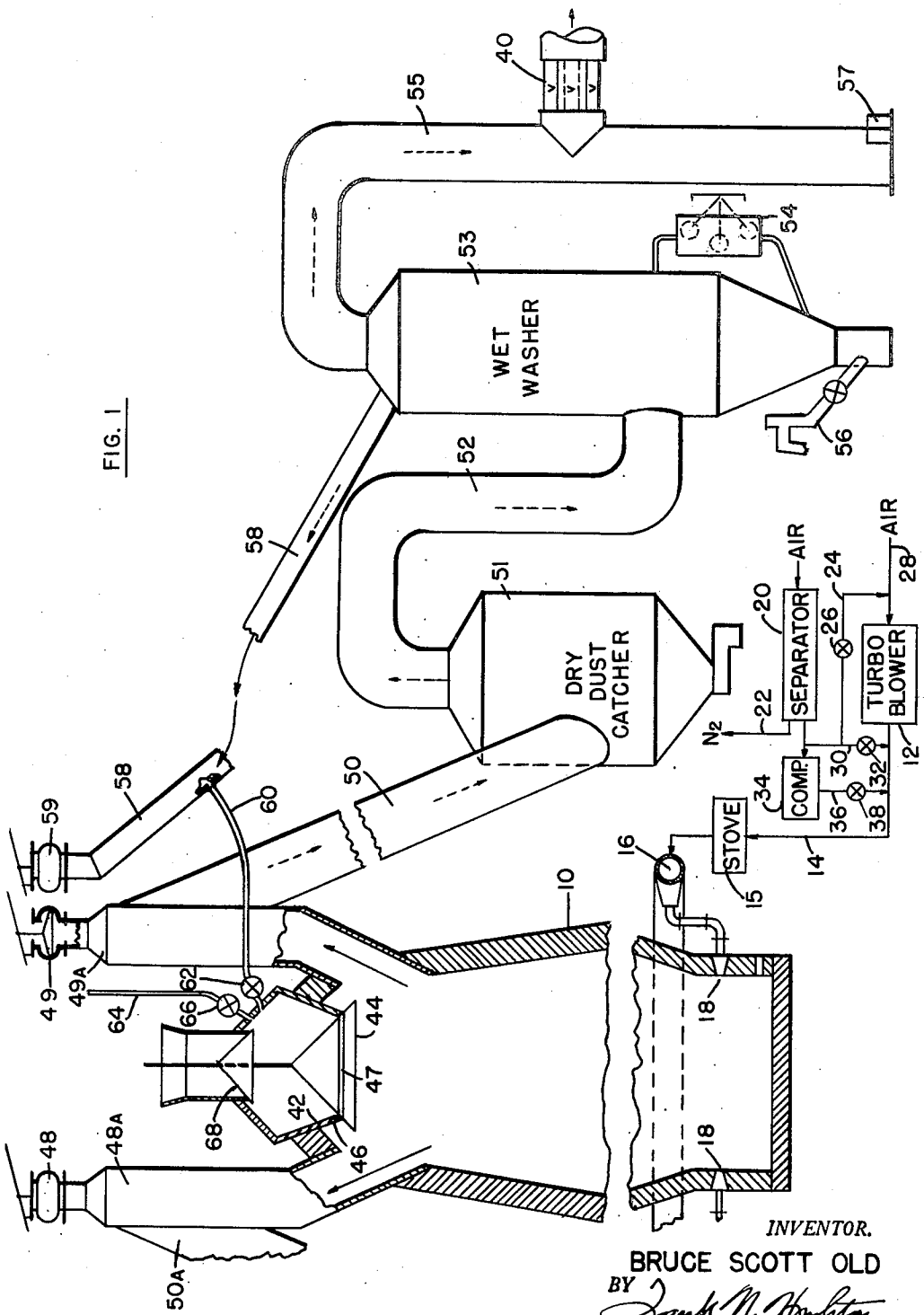
July 1, 1952 B. S. OLD 2,602,027

METHOD OF OPERATING BLAST FURNACES

Filed May 6, 1947 3 Sheets-Sheet 1

FIG. 1



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July 1, 1952 B. S. OLD 2,602,027

METHOD OF OPERATING BLAST FURNACES

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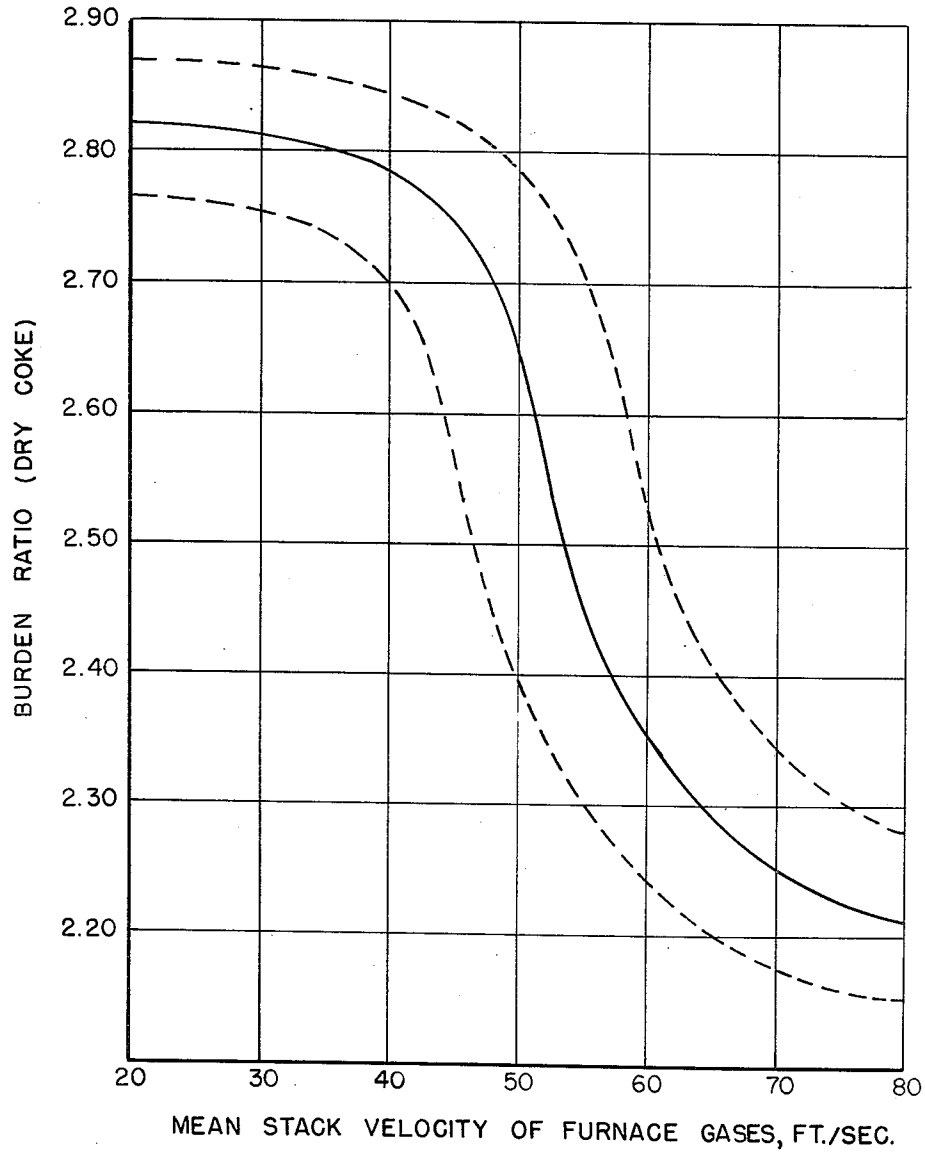


FIG. 2

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METHOD OF OPERATING BLAST FURNACES

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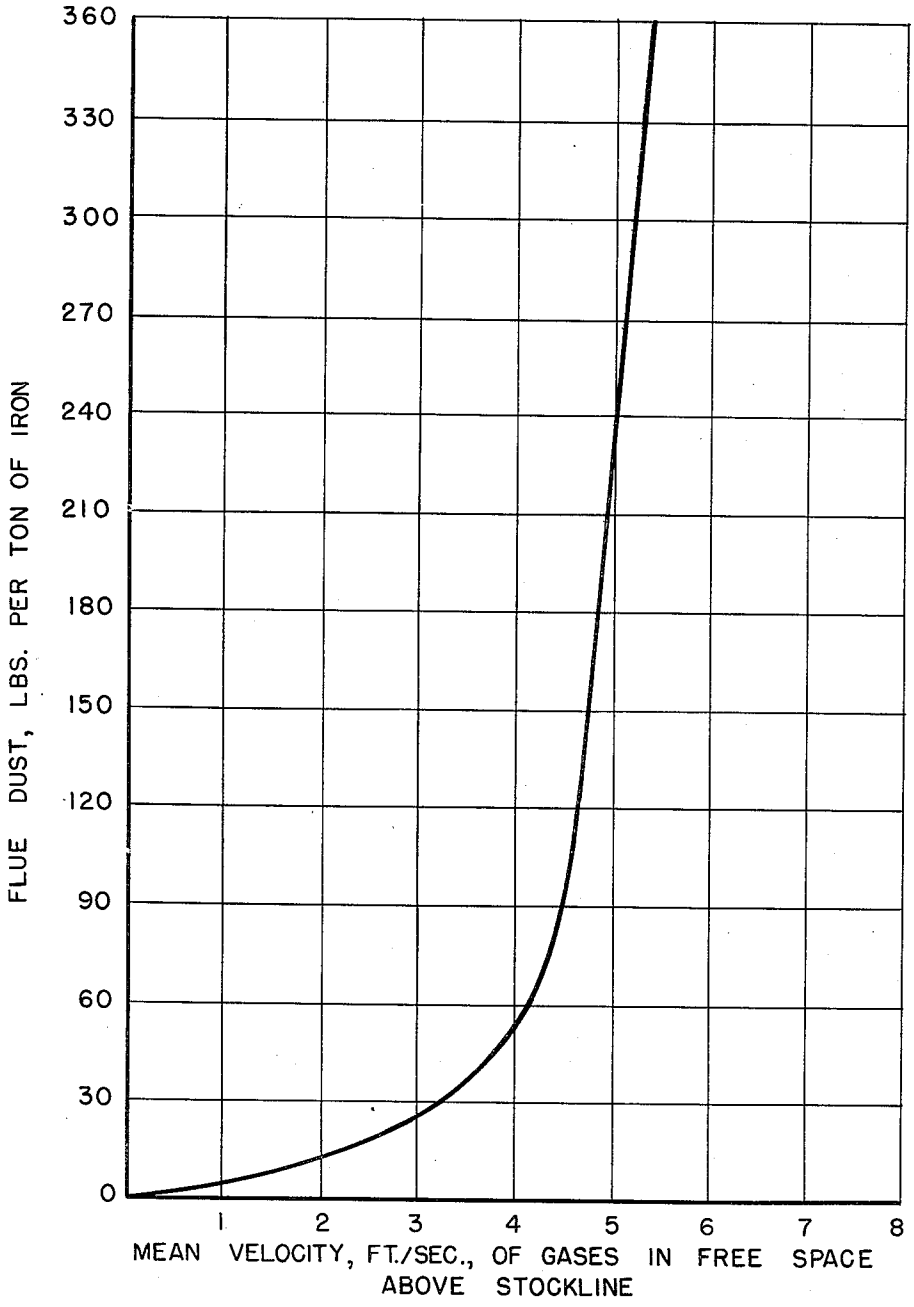


FIG. 3

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Patented July 1, 1952

2,602,027

UNITED STATES PATENT OFFICE

2,602,027

METHOD OF OPERATING BLAST FURNACES

Bruce Scott Old, Concord, Mass., assignor, by mesne assignments, to Republic Steel Corporation, Cleveland, Ohio, a corporation of New Jersey

Application May 6, 1947, Serial No. 746,220

4 Claims. (Cl. 75—41)

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This invention relates to the operation of blast furnaces under internal pressures substantially greater than those normally employed.

In his U. S. Patent 2,131,031, patented September 27, 1938, Julian M. Avery has set forth the principles of blast furnace operation at increased internal pressures, and has described the manner of doing so and the advantages attained thereby. The procedure set forth in that patent includes, among other things, supplying the blast feed gas at a sufficiently high superatmospheric pressure, and throttling the gas discharge from the furnace, to create the desired pressure within the furnace. This desired pressure may range anywhere from about one to about ten atmospheres gauge, with advantageous operating results.

The procedure of the said Avery patent has already been adopted in some existing blast furnaces, with excellent results. Those furnaces, as would be expected, were designed and built for the normal average internal operating pressures of ¼ to 1 atmosphere gauge, and pressures within the range of the Avery patent are attained by increasing the blowing pressure and installing throttling means upon the exit gases from the furnace.

Present practical considerations require that operations under the Avery patent, with presently available equipment, be carried out within the lower part of his pressure range. This is accomplished by using blowers capable of delivering the blast at say 30 to 40 p. s. i. g. (pounds per square inch, gauge) and imposing a top pressure of up to say 20 p. s. i. g. upon the exit gases. The resulting average internal pressures in the furnace are consequently between about 1-plus and 2-plus atmospheres gauge. While many existing furnaces can safely withstand somewhat higher internal pressures, it is at present either impossible, or exorbitantly expensive, to obtain blowers which will provide adequate wind at pressures in excess of about 40 p. s. i. g.

Although higher-pressure furnaces with greater blowing capacity may well be built in the future, practical considerations limit the procedure of the Avery patent for the present to the existing types of furnace, wherein suitable modifications in blowing capacity and in the throttling and handling of the exit gases are employed for increasing furnace pressure. Nevertheless, it would be highly advantageous to attain in existing furnaces the increased benefits which would flow from the operation of the Avery process under still higher pressures and rates of blowing.

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It is now found, in accordance with the present invention, that such benefits may be attained, by proper control of operating conditions, while still operating the furnaces at the above-stated pressures of 30 to 40 p. s. i. g. blast and up to 20 p. s. i. g. top pressure, or thereabout. Also, and within the scope of the present invention, it is possible to improve production, operations, and economies over those set forth in the Avery procedure, when operating at higher pressures within his range (e. g. up to 7 atmospheres gauge average static pressure), as well as at the lower pressures (e. g. 2 atmospheres gauge, average static pressure) at which the present type of furnaces can be operated.

The procedure of the present invention also makes possible the utilization of the finer particle size ores which increasingly constitute the major reserves because of the depletion of higher-grade ores. And furthermore, even when using such finer ores, the procedure of this invention assures that the amount of solids in the exit gases (i. e. flue dust) is maintained well below that occurring with normal operation.

These several advantages are brought about, in accordance with the present invention, by the proper control of certain operating variables within specified limits, as set forth below. These operating variables are, in particular, the velocity of the gases through the furnace, and the burden ratio.

The principal economies which can be realized in the operation of a blast furnace with the present invention are those incident to increasing iron production; decreasing coke rate; decreasing flue dust production; and obtaining more uniform iron quality with a lesser per cent of casts falling outside specification limits. Proper control of the mean linear stack velocity of the reducing gases within the interstices of the furnace charge makes possible a substantial increase above normal in the amount of wind blown per unit of time and hence in the iron production of the furnace; it also increases the thermal efficiency of the furnace by increasing the efficiency of heat transfer and decreasing the heat losses per ton of iron produced. In addition, I have found that this control of gas velocity makes it possible to increase substantially the burden ratio with resulting fuel economy; to carry higher blast temperatures which further effects coke saving; to decrease the pressure drop through the furnace stock column to bring about smoother operation with less slipping and hanging; and to minimize markedly the dust blown out of the furnace. For

the greatest overall economy this control can best be exercised through enriching the air blast with oxygen while maintaining the highest average pressures that the shaft of the furnace is capable of withstanding, by throttling the exit gases. In accordance with the preferred embodiments of my invention, I now describe in what follows the operation of a modern type blast furnace. The normal amount of wind blown per minute (or normal blast rate) referred to above is the normal blast rate at which a given furnace is designed to operate using top pressures of not over about 2.5 p. s. i. g. Methods of calculating such blast rates are well known and are used by all steel companies.

This invention will now be described in detail with reference to the accompanying drawings, wherein:

Fig. 1 represents, largely diagrammatically, and partly in section, a side elevation of a blast furnace and associated equipment adapted to carry out the procedure of this invention;

Fig. 2 is a chart showing mean stack velocity of furnace gases plotted against burden ration; and

Fig. 3 is a chart showing velocity of furnace gases in the free space at the top of the furnace just above the stock line plotted against flue dust produced per ton of iron.

Fig. 1 illustrates a blast furnace 10 and auxiliary equipment, having certain special features found to be desirable for operation at high average static pressure, but which are otherwise of more or less conventional design.

In operating the blast furnace according to the new method and with the equipment described, turbo blower 12 operates to supply the blast, and the average static pressure in the shaft of the furnace 10 is raised to the desired level by throttling the discharge of gases, as by means of the throttling valve 40. The blast pressure is increased an appropriate amount which is dependent on the pressure at the top of the furnace and the pressure drop through the stock column, which is dependent on several factors such as the velocity of the gases through the stock column, average static pressure in the shaft, and character of the charge. The wind blown, defined as cubic feet of blast per minute delivered to the furnace, is then regulated at the proper level by means of turbo blower speed control and any enrichment oxygen which is fed into the conduit 14 beyond the turbo blower. The blast is compressed by turbo blower 12 and passes through conduit 14, stove 15, and bustle pipe 16 to tuyères 18. Enrichment oxygen may be supplied to the blast in any desired manner, e. g. by the use of a separator 20 which may for example be a Linda-Fränkl type separator. By-product nitrogen from the separator passes off at 22, while the oxygen is supplied to the blast at a suitable place as determined by the relative pressures of the exit oxygen and of the blast. For example the oxygen may be passed via conduit 24 controlled by valve 26 to conduit 28 which supplies air to the turbo blower, or it may be passed via conduit 30 (controlled by valve 32) to conduit 14 after the turbo blower. Alternatively to the latter procedure, compressor 34 may be used to raise the pressure of the oxygen supply to conduit 14, the oxygen passing to the latter conduit through conduit 36 controlled by valve 38.

As already indicated, a static pressure is imposed upon the furnace shaft by any suitable means, for example a pressure operated throttling valve 40, which as shown consists of three pipes with a butterfly valve in each, and which discharges into the Cottrell precipitator. To seal the top of the furnace 10 against leaks because of the pressure within the furnace, hopper 42 and lower bell 44 may each be made in one piece, with their contacting surfaces 46 and 47, respectively, being hard-surfaced. Alternatively, a flexible sealing member such as an internally-water-cooled hose may be associated with the lower surface 46 of hopper 42, to ensure a gas-tight fit against bell 44.

Hard surfaced bleeder valves 48, 49 are provided in the customary position, at the top of uptakes 48*a* and 49*a*, respectively. Gas from the furnace passes through downcomers 50, 50*a*, thence into and through dry dust catcher 51, and thence through conduit 52 to wet washer 53. The latter has a control system and overflow 54, 56, to maintain the water seal in the wet washer within predetermined limits in spite of variations in pressure due for example to slipping or hanging of the charge.

The gas discharged from washer 53 passes through conduit 55 to throttling valve 40 already referred to. Conduit 55 extends on downwardly to form a blind end for collecting any water and solids coming over with the gas; these collect at the bottom and may be removed from time to time through a suitable gate 57.

Instead of using a throttling valve 40 for controlling the gas pressure within the furnace, this gas pressure may be maintained by a power recovery system of the type set forth in the aforementioned Avery Patent 2,131,031 and in Avery Patent 2,192,885. In that event, 53 may be a dry dust separator auxiliary to dust catcher 51, and 40 will be a valveless conduit leading to the power recovery mechanism, which latter then serves as the throttling means to maintain the pressure in the furnace.

The wet washer (or dust separator) 53 is also provided with relief outlet 58 communicating with another bleeder valve 59, the latter being located adjacent the bleeder valves 48 and 49 at the top of the furnace so that the gas discharge may be made at a safely high level away from the working space at the bottom of the furnace. The outlet line 58 and bleeder valve 59 serve to bleed clean gas from the washer 53 during minor slipping of the furnace.

Equalizer line 60 controlled by valve 62 permits the flow of washed gas from outlet 58 of wet washer 53 into the space between the bells, to equalize the pressure above and below lower bell 44 sufficiently to permit dumping the latter. Relief line 64 controlled by valve 66 provides a means for exhausting the space between the bells, so that the upper bell 68 may be dumped.

Among the structural features described above are a number which are of value in operating the furnace in accordance with the present invention. These are in particular the hard-surfaced contacts, or the flexible sealing members, for bell 44 and hopper 42, the wet washer control and overflow system 54, 56, and the system for bleeding clean gas from wet washer 53 through outlet 58 to bleeder valve 59 and line 60. These features are not, however, claimed herein, but form the subject matters of other applications for patent as follows: Slater, Serial No. 775,016, filed September 19, 1947, now abandoned; Latham, Serial No. 763,821, filed July 26, 1947, now Patent No. 2,599,334; Janecek and Bahney, Serial No. 773,680, filed September 12, 1947, now Patent No.

2,585,779; and Le Viseur and Larson, Serial No. 771,870, filed September 3, 1947, now Patent No. 2,585,800, relating to hard-surfaced contacts, flexible sealing members, wet washer system, and system for bleeding, respectively.

By way of example, assume that operation by the new method herein set forth is planned for a blast furnace and burden of the following characteristics (which are commonplace):

Hearth diameter, 27 ft.
Working volume, 44,346 cubic ft.
Working height, 82 ft.
Stock line diameter, 20 ft.
Ferrous burden (56% Mesabi ore, 36% Old Range ore, 8% Open Hearth slag), 50% Fe
Coke, 86.5% carbon

Calculations can then be made of the mean gas velocity of the reducing gases through the working volume of the furnace (also referred to hereinafter and in the claims as mean stack gas velocity) by the following method:

Mean stack gas velocity in feet per second= (wind delivered in cu. ft./sec. @ 60° F., 14.7 p. s. i. a.) × (absolute pressure and temperature corrections for the average of the conditions in the stack) × (gas expansion factor) ÷ (average effective cross sectional area of furnace working volume).

Specifically, as applied to a furnace having the dimensions and burden given above, blown with air at 75,000 C. F. M. wind, with a blowing pressure of 21 p. s. i. g. and a top pressure of 2.5 p. s. i. g., and having a tuyère temperature of 2800° F. and a top temperature of 300° F., all of which are normal conditions for such a furnace, the mean stack gas velocity is calculated as follows (note: p. s. i. a. = pounds per square inch, absolute):

$$\text{Mean stack gas velocity}=\frac{75000}{60}\times\frac{14.7}{26.4}\times\frac{2010}{520}\times\frac{1.35}{54}=67.2 \text{ ft./sec.}$$

Where

$\frac{75000}{60}$ = calculated wind delivered, cu. ft./sec. @ 60° F., 14.7 p. s. i. a.

26.4 = average absolute static furnace pressure

$$=\left(\frac{\text{blast pressure}+\text{top pressure}}{2}\right)+14.7=\frac{21+2.5}{2}+14.7 \text{ p. s. i. a.}$$

$$2010=\text{average absolute furnace temperature (°R.)}=\left(\frac{\text{tuyère temp.}+\text{top temp.}}{2}\right)+460=\frac{2800+300}{2}+460$$

520 = absolute air temperature (°R.) = 60 + 460

$$1.35=\text{gas expansion factor}=\frac{\%\text{N in wind}}{\%\text{N in top gas}}=\frac{79}{58.5}$$

54 = average effective cross-sectional area of furnace working volume

$$=\text{per cent voids}\times\frac{\text{working volume}}{\text{working height}}=\frac{0.10\times 44{,}346}{82} \text{ sq. ft.}$$

It has been found, in accordance with the present invention, that the mean stack gas velocity so calculated controls the burden ratio the furnace can carry, i. e., within limits, the lower this velocity, the higher the permissible burden ratio. Furthermore, when the calculated mean stack gas velocity is plotted against burden ratio as in Fig. 2, an upper critical mean stack velocity of gases in the furnace stock column of about 60 ft./sec. is found below which the burden ratio can be raised sharply, to a point where it levels off on reaching a limiting value as dictated by the thermal requirements of the smelting process. Thus the burden ratio of 2.3 or less carried by the furnace at the normal mean stack gas velocity of about 65 ft./sec. can be increased markedly, to at least 2.45 and even to 2.7 or 2.8, by throttling the exit gases to decrease the mean stack gas velocity to between about 45 and 55 ft./sec., which latter figure is just below the aforementioned upper critical stack gas velocity. The saving of over 200 lbs. of dry coke per ton of iron thus made possible by controlling mean stack gas velocity is of cardinal importance in view of the dwindling supply of metallurgical coke in this country.

By normal blast rate is meant the blast delivered to the furnace when operating at normal top pressures and blowing with ordinary air (21% oxygen) at rates as high as practicable, which limit is usually set by the tendency of the furnace to hang and produce a prohibitive amount of dust. This normal blast rate is sufficient to produce iron at a tonnage approximately equal to that of the rating of the furnace.

By "burden ratio" is meant the ratio of pounds of ferrous material charged, such as ore, scale, open hearth slag, etc., to the pounds of dry coke charged, per unit of time such as per round or per day. This ratio is commonly used in the steel industry. In cases where the charge contains appreciable amounts of carbonate ores, such as siderite, the weight of combined CO_2 in the ferrous material charged is to be excluded from the figures for pounds of ferrous material charged, in calculating the burden ratio.

The increased burden ratios attained in the practice of the present invention may be expressed in burden ratio figures, as already indicated herein, or they may be expressed as per cent increase over the burden ratios customary in prior practice, i. e. without pressure operation. A fair value, somewhat on the high side, for the burden ratios attained in such prior practice is, as already indicated, 2.3. Hence the burden ratio value of 2.45 attainable under the present invention represents an increase of 6.5% over the said normal value, while the still higher burden ratios of 2.7 or 2.8 hereby attainable represent increases of about 17% and about 22% respectively.

The solid line of Fig. 2 represents the calculated values for burden ratio vs. mean stack gas velocity, which values are also the average values found in actual operation. Obviously, the controls, and conditions of operation, and constituents of the charge, of any blast furnace can never be maintained with such exactness that the results will always fall upon the solid line of Fig. 2. They do, however, fall within a fairly restricted range indicated by the dashed lines on either side of the solid line of Fig. 2.

The main reasons found, in carrying out the present invention, for the saving in coke through control of mean stack gas velocity in the ranges of pressure operation allowable by limitations in present turbo blower and blast furnace design are: (1) More efficient use of the reducing power of the furnace gases through better gas distribution in the stock column and longer time of contact, both of which are effected by lower gas velocity. The justification for this statement is found in the decrease occurring in CO/CO_2 ratio of top gases leaving the furnace as the velocity decreases; (2) More efficient heat transfer through more uniform gas flow and longer time of contact of the hot ascending gases with the descending charge, which also results from decreased velocity. Thus the temperature of the exit gases from the top of the furnace has been found to be a direct function of the velocity for a given average static furnace gas pressure; and (3) Utilization of higher blast temperatures at the higher pressures in the shaft of the furnace.

Control of gas velocity permits another important saving to be effected in the blast furnace process. The flue dust produced per ton of iron has been found to be a function of the free-space gas velocity, as shown in Fig. 3. This free-space gas velocity is that of the gases in the free space just above the stock at the stockline of the furnace. It is calculated by the following method:

Free-space gas velocity just above the stock at the stockline, in feet per second = (wind delivered in cu. ft./sec. @ 60° F., 14.7 p. s. i. a.) × (absolute pressure and temperature corrections for conditions at the stockline) × (gas expansion factor) ÷ (cross-sectional area of furnace at the stockline).

Specifically, as applied to a furnace having the dimensions and burden already specified above, blown with air at 75,000 C. F. M. wind, with a top pressure of 10 p. s. i. g. and a top temperature of 300° F., the said free-space gas velocity is calculated as follows:

$$\text{Free-space gas velocity} = \frac{75000}{60} \times \frac{14.7}{24.7} \times \frac{760}{520} \times \frac{1.35}{314} = 4.3 \text{ ft. per sec.}$$

Where

$\frac{75000}{60}$ = calculated wind delivered, cu. ft./sec. @ 60° F., 14.7 p. s. i. a.

$\frac{14.7}{14.7+10} = \frac{14.7}{24.7}$ = absolute pressure correction for top pressure @ 10 p. s. i. g.

$\frac{460+300}{460+60} = \frac{760}{520}$ = absolute temperature correction for top temperature @ 300° F.

$1.35 = \text{gas expansion factor} = \frac{\%\text{N in wind}}{\%\text{N in top gas}} = \frac{79}{58.5}$

314 = cross-sectional area of furnace at stockline, sq. ft.

Again it will be noted that a critical velocity is reached, this being one below which the dust production of the furnace becomes inconsequential. Thus if one controls the free-space velocity at below about 4.5 ft./sec. the flue dust produced will be of the order of 90 lbs. or less per ton of iron, instead of a normal value of over 200 lbs./ton of iron for operation at 75,000 C. F. M. delivered wind at 2.5 p. s. i. g. top pressure. The resulting saving in iron yield really raises the "effective" burden ratio charged. In addition, savings will result from having to sinter only the smaller amount of flue dust for recharging into the blast furnace. The mean stack gas velocity, if so high that the free-space gas velocity is above the critical dust carry-over value found, is important in determining how much dust will be produced in the nearly vertical portion of the curve of Fig. 3, as the mean stack gas velocity controls to a large extent the slipping and channeling tendencies of the charge by controlling the pressure drop through the stack. Thus the higher the mean stack gas velocity the rougher the operation and the greater is the amount of dust thrown into the space above the stock line where it can be carried over into the downcomers by free-space gas velocities in excess of the critical value of about 4.5 ft./sec.

Although, as will be noted from the foregoing sample calculations, there is no direct connection between the mean stack gas velocity and the free-space gas velocity, the point of critical velocity of about 4.5 ft./sec. of the latter corresponds roughly to a velocity of about 45 ft./sec. for the former.

There are three methods of decreasing the mean stack velocity of gases through the furnace charge:

(1) Increasing the average static pressure within the furnace

(2) Decreasing the wind volume blown

(3) Enriching the air blast with oxygen.

It is obvious that method (2) is undesirable, except possibly during times of business depression, as low iron tonnages are produced when low wind volumes are utilized.

In Table I, below, are shown data and calculations for operations of a furnace having the particular dimensions already given, at normal pressure of 2.5 p. s. i. g., and at increased top pressures of 10 p. s. i. g. and 20 p. s. i. g., in each case with ordinary air, with 25% oxygen air, and with 40% oxygen air. By "25% oxygen air" and "40% oxygen air" are meant respectively air containing substantially 25% O_2 and 74% N_2, and air containing substantially 40% O_2 and 59% N_2, all figures being by volume. In the column headed "Wind (or O_2) Delivered (C. F. M.)" are figures in parentheses showing the C. F. M. of oxygen in the wind delivered, e. g. 90,000 C. F. M. of 25% oxygen air contains 22,500 C. F. M. oxygen. Normal air is figured at 21% oxygen. The showings of Figs. 2 and 3, and the figures under "No Air Enrichment" in Table I, are based upon extensive series of actual operating runs while the figures for the balance of Table I are obtained by calculations based upon the results practically attained in such operating runs, upon experience gained therefrom, and upon well-founded theoretical considerations.

As an example, with reference to Table I, assume that it is desired to supply to this furnace about 22,000 C. F. M. of oxygen in the wind. This is not practically feasible with ordinary air without added top pressure, because among other things, the gas velocity would be so great as to blow much of the charge out of the furnace.

Even with added top pressure, it is hardly practicable with presently available equipment, since the blowing capacity and pressures required are in general too high. However, by enriching the blast with oxygen, and imposing practicable pressure and blowing conditions, 22,000 C. F. M. of oxygen in the wind can be readily provided. Thus, by blowing 90,000 C. F. M. of 25% oxygen air at 20 p. s. i. g. top pressure, good operating results in accordance with the present invention are attainable. Similarly good results are attainable by blowing 60,000 C. F. M. of about 37% oxygen air, at about 10 p. s. i. g. top pressure.

TABLE I

Burden ratio, iron production, dry coke rate and dry flue dust production for varying furnace gas velocities and degrees of air enrichment

Wind (or O_2) Delivered (c. f. m.)	Top Pressure (p. s. i. g.)	Blast Pressure (p. s. i. g.)	Calculated Mean Gas Velocity (ft./sec.)	Burden Ratio	Iron Production Net Tons Day	Dry Coke Rate Lbs./ton Iron	Dry Flue Dust Lbs./ton Iron
NO AIR ENRICHMENT							
60,000 (12,600)	2.5	16	59.4	2.38	998	1,632	120
	10	23.5	45.2	2.725	1,151	1,429	40
	20	33.5	34.4	2.80	1,196	1,380	20
75,000 (15,750)	2.5	21	67.2	2.28	1,187	1,710	260
	10	28.5	52.4	2.58	1,358	1,507	125
	20	38.3	40.5	2.77	1,467	1,402	30
90,000 (18,900)	2.5	26.3	73.1	2.24	1,400	1,733	>400
	10	33.8	58.1	2.415	1,520	1,608	160
	20	43.8	45.5	2.72	1,657	1,483	50
105,000 (22,050)	2.5	31.3	79.1	(1)	(1)	(1)	(1)
	10	38.8	63.9	2.315	1,690	1,680	255
	20	48.8	50.8	2.625	1,935	1,480	130
25% OXYGEN AIR (BY VOLUME)							
60,000 (15,000)	2.5	16	62.0	2.34	1,168	1,660	140
	10	23.5	47.3	2.695	1,359	1,441	45
	20	33.5	35.9	2.795	1,412	1,391	22
75,000 (18,750)	2.5	21	70.2	2.26	1,404	1,720	310
	10	28.5	54.7	2.515	1,576	1,544	150
	20	38.5	42.3	2.75	1,736	1,412	34
90,000 (22,500)	2.5	26.3	76.4	2.225	1,650	1,750	>400
	10	33.8	60.6	2.365	1,765	1,643	195
	20	43.8	47.5	2.695	2,039	1,440	57
105,000 (26,250)	2.5	31.3	82.6	(1)	(1)	(1)	(1)
	10	38.5	66.7	2.285	1,987	1,702	295
	20	48.8	53.0	2.565	2,250	1,515	170
40% OXYGEN AIR (BY VOLUME)							
60,000 (24,000)	2.5	16	71.5	2.25	1,789	1,728	250
	10	23.5	54.4	2.51	2,050	1,550	70
	20	33.5	41.4	2.765	2,210	1,408	30
75,000 (30,000)	2.5	21	80.9	2.215	2,200	1,754	>400
	10	28.5	63.0	2.325	2,320	1,670	150
	20	38.5	48.7	2.68	2,700	1,450	50
90,000 (36,000)	2.5	26.3	88.0	(1)	(1)	(1)	(1)
	10	33.8	70.0	2.265	2,700	1,717	285
	20	43.8	54.7	2.51	3,010	1,550	130
105,000 (42,000)	2.5	31.3	95.2	(1)	(1)	(1)	(1)
	10	38.8	76.9	2.225	3,090	1,750	>400
	20	48.8	61.2	2.365	3,300	1,643	160

[1] Probably inoperable.

The data and calculations given in Table I are based upon the results of operating a blast furnace of the size hereinbefore described on so-called straight ore burden using untreated Lake ores, as previously outlined, or one containing amounts of sinter, scale or scrap such that the iron content of the ferrous materials in the burden is approximately 48–54%, and for coke containing about 86.5% C and about 3 to 8% moisture. For different types of burdens the values in Table I would have to be altered by methods familiar to one skilled in the art. Thus for higher iron content burdens, for example those having higher than 60% Fe in the ferrous materials charged, the normal burden ratios would be so high that relatively little increase would result from gas velocity control. For lower iron content burdens, for example 45% Fe or lower, the increase in burden ratio possible through gas velocity control should prove highly advantageous. Since the ore reserves of the United States are now largely made up of lean ores, the importance of gas velocity control cannot be overemphasized.

As is clear from this table and from the foregoing disclosure, as well as from Fig. 2, the desirable results of the present invention are attained by imposing a top pressure on the exit gases, and blowing sufficient air to effect a mean stack velocity of the furnace gases of less than 60 ft. per sec. and preferably not over 55 ft. per sec., while maintaining an average static pressure within the furnace of at least one atmosphere gauge. The top pressure so imposed should be at least 5 p. s. i. g., and for most furnaces will, for practical purposes, be in the general order of 10 to 20 p. s. i. g. For furnaces operating under say seven atmospheres gauge average internal static pressure, and constructed so to operate, and with adequate blowing capacity, the top pressure, in order to have a mean stack gas velocity of 45 ft. per sec., would be in the order of 6.6 atmospheres gauge, and the wind would be delivered at about 7.4 atmospheres gauge. For a furnace to which Table I applies, the wind blown would then be about 225,000 C. F. M. of ordinary air.

The use of a blast consisting of air enriched in oxygen confers still further advantages, as

shown in the foregoing disclosure and in Table I.

It will be noted, especially from Table I, that the high iron production and the low coke rate and low flue dust are attained with burden ratios in excess of 2.45, and mean stack gas velocities of not more than about 55 ft./sec. Preferably this stack velocity is maintained above about 35 ft./sec., although lower velocities may be used with some decrease in coke rate from what could be attained at a higher velocity (but below about 55 ft./sec.), but this will generally be offset by increase in blowing costs or decrease in productivity. In general, the best results from the operation of the present invention are attained with a burden ratio of about 2.7 to 2.8 (i. e. about 17% to 22% above normal), a mean stack gas velocity of 35 to 45 ft./sec., and a free-space gas velocity of less than 4.5 ft./sec. Such operations are in the zone of the upper inflexion point of the curve in Fig. 2, and below the point in Fig. 3 at which the flue dust production mounts nearly vertically.

As is evident from Fig. 3, there is no critical lower limit for free-space gas velocity. However, other conditions being equal, as mean stack gas velocity decreases, so does free-space gas velocity, although not necessarily in the same ratio. At the lower ranges of mean stack gas velocity herein set forth, i. e. about 35 ft./sec., the free-space gas velocities will generally be in the order of 3 to 4 ft./sec.

From Table I it will be noted that, for the normal top pressure of about 2.5 p. s. i. g., normal blast pressure of about 21 p. s. i. g., normal maximum wind volume delivered to the furnace of about 75,000 C. F. M., and normal gas velocity of about 67 ft./sec., the burden ratio is about 2.28, the iron tonnage is about 1187, the coke rate about 1710, and the flue dust about 260 lbs. per ton of iron. Ordinarily, as one increases the blast rate, the coke rate and flue dust production also increases. However, it will be seen that one can, through gas velocity control, increase the unenriched blast rate to 105,000 C. F. M. and yet decrease the coke rate from the normal value of 1710 to 1480, and decrease the flue dust by over 100 lbs. per ton of iron, and increase production of iron by around 700 tons per day. Furthermore, with 25% oxygen air at the otherwise normal operation of 75,000 C. F. M. blast rate at 2.5 p. s. i. g. top pressure it will be noted that the coke rate will actually increase unless gas velocity control is utilized to increase the burden ratio. When this is done a saving of about 300 lbs. of coke per ton of iron is made possible, as well as a substantial saving in flue dust. The importance of these savings will be recognized when it is realized they represent a manufacturing cost saving of over $1.00 per ton of iron.

Another feature of gas velocity control brought out in Table I is its flexibility. Thus the operator can adjust the gas velocity, and hence burden ratio, to suit his operating conditions (turbo blower and furnace top pressure limitations, and prevailing economic situation and plant costs) so as to balance coke rate, iron production, flue dust production, and blowing costs in order to operate the blast furnace at the optimum point of economic balance.

By using the new variable controls of this invention, gas velocity and blast enrichment, the operator can achieve economies of different kinds and adapt the furnace operation to the conditions and demands of the overall steel plant, of which the blast furnace is usually an integral unit. For example, if the coke supply is limited and the demand for pig iron above that available from normal operation of the furnace, the operator can adapt the burden ratio (which controls coke consumption) to about 2.7 by decreasing gas velocities through the furnace to say 40 ft. per sec. by going to a top pressure of 20 p. s. i. g. Under these conditions production would be increased about 280 tons per day with substantially the same total daily coke consumption; or if the furnace could not be operated for purely physical reasons at such internal pressures, then the operator could achieve the same results by going to about 10 lbs. top pressure and enriching the blast in oxygen. With this same top pressure limit and the demands for still greater production the operator could increase the blast with some sacrifice in coke economy or maintain the same desirable high burden ratio through blast enrichment, while continuing to operate under the maximum top pressure which can be safely used in the furnace. From Table I it is therefore evident that widely varying conditions of operations can be realized with any given furnace through the manipulation of the variables of gas velocity and blast enrichment while operating under higher than normal top pressures. The flexibility achieved by the procedure of the present invention is therefore of the greatest practical importance. In fact, with its provision for proper control of gas velocity in the furnace, this invention opens up an entirely new order of magnitude of production to be attained from present day blast furnaces, at efficiencies not hitherto believed to be possible.

I claim:

1. The method of producing iron from iron ore in a blast furnace utilizing a burden ratio which is high for the grades of coke and ore, with consequent decrease in coke consumption, comprising blowing air containing approximately 25% to 40% by volume of oxygen at a high blast rate sufficient to produce a mean stack velocity through the stock exceeding 55 linear feet per second at a top pressure of about 2.5 pounds per square inch gauge, throttling the outlet of the furnace to impose sufficient top pressure on the exit gases to limit the mean stack velocity to the range of 35 to 55 linear feet per second through the stock while holding the blast at said high rate, said top pressure being adjusted in the range of 5 to 20 pounds per square inch gauge to impose an average internal static pressure in the furnace of greater than 1 atmosphere gauge.

2. The method as defined in claim 1 wherein the mean stack velocity of the gas through the furnace is limited to the range of 35–45 linear feet per second.

3. The method of producing iron from iron ore in a blast furnace utilizing a burden ratio which is high for the grades of coke and ore, with consequent decrease in coke consumption, comprising blowing air containing approximately 25% to 40% by volume of oxygen at a high blast rate sufficient to produce a mean stack velocity through the stock exceeding 55 linear feet per second at a top pressure of about 2.5 pounds per square inch gauge, throttling the outlet of the furnace to impose sufficient top pressure on the exit gases both to limit the mean stack velocity to the range of 35 to 55 linear feet per second through the stock and to limit the linear gas

velocity above the stock to less than 4.5 feet per second, while holding the blast at said high rate, said top pressure being adjusted in the range of about 5 to 20 pounds per square inch gauge to impose an average internal static pressure in the furnace of greater than 1 atmosphere gauge.

4. The method of producing iron from iron ore in a blast furnace utilizing a burden ratio which is high for the grades of coke and ore, with consequent decrease in coke consumption, comprising blowing gas containing at least approximately 25% by volume of oxygen at a blast rate sufficient to produce a mean stack velocity through the stock substantially exceeding 55 linear feet per second at a top pressure of about 2.5 pounds per square inch gauge, throttling the outlet of the furnace to impose sufficient top pressure on the exit gases to limit the mean stack velocity to the range of 35 to 55 linear feet per second through the stock, said top pressure being adjusted to above about 5 pounds per square inch gauge to impose an average internal static pressure in the furnace of greater than 1 atmosphere gauge.

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