

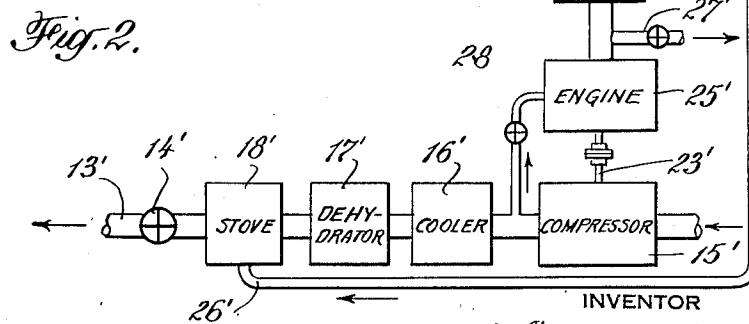
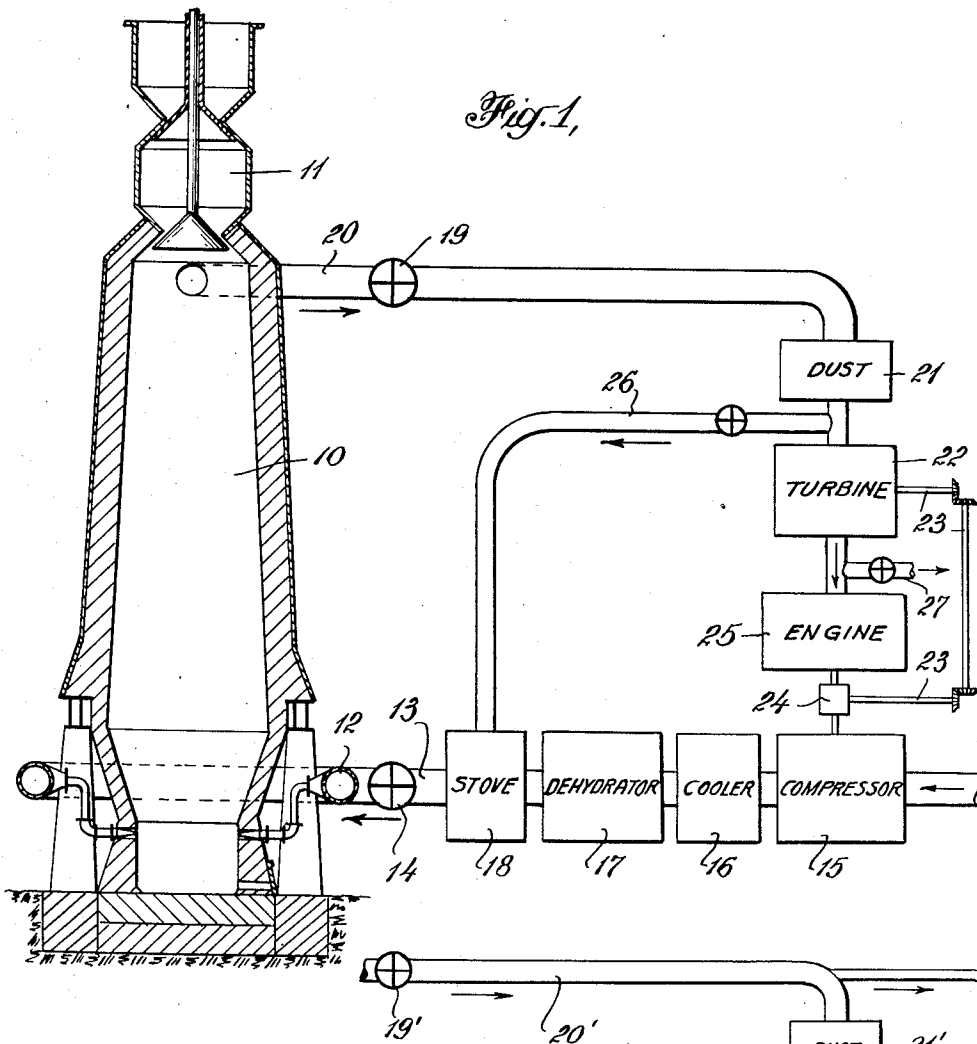
Sept. 27, 1938.

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2,131,031

METHOD OF OPERATING BLAST FURNACES

Filed June 12, 1936



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UNITED STATES PATENT OFFICE

2,131,031

METHOD OF OPERATING BLAST FURNACES

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Application June 12, 1936, Serial No. 84,797

15 Claims. (Cl. 75—41)

This invention relates to a method of operating blast furnaces for smelting metals from ores, and has particular reference to the provision of a method of greatly improving the efficiency of such smelting processes and decreasing the cost of smelting ores in blast furnaces. Although the method of this invention is particularly applicable to and will be described in connection with the manufacture of pig iron in a coke-fired blast furnace of the conventional type, it is to be understood that the method can be used with equal facility for the manufacture of such analogous products as ferro-alloys, and non-ferrous metals.

The modern blast furnace has serious inherent and fundamental limitations, although extensive research and development work in recent years has brought about considerable improvement in operating efficiency and facility. The particular fundamental limitations with which this invention is chiefly concerned are commonly referred to as "solution loss of carbon" and "deficiency of hearth heat". By solution loss of carbon is meant the percentage of carbonaceous fuel which is dissolved in the gases and is accordingly lost. For example, in the ideal or theoretical blast furnace, all of the carbonaceous fuel supplied, except that required to carburize pig iron, would be burned at the tuyères, whereas in actual practice only seventy to eighty per cent of the fuel supply is so burned, the balance being oxidized higher up in the furnace and constituting the aforementioned loss. This loss results from the fact that in normal blast furnace practice, a considerable proportion of the ore reaches high temperature zones deep in the furnace before it is completely reduced, so that when it is reduced in accordance with the slightly exothermic reaction, $(1) \text{CO} + \text{FeO} = \text{Fe} + \text{CO}_2$, the carbon dioxide which is formed immediately reacts with the carbon present in accordance with the strongly endothermic reaction, $(2) \text{CO}_2 + \text{C} = 2\text{CO}$. Thus, not only is carbon lost as fuel at the tuyères, but the gases rising from the hearth of the furnace are cooled by absorption of part of their sensible heat, which is required to supply the requirements of reaction (2) and to preheat the charge. Consequently, the solution loss phenomenon greatly increases the fuel requirements of coke per ton of pig iron produced, beyond the solution loss per se.

By "deficiency of hearth heat" is meant that cooling off of the hearth which results from blowing the furnace at a blast rate greater than a certain optimum rate, so that when the furnace is operating at normal capacity it is very sensi-

tive to changes in temperature of the preheated gases. The deficiency of hearth heat is probably due to the fact that the hearth performs functions which require that a certain minimum amount of heat developed at the tuyères shall be at a thermal potential considerably above an indefinite critical temperature, which is commonly assumed to be the free running temperature of the slag. This critical temperature has been given as about 1500°C . It has been found that, although this analysis of the condition is generally correct, a fundamental cause of the limitation is the inability of the shaft furnace to perform properly its functions of preheating and reducing the charge before it reaches the high temperature zones of the furnace. Therefore, if the shaft can be made to perform its functions adequately and low temperature heat thus used to maximum advantage, the necessity for so large a quantity of high temperature heat in the hearth is much less urgent.

In ordinary blast furnace practice, the blast gas pressure used is only that necessary to force the gas through the stoves and the ducts into the furnace, through the charge therein and out through the down-take pipe and auxiliary equipment. Nearly all of the pressure drop occurs in the shaft, and as the pressure at the tuyères is usually between $\frac{1}{2}$ and 1 atmosphere gauge and the top pressure is ordinarily so small as to be practically negligible, it follows that the average static gas pressure within the furnace shaft is between about $\frac{1}{4}$ and $\frac{1}{2}$ atmosphere gauge, or $1\frac{1}{4}$ to $1\frac{1}{2}$ atmospheres absolute, with the ordinary blast furnace construction and operation. If the blast pressure is increased, a larger volume of blast is forced through the furnace, i. e., the blast rate is increased, with a resultant increase of dust loss, or of the tendency of the charge to hang, or of the hearth to run cold. These are, in fact, the conditions which ordinarily limit the blast pressure and hence the blast rate of the ordinary blast furnace, and result in the aforementioned solution loss and hearth heat deficiency.

In accordance with the present invention, a blast furnace for smelting metals from ores is artificially maintained and controlled under a static internal gas pressure which is substantially greater than the pressure developed in the shaft in normal operation, preferably in combination with a material increase in the blast gas feed rate. This method of operation, as will appear hereinafter, radically alters in a favorable manner the thermal balance of the blast furnace and the chemical reactions which take place within

it. Thus, under proper conditions of operation after the manner of the invention, the solution loss may be nearly or quite eliminated, the deficiency of hearth heat may be overcome, the thermal efficiency of the furnace may be increased, and the production capacity of the furnace may be greatly increased.

As will appear from the theoretical discussion hereinafter set forth in detail, if the gases within a blast furnace are maintained under superatmospheric pressure after the manner of the invention, and the blast rate is maintained at the same rate as in normal methods of operation, solution loss will be practically eliminated and the capacity of the furnace will be increased substantially in proportion to the decrease in fuel consumption per ton of pig iron. On the other hand, if the blast rate is increased in like proportion to the increase of absolute average pressure in the shaft, the output of the furnace will be increased in substantially the same proportion and the solution loss will remain substantially unchanged. For most furnaces this would mean too large a production, and there would be no great saving per ton of product. The invention in its preferred form contemplates increasing the blast rate in about half the proportion of the increase in average absolute static gas pressure in the shaft, whereby solution loss is eliminated and at the same time, the capacity of the furnace is increased not only in proportion to the blast rate, but also by the added effect of less fuel per ton of product.

In order to carry out the method of this invention in a blast furnace, the shaft is sealed pressure-tightly, the blast gas feed duct and the gas down-take pipe of the furnace are equipped with valve controls, and suitable blast equipment is supplied whereby the static pressure within the furnace can be built up to some predetermined desired value, preferably between two and seven atmospheres gauge, and thereafter regulated by the valve controls. More particularly, in addition to the aforementioned intake and outlet gas valve controls, the preferred arrangement of the blast furnace and its appurtenant parts for realizing the method of the present invention, comprises a compressor for increasing the pressure of the blast gas or gases, a cooler for reducing the temperature of the compressed blast gas below the dew point, and a dehydrator for condensing the moisture therein by precipitation before supplying it to the bustle pipe at a predetermined high pressure, which is regulated and maintained by proper manipulation of the intake and outlet valve controls of the furnace. The down-take pipe preferably supplies the combustible blast furnace gas to an internal combustion engine or a compressed gas engine or turbine of suitable form for operating a compressor positioned in the blast gas line, suitable dust catchers being provided for removing the dust from the blast furnace gas before it is introduced into the engine. If desired, a part of the blast furnace gas may be supplied to hot blast stoves for preheating the blast in the conventional way instead of being consumed in the compressor engine, but one of the principal advantages of the invention is that preheating of the blast is in many cases rendered unnecessary.

It will be seen that with a blast furnace provided with the valve controls in the blast feed duct and the gas down-take pipe and supplied with high pressure blast gas, the rate of blast passing through the furnace at a predetermined

static pressure may be controlled by suitable valve manipulation, with the result that the internal static gas pressure is increased several fold, depending upon requirements, so that, with a blast supplied at a volume greater than the normal volume of equivalent free air per unit of time, the effect in the furnace is far reaching in character.

For a more complete understanding of the invention, reference may be had to the accompanying drawing, in which:

Figure 1 is a schematic diagram of an arrangement involving the invention as applied to an existing blast furnace installation, for example; and

Fig. 2 illustrates a modified arrangement of the auxiliary equipment for a new installation in which advantage is taken of the pressure of the exit gases and the blast air to operate a compressor engine.

Referring to Fig. 1 of the drawing, numeral 10 designates a blast furnace of more or less conventional design, having a double bell and hopper arrangement 11 at the upper end of the furnace, which serves as a pressure lock, whereby pressures built up within the shaft of the furnace 10 may be maintained during charging operations by proper manipulation of the pressure lock 11.

The bustle pipe 12 is also of conventional design supplied by the blast feed duct 13 which is fitted with a control valve 14, in accordance with the present invention. The air or other feed gas for the blast is compressed by the compressor 15 to a suitable predetermined pressure, say five atmospheres gauge. The compressed gas is supplied to a suitable cooler 16, which removes the heat of compression therefrom and reduces the temperature of the compressed gas below the dew point. The compressed blast feed gas is then passed through a suitable dehydrator 17, which condenses the moisture in the gas by precipitation, so that at the suggested pressure of five atmospheres gauge, 75% of the moisture is precipitated from air having originally 70% humidity.

The invention accordingly offers a ready means for drying the blast at practically no additional cost and very little added equipment. The advantages of a dry blast are apparent for with a dry blast the temperature at the tuyères is considerably higher than with a wet blast.

From the dehydrator, the compressed gas passes directly to the feed duct 13 and through the control valve 14, without preheating, or optionally, it may be preheated by hot blast stoves 18 in the conventional way.

The static pressure within the sealed furnace 10 and the blast rate therethrough are controllable by means of throttling valve 19 provided in the down-take pipe 20 in accordance with the present invention. The throttling valve 19, and the control valve 14, may be manually operated or pressure operated, depending upon requirements. Thus, with the assumed compressor pressure of five atmospheres gauge, and allowing for a certain drop due to duct and stove friction, the static pressure in the shaft can be built up to at least four atmospheres gauge pressure in the manner described.

The combustible gases generated during smelting in the blast furnace 10 are passed under pressure through a suitable dust catcher 21 and decompressed in a suitable decompressor, such as the turbine 22, the power output of which may

be employed to assist in driving the compressor 15, the connections being through shafts 23 and differential gearing 24. A portion of the combustible gas may be utilized to operate an internal combustion engine 25 connected through differential gearing 24 to the compressor 15. A portion of the remaining gas may be led by pipe 28 to the hot blast stoves 18, if preheating of the blast feed is desired, although that is optional with the present invention. The remainder of the combustible gas may be led by pipe 27 to a boiler or the like for generating additional power for operating conveying equipment or the like.

In cases where new equipment is to be installed, advantage can be taken of the high blast air pressure and the high combustible gas pressure for operating an internal combustion engine at high efficiency under supercharged conditions. Such an arrangement is shown schematically in Fig. 2, in which the control valves 14' and 19' are employed as before in the blast air and down-take pipes 13' and 20', respectively. The combustible gas is passed under pressure through dust-catcher 21', and a portion thereof is supplied to the internal combustion engine 25', directly connected by shaft 23' to the blast air compressor 15', which compresses the air in the manner described. The pressure air passes through cooler 16', dehydrator 17', and, if desired, through blast air preheating hot blast stoves 18' supplied with the combustible gas by pipe 26' from pipe 20'. As aforementioned, the use of stoves for preheating the blast air is not essential, but optional.

The engine 25' is supplied with the compressed air from pipe 13' by pipe 28, so that with the combustible gas and the combustion-supporting air supplied under substantial superatmospheric pressure, the power output economy of the engine is high. The remainder of the combustible gas is led by pipe 27' to suitable boilers, or the like, for any desirable purpose.

In operating the blast furnace according to the new method and with the equipment described, the static pressure within the shaft of the furnace 10 is built up by initially closing valve 19 or 19', the blast pressure being regulated by control valve 14 or 14'. The valve 19 or 19' may, of course, be substituted by a valve controlling the flow of the gases to the turbine, engine or the like. When the gas static pressure within the furnace has reached the predetermined amount, control valve 19 or 19' is opened manually, or by automatic pressure-controlled means of conventional type, by an amount which permits the blast to travel through the furnace at the proper predetermined rate, valve 14 in the blast gas feed duct 13 being regulated manually, or automatically by pressure-controlled means, to maintain the proper feed rate of the blast gas through the shaft.

By way of example, it may be assumed that the internal static gas pressure in the shaft 10 is increased fourfold or from four to five atmospheres gauge in this way. Since the specific rate of gas-solid reactions is a direct function of the concentration of gaseous reactants, the specific rate of combustion of the fuel and reduction of ore, are likewise increased fourfold. However, if the blast rate, i. e., pounds of oxygen fed per minute, remains the same as in normal operation, the total chemical work done within the furnace per unit of time remains substantially unchanged. Consequently, the ore is, in effect, exposed to four times the normal reducing action, which is far more than enough to insure its complete reduc-

tion long before it reaches the high temperature zones of the shaft. The result is the substantial elimination of solution loss of carbon and an approach in this respect to the operation of the ideal blast furnace.

The specific rate of heat transfer from gases to solids in turbulent flow is proportional to the mass velocity of the gas up to pressures of at least thirty atmospheres. Since, in the assumed example, the blast rate is normal, the specific rate of heat transfer likewise remains normal, and as the total transfer of heat to be effected per unit of time is therefore practically the same as in normal operation, it might be supposed that efficiency of heat exchange between the gases and the solid charge would not be affected. However, in most blast furnace operations, this exchange of heat is very seriously affected by channeling in the charge due to high gas velocities, and I have found that the much lower gas velocities of the example cited, i. e. one-fourth the normal velocity, practically eliminate such channeling. The result is a substantially complete exchange of heat between the gases and the charge, which insures that much of the sensible heat ordinarily lost in the stack gases is conserved by being utilized to preheat the charge.

Similarly, the pressure drop of gases flowing through heterogeneously packed towers for a given rate of flow or mass velocity varies inversely as the overall pressure. The pressure drop through the furnace with normal blast rate and four times normal pressure according to the present invention will consequently be about one-fourth atmosphere instead of about one atmosphere, which has an important effect upon the amount of power required to compress the blast, and upon the tendency of the charge to hang. In the ordinary blast furnace the normal pressure drop is about one atmosphere with a blast pressure of two atmospheres absolute. Therefore, to quadruple the average absolute pressure in the shaft, as compared with normal blast furnace operation, i. e., in order to produce an average absolute static pressure of $4 \times 1\frac{1}{2} = 6$ atmospheres in the shaft, the blast pressure required would be, not $4 \times 2 = 8$, but $6 + \frac{1}{4} = 6\frac{1}{4}$ atmospheres absolute, provided the normal blast rate is used at the increased pressure.

The use of pressure has further advantages. For example, the substantial elimination of solution loss and increased efficiency in the use of heat, make it possible, other conditions being constant, to considerably decrease the ratio of coke to ore, i. e., to increase the burden of the furnace. Since, in the assumed example, the blast rate is taken as normal, coke will be burned at the normal rate at the tuyères and the throughput of the furnace will therefore increase in proportion to the increased burden. It has been found that under such conditions, using normally preheated blast, the capacity of a furnace rated at 400 tons a day, for instance, will be increased to as much as 500 tons a day, while the coke required will be decreased from about 2000 pounds to as little as 1460 pounds per ton of pig iron.

There is, however, an upper limit to the permissible pressure, set by the equilibrium conditions of the reaction $2\text{CO} = \text{CO}_2 + \text{C}$ which is driven strongly from left to right by increased pressure, and which is strongly catalyzed by metallic iron and iron ore. Thus, a mixture of CO and CO_2 in equilibrium with excess carbon at 900°C. will contain about 3% CO_2 at one

atmosphere total pressure, and about 14% CO₂ at six atmospheres total pressure. At lower temperatures the effect is still more pronounced; at 700° C. the corresponding figures being 38% CO₂ and 68% CO₂ respectively. In the blast furnace the partial pressures of the gases are greatly decreased by dilution with nitrogen, but there nevertheless remains a limitation in pressure which it is not desirable to exceed because of this side reaction. I have found that at overall pressures of about ten atmospheres gauge this effect may become serious, and for this and other reasons I prefer to carry out the method of the invention at lesser pressures, namely, from two to seven atmospheres gauge.

It has been ascertained that under the conditions assumed in the example, the amount of high temperature heat available in the hearth is far more than is required, instead of less as is usual. The excess of high temperature hearth heat is, in fact, so great that it becomes possible to use cold blast together with a larger proportion of fuel, with the result that the throughput is decreased 7%, and the amount of coke required per ton of pig iron decreased 4%, as compared with normal operation. This small decrease in capacity is far more than offset by the saving in coke, elimination of preheating stoves, and the diversion to useful purposes of the fuel gas normally required to preheat the blast.

Thus far it has been assumed that the blast rate is maintained at the normal rate. If, however, the blast rate is assumed to be increased in proportion to the increase in pressure, it is apparent that the total chemical work effected within the shaft per unit of time will likewise increase in substantially the same proportion, from which it follows that the thermal balance of the furnace, and the solution loss of carbon will be much the same as in present methods of operation. There is therefore a very definite upper limit of blast rate beyond which the peculiar advantages of operation under relatively high static pressure cease to exist, and that limit is a ratio of increase in blast rate somewhat less than the ratio of pressure increase. It seems to be generally agreed that, for reasons not connected with actual thermal and chemical conditions within the furnace, the practical limit of blast furnace capacity has been reached at about 1000 tons of pig iron per day, and as modern furnaces have an average capacity on the order of 400 to 500 tons a day, there would seem to be only moderate advantage in the use of pressure merely as a means of increasing the capacity of a furnace. But, as previously pointed out, if the average absolute static pressure within the shaft is increased for example fourfold, i. e., to about 6 atmospheres absolute, and the blast rate is increased, but in substantially smaller proportions, for example twofold, the results upon furnace operation and economy are far reaching. Elimination of solution loss and greater thermal efficiency increases the furnace capacity per unit blast rate by about 20%, and this coupled with the assumed doubling in blast rate increases the furnace capacity by a factor of about 2.5 as compared with normal operation. The invention in its preferred form therefore contemplates maintaining within the shaft of the blast furnace an average absolute static gas pressure of about four times the normal pressure, and increasing the blast rate in proportion to about half the increase in absolute static gas pressure within the shaft.

In view of the large amount of air required for the blast it is apparent that the power and equipment required to compress the blast to the relatively high pressures of the method of the invention must be carefully considered. It has been found that, contrary to offhand judgment, high blast pressure may actually result in a decrease in the net amount of power required for blowing. If the average internal furnace pressure is quadrupled, the blast pressure must be increased from between about one-half and one atmosphere gauge to between about four and five atmospheres gauge, which requires about three times the normal amount of power per unit of blast rate. In the case of normal furnace operation practically all of the power used to compress the blast is lost by friction of the gas in passing through the furnace and the gas leaves the furnace at substantially atmospheric pressure. But in the method of the invention the pressure drop through the furnace is only a fraction of one atmosphere, so that in the example given the gas leaves the furnace at approximately the static internal pressure. Consequently, the blast furnace gas may be expanded through a turbine or reciprocating compressed gas engine whereby some 60% of its energy of compression may be recovered. Moreover, the heat of compression of the blast corresponds to a temperature rise of about 400° F., and a large part of this heat may be recovered by heat exchange. In this manner about 80% of the power originally required to compress the blast may be reconverted into mechanical energy and used to compress the blast.

It is thus clear that the net power which must be used for compressing the blast is, in the preferred method of the invention, on the order of half that required in normal blast furnace operation, per unit of pig iron produced. In the case of existing installations the present equipment may be used for preliminary compression, and additional equipment provided merely for raising the blast from the present pressure to the desired pressure. It will be evident that in blast furnace operation after the manner of this invention, the blast can be dehydrated without extra expense, the blast in most cases need not be preheated, solution loss is practically eliminated, the capacity of a furnace of given size can be increased several fold, and most of the energy required for blast compression can be recovered and usefully employed.

The method of the invention accordingly provides means whereby long recognized difficulties and limitations relating to the manufacture of pig iron and ferroalloys in blast furnaces may be largely overcome. By substantially eliminating solution loss of carbon and correcting the deficiency of hearth heat, the method greatly increases the capacity of a furnace of given size, decreases the ratio of fuel required per ton of product, and nearly or quite eliminates the necessity of preheating the blast. It simplifies the problems of smelting fine or improperly sized or difficultly reducible ores, and eliminates many of the causes of irregularities of furnace operation. Its beneficial effects lead to a substantial saving in fuel both for smelting the ore and for preheating the blast, in the net amount of power required to compress the blast, and in labor costs and fixed charges. In the case of new plants, it greatly decreases the capital investment required for a given capacity.

Although the invention has been described in

connection with the manufacture of pig iron and ferroalloys, and has perhaps greatest utility in that field, it is also applicable to smelting those non-ferrous metals which do not volatilize under conditions of operation described herein. Also, the term "throttling", as employed herein and in appended claims, comprehends within its scope the retardation, by any means, of the furnace discharge gas, whereby a back pressure is created.

I claim:

1. The method of operating a sealed blast furnace, which comprises supplying the blast feed gas at superatmospheric pressure, and throttling the gas discharge from the furnace to maintain an average static internal pressure of between about two and seven atmospheres gauge.

2. The method of operating a sealed blast furnace, which comprises subjecting the ore therein to an average static pressure of between two and seven atmospheres gauge by maintaining the blast gas feed pressure above about two atmospheres gauge and controlling the flow thereof through the furnace and ore to avoid a pressure drop in excess of about one atmosphere.

3. The method of decreasing the deficiency of hearth heat in a blast furnace during operation, which comprises maintaining the pressure of the blast feed gas at the hearth in excess of a normal blast pressure of between about one and one-half and two atmospheres absolute, and regulating the rate of flow of the blast gas through the furnace by throttling the discharge of the gas from the furnace to create a static pressure in the furnace of between about three and eight atmospheres absolute.

4. The method of operating a sealed blast furnace, which comprises compressing the blast feed gas in excess of two atmospheres absolute and not materially in excess of about eight atmospheres absolute, throttling the discharge of the gas from the furnace to prevent a pressure drop exceeding about one atmosphere to maintain the average static pressure within the furnace in excess of about two atmospheres absolute, and preheating the blast feed gas after compression.

5. The method of smelting ore in a blast furnace, which comprises maintaining a blast feed gas pressure between about two and seven atmospheres gauge in the furnace, and throttling the discharge of the gas from the furnace to maintain the average static pressure within the furnace in excess of two atmospheres absolute and to increase the blast rate through the furnace by an amount not materially in excess of about one-half the blast rate produced with unthrottled gas discharge.

6. In a blast furnace having a blast gas feed pipe and a gas discharge pipe, the combination of a sealed furnace shaft capable of operation at internal pressures in excess of about two atmospheres gauge, means for compressing the blast feed gas supplied to the feed pipe to a pressure in excess of two atmospheres absolute, and throttling means in the gas discharge pipe for building up the pressure within the furnace in excess of two atmospheres gauge.

7. In a blast furnace having a blast feed pipe and a gas discharge pipe, the combination of a sealed furnace shaft capable of operation at superatmospheric pressure, a compressor for compressing the blast feed air supplied to the feed pipe to a pressure in excess of two atmospheres absolute for maintaining the pressure within the furnace and the discharge therefrom at not in excess of about eight atmospheres absolute, an

internal combustion engine, connections between the gas discharge pipe and the engine for supplying at least a part of the discharge gas as fuel to the engine at said pressure in excess of two atmospheres absolute, means for supplying a part of the blast feed air to the engine as combustion-supporting air at said pressure in excess of two atmospheres absolute, and driving connections between said engine and said compressor.

8. The method of increasing the output, decreasing the solution loss, and increasing the quantity of hearth heat available in a blast furnace during operation, comprising maintaining the blast pressure at a gauge pressure substantially greater than the normal gauge blast pressure of about one-half to one atmosphere and not materially in excess of seven atmospheres, and throttling the discharge of gases from the furnace to control the blast rate to a rate not greater than about one-half the rate obtained by allowing the gas to escape without throttling.

9. The method of increasing the output, decreasing the solution loss, and increasing the quantity of hearth heat available in a blast furnace during operation, comprising maintaining the blast pressure at a gauge pressure substantially greater than the normal gauge blast pressure of about one-half to one atmosphere and not materially in excess of seven atmospheres, and throttling the discharge of gases from the furnace to control the blast rate to a rate substantially less than the normal blast rate multiplied by the ratio obtained by dividing the absolute blast pressure employed, by the normal absolute blast pressure.

10. The method of increasing the output, decreasing the solution loss, and increasing the quantity of hearth heat available in a blast furnace during operation, comprising maintaining the blast pressure at a gauge pressure substantially greater than the normal gauge blast pressure of about one-half to one atmosphere and not materially in excess of seven atmospheres, and throttling the discharge of gases from the furnace to control the blast rate to a rate substantially equal to the normal blast rate produced by allowing the gas to escape without throttling multiplied by one half the ratio obtained by dividing the absolute blast pressure employed, by the normal absolute blast pressure.

11. The process of operating a blast furnace to reduce solution loss of fuel, increase output and the quantity of hearth heat available in the blast furnace during operation, comprising maintaining the blast pressure at a gauge pressure in excess of two atmospheres, and throttling the discharge of gases from the furnace to maintain a pressure drop through the furnace not greater than about one atmosphere and an average static pressure in the furnace of between about two and about seven atmospheres gauge.

12. The process of operating a blast furnace to reduce the solution loss of fuel, increase output and the quantity of hearth heat available in the blast furnace during operation, comprising maintaining the blast pressure while throttling the discharge of gas from said furnace to maintain an average gauge pressure in said furnace of between about two and about seven atmospheres, and a blast rate substantially less than if the discharge gas were allowed to escape without throttling.

13. The process of operating a blast furnace to decrease solution loss and increase output per unit of blast rate, which comprises maintaining

a blast pressure in excess of a normal blast pressure of about one-half to about one atmosphere gauge, and throttling the discharge of gas from the furnace to create an average static pressure 5 in the furnace not materially exceeding seven and less than ten atmospheres gauge.

14. The process of operating a blast furnace to increase output and decrease solution loss, which comprises maintaining a blast pressure 10 in excess of a normal blast pressure of about one-half to about one atmosphere gauge, and throttling the discharge of gas from the blast furnace to create a static pressure in the furnace of less than ten atmospheres gauge and to main- 15 tain a blast rate substantially less than would result by allowing the gas at a normal shaft

pressure of between about one-fourth and one-half atmosphere gauge to escape without throttling.

15. The process of operating a blast furnace to increase output and decrease solution loss, 5 which comprises maintaining a blast pressure in excess of a normal blast pressure of about one-half to about one atmosphere gauge, throttling the discharge of gas from the furnace to create an average static pressure in the furnace 10 not materially exceeding seven atmospheres gauge and to maintain a blast rate not materially in excess of one-half the rate that would result if the gas were allowed to escape without throttling. 15

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