because some of these furnaces are already more advanced than others in the use of higher blast temperature, in the amount of flux incorporated into agglomerates, and the improvement of burden size-consist. For example, in 1957 when the average annual production rate for all 10 furnaces was 1729 tpd, one of the furnaces had an average production rate as high as 2284 tpd for one month and in 1961, when the average annual production rate was 2190 tpd, one furnace showed an average production rate of 2946 tpd for a full month.
Although we will discuss the changes in the order in which we have listed them, we do not intend to imply that they will necessarily take place in this order. Many of these changes are taking place right now and will continue for several years. In fact, some of them may actually take place simultaneously.

Increase in Hot Blast Temperature

In 1961 the average hot blast temperature for the 10 leading furnaces was only 1590°F; however, several plants have already demonstrated that hot blast temperatures above 1800°F are quite feasible with the present stoves and hot blast systems. With the use of super-duty refractories in the top portion of the stoves, and with adequately sized burners, hot blast temperatures of 2200°F will be possible. Improvements that are now being made in the design of the hot blast system, including valves and valve cooling systems, will permit satisfactory operation at these elevated temperatures.

Although several years ago difficulty was encountered with hanging and slipping when the hot blast temperature exceeded 1200°F, recent advances in blast furnace technology have shown that the hot blast temperature can be increased to much higher levels without interfering with burden movement, if moisture or hydrocarbon fuels are injected at the tuyeres to control the flame temperature and the amount of carbon monoxide (CO) and hydrogen (H₂) in the bosh gas.
The production rate was calculated by providing enough reducing gas through moisture additions to keep the ratio of direct and indirect reduction fixed while the temperature was increased. Injected fuels could also be used for this purpose. As shown in Figure 2, increasing the hot blast temperature from 1590° to 2200°F will increase the production rate 22 pct of the amount required to attain 4000 thm per day and the coke rate will decrease 6 pct if moisture is used as the tuyere injectant. If natural gas is used, the effect on the production rate will be the same, but the coke rate will decrease to a greater extent.

**Incorporation of More Flux in the Iron-Bearing Agglomerates**

Between the years 1957 and 1961 the amount of raw flux charged into the blast furnace was decreased from 527 to 357 lb per nthm. Further decreases in the amount of raw flux charged can be expected by 1972. Accordingly, less CO$_2$ will be evolved by calcination of stone so that the indirect reduction of FeO will be favored. The net effect of the decrease in raw flux charged will be a 4 pct increase in production rate and a 10 pct decrease in coke rate.

**Improvement of the Size-Consist of the Iron-Bearing Materials**

In the year 1957 only a small percentage of the burdens used in the leading 10 blast furnaces was beneficiated, but by 1961, 74 pct of the material used in these furnaces was agglomerated in one form or another. The balance of the burden in 1961 consisted of 18 pct screened and 8 pct unscreened ore. Examination of the operating records for the furnaces using different types of agglomerates show that burdens containing high percentages of good quality pellets were much more permeable than burdens containing high percentages of sinter, as was evident from the higher wind rate and lower pressure drops across the pellet burdens. The effect of the different sized materials on burden permeability, that is, the burden resistance index, can be calculated from the blast furnace operating data by means of the formula proposed by Ergun.$^3$

Ergun’s formula states that the difference between the squares of the blast pressure and the top pressure in absolute units is equal to the resistance of the burden at the average gas temperature in the furnace times the square of the wind velocity (wind rate divided by the average cross-sectional area) times the working height. Since the average cross-sectional area is the working volume divided by the working height, the equation can be simplified to the following expression:
\[(BP)^2 - (TP)^2 = (\text{Burden Resistance Index}) \times (WR)^2 \times \frac{(WH)^3}{(WV)^2}\]

BP = blast pressure, psia
TP = top pressure, psia
WR = wind rate, scfm
WH = working height, ft
WV = working volume, cu ft

By applying this formula to the 1961 monthly operating results for different blast furnaces, the burden resistance index for ordinary sinter burdens (75 to 95 pct sinter) was found to be about $6.0 \times 10^{-4}$ and for pellet burdens only about $4.4 \times 10^{-4}$. The average burden for the 10 leading furnaces for the year 1961 had a burden resistance index of $5.3 \times 10^{-4}$.

![Size Range](attachment:image.png)  

**Fig. 3.** Size-consist of sinter and pellets.

With the pellet type burden resistance index of $4.4 \times 10^{-4}$, the average wind rate can be increased from 100,100 to 110,000 scfm without increasing the average pressure drop (blast pressure minus top pressure) across the burden. Under these conditions, the furnace will continue to move satisfactorily in spite of the higher wind rate.

Figure 3 is a plot of the typical size of sinter, as is normally found in the blast furnace stockhouse bins, and of pellets. Note that, if the minus $\frac{3}{8}$-in. portion of the sinter were removed by screening prior to charging in the blast furnace, the size consist of the sinter and the pellets would practically coincide.
We believe that by 1972 the burdens of the 10 leading furnaces will consist of all pellets or all sinter, and in some cases, combinations of these two. When sinter is used, the fines will be removed by screening to produce a size-consist and a burden resistance index similar to that of pellets. Sinter will remain as a prime blast furnace charge material for some time because of the large number of sintering plants now in existence. Advances will be made in the sintering technique to improve further the quality of the sinter product. Blending the sintering plant ores so that the chemical uniformity of the sinter will approach that of pellets is also necessary if the blast furnace performance with sinter is to
equal that with pellets. In general, there has been a gradual trend toward increasing the amount of pellets in the burden relative to the amount of sinter. Figure 4 shows the per cent of sinter and the per cent of pellets in the blast furnace burdens for the entire American steel industry between 1957 and 1960. In 1957, the ratio of pellets to sinter was only 0.18, but in 1960 it had increased to 0.34. Another burden that we expect will have a permeability almost equal to that of pellets is hot briquetted ore. Hot ore briquetting is the process that was described by R. G. Thompson at last year's meeting.

A more dramatic way of displaying the effect of the size of the burden materials on the relative resistance to gas flow was demonstrated by Joseph in 1934. His curve, Figure 5, shows that the resistance to gas flow varies inversely as the 1.2 power of the average particle diameter. The curve clearly indicates that the greatest benefits will be attained when the particles smaller than \( \frac{3}{8} \) in. (0.371) are removed. The relative resistance to gas flow increased only slightly as the particle size decreased from 1.05 to 0.371 (approximately \( \frac{3}{8} \) in., but increased rapidly with decreasing size below \( \frac{3}{8} \) in. (0.371).

The elimination of the extremely fine particles (minus \( \frac{3}{8} \) in.) from the burden will also have a beneficial effect on the distribution of the reducing gases in the furnace so that lower coke rates will result. It is difficult to determine from purely theoretical considerations the size of the savings that can be obtained from the elimination of these fines; consequently, we have assumed that the change in coke rate will be similar to that reported by Macdonald last year.

As an over-all effect of proper burden sizing, the production rate should increase about 20 pct of the goal and the coke rate will decrease about 15 pct.

**Improvement of the Size-Consist of the Coke**

There is no report to indicate whether there was a change in the size-consist of the coke used between 1957 and 1961, but we believe that no significant changes occurred during these years.

Recent tests in which the coke was sized to a narrow range (75 pct in the \( \frac{3}{4} \)-in. to 2-in. size range with a median size of 1.66 in.) showed that the wind rate could be increased and higher production rates could be obtained when the more closely sized coke was used with burden materials screened to an improved size-consist.

These tests demonstrated that with properly sized coke the wind rate can be increased more than 5 pct. Five per cent additional wind will increase the production rate 8 pct of the goal.
Along with the improved size-consist, it is important that the chemical and physical properties of the coke be of the highest quality. During 1961, the coke used by the 10 leading furnaces averaged about 8.25 pct ash, 0.70 pct sulfur, and had an average ASTM stability of approximately 58. We agree that the ASTM stability test may not be a true measurement of a coke's physical strength, but it is the best parameter at the present time. Regardless of the method of measurement, the coke must be sufficiently strong to resist degradation within the furnace. The 1961 average coke chemistry was fairly good, but if the ash and sulfur content were lowered, the slag volume would decrease and so would the hot metal sulfur, a decided advantage in the production of quality steel.

**Increased Top Pressure**

Although the beneficial effect of top pressure on production rate has been known for some time, the average top pressure for the leading 10 furnaces was only 6.2 psig in 1961. We believe that the reason for not using higher pressures has been the difficulties encountered with maintenance of suitable seals on the bells and bleeders. However, recent studies have shown that it may be quite possible to operate with top pressures as high as 30 psig, and at least one furnace in this country is now being designed for this type of operation.

With such high top pressures, the tuyere pressures will increase almost proportionately to the top pressure so that the energy required for compressing the blast will increase significantly. This will greatly increase the cost of compressing the blast unless some of the energy of compression of the top gas can be gainfully recovered. However, recovery of this pressure appears to be quite feasible and several blower manufacturers are investigating the possibility of using expanding turbines to help supplement the power input to the blast furnace blower when operating with such extremely high top pressures.

Using the formula proposed by Ergun, it is possible to calculate the extent to which the wind rate can be increased for changes in top pressure. At 30 psig top pressure, the wind rate can be increased to 154,000 scfm, as illustrated in Figure 6, without increasing the pressure drop \((\Delta P)\) across the burden to more than 19.7 psi, the average for 1961. As the throughput rate of the burden increases, the retention time decreases. With such extremely short throughput times, we may find it necessary to increase the CO content of the bosh gas. If this is the case, the per cent increase in production rate will not be quite as great as the per cent increase in wind rate. Past studies have shown that as the wind rate increases, the amount of reducing gas in excess of that required for
chemical equilibrium is almost exactly proportional to the rate of throughput of the solids.

Consequently, in determining the effect of top pressure on production rate, the increase in reducing gas requirement has been taken into account. Considering all of these factors, calculations show that an increase to 27.5 psig top pressure will permit the attainment of 100 pct of the predicted production goal of 4000 tpd.

Figure 7 illustrates the effect of increasing top pressure on the production rate. At the wind rate indicated in Figure 6, a production of 4000 thm per day can be achieved at a top pressure of about 27.5 psig.
Although a considerable portion of the increase in production rate will result from the use of higher top pressures, some people may be skeptical about the prediction that by 1972 as many as 10 blast furnaces will use top pressures as high as 27.5 psig. The expense of equipping the furnaces for pressures this high and the cost of maintaining this equipment may be so great that alternate methods for increasing the production rate to the 4000 tpd level may look more attractive. Recent tests at the Pueblo, Colorado, plant of the Colorado Fuel & Iron Corporation have shown that the production rate can be increased with oxygen enrichment if fuels are injected in the tuyeres simultaneously. Calculations show that with a top pressure of only 20 psig it should be possible to obtain the production rate of 4000 tpd by increasing the oxygen content of the blast and increasing the amount of fuel injected at the tuyeres. Figure 8 shows that 100 pct of the predicted production rate can be attained by increasing the oxygen content of the blast to about 23 pct with a top pressure of 20 psig.

Furnace Size

Between 1957 and 1961, the furnace hearth diameter increased at the approximate rate of one inch per year. At this rate of increase, as shown in Table IV, the 10 leading furnaces will have an average hearth diameter of 29 ft 6 in. in 1972. As shown, the hearth area will increase to 683.5 sq ft. The rate of increase in working volume of 609 cu ft in four years is not enough to give a suitable working volume for the anticipated high
production rates. The working volume of the 29 ft 6 in. hearth diameter furnace should be at least 52,500 cu ft, making the working volume to hearth area ratio 76.8. We believe that the increase in volume should be made without increasing the furnace height.

<table>
<thead>
<tr>
<th>Present and Projected Furnace Size</th>
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<tbody>
<tr>
<td><strong>Hearth diam, ft-in.</strong></td>
</tr>
<tr>
<td><strong>Hearth area, sq ft</strong></td>
</tr>
<tr>
<td><strong>Working volume, cu ft</strong></td>
</tr>
<tr>
<td><strong>Working volume per hearth area ratio</strong></td>
</tr>
</tbody>
</table>

**Furnace Casthouse**

The high production rates of 1972 will require about 10 casts per day, averaging about 420 tons per cast. Using a 3 in.-diam tap hole, this would require about 10 hr of tapping time each day. Since such a schedule would allow only 1 1/2 hr between casts, 2 tapping holes will be required to allow time for preparing the troughs, tap holes, dams, and skimmers between casts.

Unless two casthouses are provided, the common runner system to the hot metal ladles will be the crucial part of the hot metal handling system, because only one hour and 25 min. will be available between casts to prepare this particular runner section. To overcome this problem, better hot metal runner-lining material will be needed (a number of these are now being tested) or spare runner sections that can be easily interchanged by means of the overhead casthouse crane. An alternate would be to have two completely separate runner systems utilizing three hot metal ladle tracks, with the center track common to both runner systems.

The furnace will require two cinder notches, but if a common slag runner is used only about one hour and 25 min. preparation time will be available. Runner lining materials must be improved and the method of clean-up and placement of runner lining material must be mechanized. This could be done with a mechanized car similar to a modern ditch digger with a shovel head formed to fit the contour of the runner.

To eliminate flushing delays, a mechanical device will swing into the exact position and punch or drill through the slag notch skull similar to the presently installed remotely controlled iron notch drill-out devices. The same device could also be used to bott the slag notch at the conclusion of the flush.
The slag disposal will have to be independent of intermittent transportation service. We believe that the hard slag pits are best suited to handle this large quantity of slag without interference with furnace operations.

The hot metal ladles should be as large as practical, having a capacity of at least 250 thm. The larger the ladles, the shorter will be the hot metal runner systems. This will reflect itself in shorter preparation time.

**Furnace Charging**

A furnace can produce only to the limit of its charging facilities. To produce 4000 thm per day, skip cars having a minimum capacity of 450 cu ft will be required. For skips of this size, alterations to the skip incline bridges, pits and skip dumping arrangements will have to be made on a number of existing furnaces that would otherwise have the dimensions adequate for this amount of hot metal production.

The scale car in the stockhouse may be too slow to accomplish the skip filling in the allowable time and may have to be replaced by conveyor belts which both weigh the burden materials and automatically charge the skips, directly from the bins, or which feed the material to weigh hoppers which in turn discharge into the skips. A few installations of this type are already in use and several more are being installed.

In some instances, the furnace charging may be completely accomplished by conveyor belts similar to the installation currently in operation in the USINOR plant at Louvroil, France.

**Summary**

We have attempted to show that a production of over 4000 thm per day will be possible from a conventionally sized blast furnace in the next 10 years. Figure 9 is a graphical plot showing in a step-wise manner the increase in production rate versus the operating change made. We have deliberately been conservative in stating the tonnage possibilities for 1972.

Table V lists the average daily production rates per unit of hearth area and working volume for the year 1961 compared with the figures projected for the year 1972. The production per day per square foot of hearth area will increase from 3.41 to at least 5.85, and the tons per day per 100 cu ft of working volume will increase from 4.5 to 7.6 tpd.

Occasionally we hear of promising new direct reduction processes, but for almost every one of these the operating expense is too great for the new process to succeed in its originally conceived form. We believe that
when new and improved process features are developed the blast furnace will be modified to incorporate these processes, as has been done with elevated pressure and fuel injection. In this way, the blast furnace will improve in productive capacity and efficiency.

From the foregoing, it should be quite evident that the blast furnace is not to be relegated to a role of oblivion, but rather is on the threshold of an entirely new era, an era that will be matched in adventure only by man's space explorations.

TABLE V
Daily Production Rate vs. Hearth Area and Working Volume

<table>
<thead>
<tr>
<th></th>
<th>1961</th>
<th>1972</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTHM per day per SFHA</td>
<td>3.41</td>
<td>5.85</td>
</tr>
<tr>
<td>NTHM per day per 100 CFWV</td>
<td>4.5</td>
<td>7.6</td>
</tr>
</tbody>
</table>

References

1. Private communication.
4. Internal sources.


**Discussion**

**C. M. Horan** (*The Youngstown Sheet & Tube Co., East Chicago, Indiana*). There is no question as to the magnitude of work and responsibility we must assume in our future operations. Certainly, the goals are extremely high, but, with sincere effort, are attainable.

After reading *The Future of Ironmaking*, I reviewed a paper, *Blast Furnace Progress and Design*, presented by the Blast Furnace and Coke Oven Assn. of Chicago in 1930 by Harry Strain, Pat Boynton, Hjalmar Johnson and others, and discussed by such outstanding blast furnace personalities of that era as Pete Mauthe, Bill Geesman, Frank Thacher, Bill Unger, Arthur McKee, Jim Fulton (the outstanding Wet Blast advocate of the day), and Larry Riddle (the outstanding Dry Blast advocate of the era).

This paper was quite remarkable, as tonnages had increased approximately 300 pct in the era of 1900–1930, and at that time they were designing a model 1000-tpd furnace. Such a figure, if attained, would create many problems such as filling capacity, blowing capacity, hot blast, and hot metal handling. Beneficiation was being developed in the form of sinter. I recently learned that Tiny McMahan was running screen tests on sinter at Lorain during that period. It all resembles closely the paper under discussion.

So, 30 years later, we review progress and tonnages again increased about 300 pct. Certainly, these gentlemen set the pattern for our present blast furnace practice which has been developed in these three past decades; now we are developing the pattern which must be followed in the future.

There is no question in my mind that a right combination of materials, equipment, engineering, and a dedicated blast furnace personnel will achieve these predicted tonnages. However, I wish to state that hot metal handling will certainly present a challenge, as we at Indiana Harbor have experienced quite a problem in handling tonnages of 2800–3000 per day. I am certain the additional 1000–1200 tpd will demand an extremely vigilant attitude by the furnace personnel.

With a final remark, blast furnaces will be relegated to a role of oblivion instead of matching adventures into space if the operators fail to handle correctly that most precious metal—pig iron.