

ON THE WORKING AND CAPACITY OF BLAST FURNACES.

BY MR. CHARLES COCHRANE, OF DUDLEY.

At a former meeting of this Institution in 1860 the writer read a paper on a method of taking off the gas from a close-topped blast furnace at the Ormesby Iron Works, Middlesbrough (see *Proceedings Inst. M. E.*, 1860, page 121); and the original construction of closed top and lifting valve for charging is shown in the accompanying Fig. 1, Plate 56, the materials for the charges being filled into the exterior space B surrounding the charging valve A, which is drawn up into the position shown by the dotted lines for allowing the materials to fall into the furnace; while the gas is taken off from the furnace top by the passage E.

The usual plan of closed top adopted in blast furnaces is that represented in Fig. 3, Plate 58, in which it will be seen that the materials are filled in against a lowering cone C, placed in the throat of the furnace, which on being lowered into the position shown dotted permits their fall into the furnace. The tendency of the material in this case is to roll outwards from the charging cone to the side of the furnace, and thence back again to the centre, as shown in the drawing.

It was thought at the time of adopting the plan shown in Fig. 1, Plate 56, that the height of the materials carried by the same furnace would be increased, and that a corresponding economy in consumption of fuel would result, owing to the circumstance that where the plan shown in Fig. 3 is adopted the level of the materials must always be maintained at a certain distance below the top, to ensure the fall of the cone C at charging time. The plan shown in Fig. 1 was devised with due regard, as it was thought, to the arrangement of the materials in the furnace; and it was

intended that they should arrange themselves as shown by the dotted line in that drawing, part of the larger material rolling to the outside of the furnace and part to the centre.

As long as the furnace could be kept so full as to ensure the arrangement of materials shown by the dotted line in Fig. 1, there was no reason that it should not work uniformly; but the practical result was that it was found impossible to keep the furnace sufficiently full to secure the distribution of the materials in the manner intended. The level of the surface of the materials was generally below that intended, the consequence of which was that the material on falling into the furnace was shot into the centre, from whence the largest pieces rolled outwards, and the whole charge arranged itself as shown by the full line in Fig. 1. The result of this was irregular working of the furnace over a period of many months, during which an explanation of the irregularity was in vain sought for. At one time it was thought the back pressure of the escaping gas had something to do with the irregularity; at another the cause was sought for in the difficulty of keeping the hopper valve A of the furnace tight, and the necessity for using small material around the valve as a kind of lute between every charge to prevent the escape of the gas: until it occurred to the writer that the arrangement of the materials in the furnace was the sole explanation of the difficulty, and that as all the material was shot into the centre of the furnace the small pieces would remain there whilst the large would roll to the outside. Believing that it was of great importance, in order to secure uniform results, that there should be a uniform distribution of the heated gas from the hearth over the entire horizontal area of the furnace at each stage of its height, he considered that the effect of any small material being collected in any portion of the area would be to obstruct the passage of the gas at that part, and so prevent that portion of the material from being heated to its proper degree of temperature.

Deeming this to be the explanation of the irregularities experienced in the working of the furnace, the writer devised a method of distributing the material so as to prevent such a result,

by the introduction of a frustum of a cone D, Fig. 2, Plate 57, suspended inside the throat of the furnace, which was found to be all that was necessary. The materials then arranged themselves in the desired manner, as shown in the drawing; and the result has since been a perfect uniformity in the working of the furnace. Where previously a yield of foundry iron from the same furnace could not be relied upon for more than about 24 hours at a time, and the annoyance was incurred of the furnace suddenly changing to white iron, the production of white iron except when desired is now unknown. A consideration of these facts will lead to a fair estimate of the importance of the arrangement of the materials in a blast furnace. Anything that opposes the free passage of the ascending heated gas at any part of the furnace must direct the gas into another channel, and the material thus left insufficiently acted upon finds its way into the hearth at a low temperature, and white iron is the result.

The effect produced on the distribution of material by this internal frustum of a cone is obviously similar to that of the ordinary lowering cone when lowered, shown in Fig. 3, Plate 58; and the latter has now consequently been finally adopted at the Ormesby Iron Works as the permanent form of the arrangement, and is now being carried out there.

The most perfect action of a blast furnace the writer conceives to consist in the development of the highest temperature needed for the production of the required quality of iron, in a layer or stratum as little removed from the tuyeres as possible; and the gradual absorption of the heat from the ascending gas by the materials through which it passes, until it leaves the throat of the furnace at the lowest possible temperature. Anything which tends to cause a more perfect absorption of the heat developed in the hearth, or to lower the level of the region of highest temperature in the furnace, will thus be beneficial.

With regard to the absorption of the heat from the gas, it is obvious that the hotter the temperature at which the gas escapes, the more wasteful must be the effect; and theoretically the height

of a furnace should be increased until the temperature of the escaping gas is reduced to that of the materials on their introduction into the furnace top. This is the theoretical limit to the height of a blast furnace: but it must not be forgotten that the less the difference in temperature between two bodies, the less rapid is the communication of heat from the hotter to the cooler; hence for the absorption of the last few degrees of temperature from the ascending gas a much greater height of material is necessary than where the gas and the material differ more widely in temperature. Already with 50 to 60 feet height of blast furnace in the Middlesbrough district the temperature of the escaping gas does not exceed 500° to 600° Fahr.; and it is a question to be answered only by experiment how far the gain from the heights of 70 to 75 feet already accomplished at Middlesbrough, and further heights of 10 or 20 feet additional that are contemplated, will compensate for the extra work in raising the materials to the additional height and for the more substantial plant required. In the direction of height there is unquestionably on this account a limit which will speedily be attained; supposing the limit be not previously determined by the necessity for increased pressure of blast and by the increased difficulty in working the furnaces.

As regards the benefit produced in the working of a furnace by lowering the level of the region of highest temperature, it is evident that this benefit is of the same nature as in the previous case, since the lowering of that level is equivalent to an increase in the height of the furnace. The level of the region of highest temperature is dependent upon the heat of the blast, and is brought down nearer to the tuyeres only by using a hotter blast: and in the writer's opinion the chief source of economy yet to be attained in the working of blast furnaces, independent of the more extended application of the waste gas, lies in the use of blast heated to a still higher temperature than that hitherto known. The yield of iron from any ironstone is governed by the percentage of iron it contains, and the consumption of limestone by the nature of the ironstone; and both these are therefore fixed quantities for the special materials employed. But that is not the case with the coke, which

offers a fruitful source of saving; and in what way therefore this saving is effected by increased temperature of the blast becomes a most important question, involving as it does the general theory of hot blast.

It appears to the writer that in order to explain the effect of the hot blast it is necessary to regard the nitrogen of the atmosphere and the generated carbonic oxide as the great heat "carriers" in the operations of the blast furnace. This consideration involves two others: namely the time required for heating the nitrogen from its initial temperature at entering the furnace up to that needed for the fusion of the materials in the furnace; and also the method by which the gases are heated. Taking it for granted that the colder and consequently the denser pure oxygen is the more intense is the combustion of any body burning in it, there is evidently no necessity for heating this constituent of the atmosphere. It is further obvious that supposing 3000° Fahr. be the temperature required for the fusion of the materials on their reaching the hearth, then every pound of the nitrogen introduced by the blast must be raised to that temperature before the fusion can take place.

Now in a cold-blast furnace the nitrogen is introduced at the lowest temperature, and requires necessarily the longest time for being raised to the requisite temperature: hence the maximum temperature in the furnace is produced at a higher level, and diffused over a larger portion of the furnace where it is not wanted; and it is consequently impossible in some cases ever to get the temperature sufficiently high at any part of the furnace to produce more than the qualities of iron known as forge iron. In proof of this may be mentioned an attempt made some years ago at the Ormesby Iron Works, Middlesbrough, to produce cold-blast iron of a gray or foundry quality. It was in vain however that the burden of ironstone was reduced, that is the proportion of coke increased: the temperature of the hearth could not be sufficiently raised to produce any other quality than forge iron, the effect of the reduced burden being only to throw an increased temperature into higher regions of the furnace. The attempt was consequently

abandoned; not however until it became obvious that the burden might have been still further diminished with only the effect of diffusing the hottest temperature into still higher regions of the furnace.

Whatever heat is imparted to the nitrogen of the atmosphere and also to the carbonic oxide generated in the furnace is of course delivered up again to the materials in the furnace, excepting only the portion lost by the temperature at which the gas escapes at the throat of the furnace. The effect of heating the nitrogen before its entrance into the furnace now becomes more clear. It has a shorter distance to travel up within the furnace before the maximum temperature is attained, for the simple reason that, having been partly heated already, it requires less time to become further heated to the temperature required in the furnace, having got the start by the amount of its initial temperature. Hence the fusing heat is generated nearer to the tuyeres; and this circumstance, together with the smaller expansion of hot blast compared with cold blast on entering the furnace, seems to furnish a satisfactory explanation of the more immediate effect of heated air in preventing diffusion within the furnace of the region of highest temperature.

As to the method of heating the nitrogen, it must be borne in mind that the heat generated in a blast furnace is obtained wholly or nearly so by the imperfect combustion of the carbon of the coke into carbonic oxide as the final result, a process by which theoretically only about one fourth the total quantity of heat is developed that would be obtained by the perfect combustion of the same carbon into carbonic acid, showing a loss in the fuel of about 75 per cent. of heat; since 1 lb. of carbon burnt into carbonic oxide develops only 2880 units of heat, whilst 1 lb. of carbon burnt into carbonic acid develops about 11700 units of heat. For although the combustion of the carbon of the coke in the blast furnace is partially or wholly into carbonic acid so long as the supply of oxygen is in excess, this condition applies only to the lower portion of the furnace nearest the tuyeres; and this carbonic acid becomes ultimately reduced to carbonic oxide by passing through the excess of carbon in the mass of incandescent coke

occupying the upper portion of the furnace. If therefore the nitrogen be heated partially or wholly before entering the furnace, by any means involving the perfect combustion of the fuel employed into carbonic acid, it follows that a large saving in fuel must necessarily result; and to give an idea of the real influence of the nitrogen of the atmosphere on the consumption of fuel in the blast furnace, the writer has endeavoured to express numerically the effects produced by taking three different cases of the blast entering the furnace at the various temperatures of 50° , 650° , and 1150° Fahr. respectively. It is assumed that the air has to be heated within the furnace to 3000° Fahr. in each case; that 1 lb. of carbon burnt into carbonic oxide will develop 2880 units of heat, that is, will raise 2880 lbs. of water through 1° Fahr.; and that the specific heat of air is $\cdot 275$, compared with that of water as 1.000. It is further assumed that 4500 cubic feet of blast enter the furnace per minute; and as 1000 cubic feet weigh 76 lbs., the weight of blast entering the furnace per minute will be 342 lbs., 77 per cent. of which or 263 lbs. weight is nitrogen.

In the three cases cited it will be seen that the work to be done within the furnace is to raise the temperature of the air through

2950° in the first case,

2350° in the second,

1850° in the third.

In the first case, namely to heat 263 lbs. of nitrogen through 2950° , there will be required

$$\frac{263 \times 2950 \times \cdot 275}{2880} = 74 \text{ lbs. of carbon per minute.}$$

In the second case, namely to heat 263 lbs. of nitrogen through 2350° , there will be required

$$\frac{263 \times 2350 \times \cdot 275}{2880} = 59 \text{ lbs. of carbon per minute.}$$

In the third case, namely to heat 263 lbs. of nitrogen through 1850° , there will be required

$$\frac{263 \times 1850 \times \cdot 275}{2880} = 46 \text{ lbs. of carbon per minute.}$$

These results show that to raise the temperature of the blast from 50° to 650° before it enters the furnace causes a saving in the blast furnace of 15 lbs. of coke out of 74, or about 20 per cent.; and that a further increase of temperature from 650° to 1150° occasions a saving of 13 lbs. out of 59, or about 22 per cent. To show that these calculations are not so merely theoretical as might at first be supposed, it may be here stated that in the writer's experience the raising of the temperature of the blast from 650° to 1150° at the Ormesby Iron Works has accomplished an actual saving of from 17 to 18 per cent. of coke in the blast furnace; and this was effected at an expense of coal outside the furnace of about one half the weight of coke saved within the furnace. The writer believes however that, were it in his power to compare two exactly similar systems of hot-air stoves, the additional fuel consumed outside the furnace would approximate more nearly to one third of the weight saved inside the furnace than to one half. But the difficulty of having to compare the ordinary cast iron stoves with the regenerative hot-blast stoves, by which the highest named temperature of 1150° is attained, is too great to allow of the comparison being made more precisely.

In the cold-blast furnace the method of heating the air is simply by its direct contact with the heated material and incandescent coke, and it is heated altogether at the expense of carbon burnt only into carbonic oxide instead of into carbonic acid. In the hot-blast furnace, by the more complete combustion of the heating fuel in the hot-blast stoves, exterior to the furnace, the nitrogen is heated not only at a cost of fuel represented by a saving of theoretically three fourths in the actual weight of coke required within the furnace to raise the nitrogen to the same temperature, but also with the further advantage that instead of burning coke it is coal that is used for the purpose. In other words, for every pound of coal economically burnt outside the furnace in raising the temperature of the blast, three pounds of coke will be saved within the furnace, whether the furnace be open or closed at the top.

It may be thought that a comparison made between an open-topped furnace where the gas burns freely as it escapes, and a

close-topped furnace where no such combustion takes place, is not a fair one; and that the combustion of the gas at the throat of the open-topped furnace, by imparting heat to the materials at the throat of the furnace, would tell in favour of the consumption of fuel in the open-topped furnace. But facts speak otherwise, and it appears that there is practically no difference whatever due to this cause.

It will thus be seen that a definite limit to the height of a furnace is soon reached in practice; and that the advantage derived from increasing the actual height of a furnace may be partly secured by increasing the temperature of the blast, and thereby lowering the region of maximum temperature in the furnace.

The only question that remains is as to the diameter of the furnace. In reference to this dimension, the danger that has been alluded to from the formation of cold masses in the centre of a blast furnace serves as a caution against the more dangerous formation of cold masses attached to the sides of the furnace, technically called scaffoldings. It is obvious that, if the width of the boshes of a furnace be large in proportion to the height and the volume of the ascending gas, there will be a tendency to unequal diffusion of the heat imparted by that gas over the successive horizontal sections of the furnace, and irregularities in its working will consequently set in. There is then a limit to the diameter of the boshes, the largest of which yet in use is believed to be about 21 feet; beyond this size it appears very questionable whether any beneficial result would arise, though a furnace has been stated to be in course of construction at Cwm Celyn having a diameter of 24 feet at the boshes.

The nature of the materials of the charge in any contemplated increase of the dimensions of a blast furnace must be most scrupulously borne in mind. The density of the coke is the most important consideration; but next to that is the friability of the ironstone itself. In the Staffordshire district it would be useless to build furnaces of the height contemplated and actually employed in the Middlesbrough district, for the simple reason that the

Staffordshire coke is friable and would be crushed most injuriously by the weight of superimposed material.

It is thus evident that the actual dimensions of a blast furnace in any particular instance are much dependent upon special local circumstances ; but the writer has endeavoured to point out the general principles which guide the determination of the dimensions to be adopted.

The PRESIDENT thought the paper that had been read was an excellent one and gave a clear explanation of the advantage of hot blast and the principles involved in the arrangement of the materials in a blast furnace. He enquired what had been found to be the effect of the internal distributing cone in the throat of the furnace at the Ormesby Iron Works, as regarded the quality of the iron produced, and whether there had been any difficulty in keeping the furnace up to the desired quality of foundry iron since the internal cone had been added.

Mr. COCHRANE replied that the quality of the iron now made by the furnace was the same as the foundry iron made in the same furnace before the internal distributing cone was added ; but the difference produced by the cone was this : that before its application, although the furnace would make as good a quality of foundry iron when in good working order, it was liable continually to be thrown suddenly to white iron, owing to irregularities in the arrangement of the materials in the furnace, causing them to reach the hearth in an imperfect state of fusion, so that white iron was produced notwithstanding the burden was the proper one for foundry iron ; whereas since the addition of the internal cone no white iron had ever been produced with a foundry iron burden, but the furnace was now kept regularly to foundry iron without any irregularities occurring in its working.

The PRESIDENT enquired what was the construction and weight of the internal cone, and what was found to be its durability in that situation.

Mr. COCHRANE replied that the cone was made of sheet iron and was suspended inside the throat of the furnace by four chains from the charging plate, as shown in the drawing; its weight was about 5 cwts. The cone had now been in regular use for about four months, and would probably have lasted ten or twelve months before requiring renewal, if that plan of charging had been continued in constant work; it was however only a temporary construction which he had adopted by way of trial, for the purpose of satisfying himself respecting the arrangement of the materials in the furnace top; and the entire furnace top was now in process of alteration to the ordinary plan of closed top with the cast iron lowering cone for charging, as shown in Fig. 3, Plate 58, since this served the same purpose of distributing the materials in the furnace as the internal distributing cone; a single large opening was also employed for taking off the gas at one side, instead of the annular gas chamber previously used.

Mr. J. E. SWINDELL enquired how the impossibility of making No. 1 foundry iron with cold blast in the Middlesbrough district was accounted for, and whether it was considered due to the more intractable nature of the materials in that district.

Mr. COCHRANE believed it was entirely owing to the more intractable nature of the materials that it was impossible to make the best qualities of foundry iron with cold blast in the Middlesbrough district, because in Staffordshire No. 1 foundry iron could be produced with cold blast. The explanation he thought was as submitted in the paper just read: that with cold blast the air had to travel higher up into the furnace before a sufficient heat was obtained for the reduction of the iron ore; and it was possible also that the nature of the materials in the Middlesbrough district required a temperature which could not be produced at all with cold blast.

Mr. J. E. SWINDELL asked whether it was considered that the materials in the furnace really did melt nearer to the tuyeres with

hot blast than with cold blast; he understood that practical men who had worked both hot and cold-blast furnaces stated distinctly that the materials melted nearer to the tuyeres in a cold-blast furnace than with hot blast.

Mr. COCHRANE said the object to be aimed at in the blast furnace was to get the region of maximum temperature limited as much as possible in its extent above the tuyeres, and to leave all possible height of the furnace available for the absorption of the heat generated in the lower parts. No doubt with cold blast the materials were melting as close to the tuyeres as with hot blast, but the objection to the cold blast was that it caused them to be melting also considerably above the tuyeres, for a height of probably as much as 10 or 12 feet above. The object more correctly stated was therefore to bring down, not the point at which the materials *did* melt, but the point at which they *did not* melt; that is, to bring down the upper limit of the region of fusion, and confine the maximum temperature to the least possible height above the tuyeres: and he was fully satisfied that this was the effect produced by the hot blast as compared with the cold blast.

Mr. E. REYNOLDS suggested that the difficulties which had been met with in the working of the furnace arose from the construction of the closed top and charging valve, which appeared to be a reversing of the old mode still employed at the Butterley Iron Works, where the charging was done by means of a filling barrow, which carried the charge in a bucket at the end of a projecting arm reaching over the centre of the open top of the furnaces; each bucket consisted of a vertical cylinder, the bottom of which was closed by a cone held up against it, and the charge was dropped into the furnace by lowering the cone valve. By that plan, when the cone was lowered for charging, the tendency of the charge was to shoot outwards; but with the construction of the closed top shown in the drawings, when the charging valve was raised, the slope of the charging plate surrounding the valve would cause the material to be shot towards the centre of the furnace, and would thus occasion the difficulties that had been experienced. These he suggested might be obviated if the sides of the charging plate

were more nearly vertical, so as to shoot the material less into the centre of the furnace, and agree more nearly with the vertical sides of the charging cylinders in the old plan used at Butterley.

Mr. COCHRANE did not see how such an arrangement of the charging plate could have been carried out with the construction of charging valve that had been employed at the Ormesby Iron Works, nor was the slope of the charging plate a point of importance after the internal distributing cone had been added. The object of having a charging valve that should be raised for charging, in place of the ordinary cone valve that was lowered in the furnace at each charge, had been to save as much height as possible in the furnace and admit of keeping the materials charged up to a higher level in the throat of the furnace. It had been a question therefore in the first instance between employing a much larger charging valve, so as to avoid all risk of the charges being shot into the centre of the furnace; or keeping the size of the valve as small as was compatible with maintaining the level of the materials in the furnace up to the full height intended: and it had been found, as the result of experience, that the original size of the charging valve, only 6 ft. 6 ins. diameter, was too small to prevent the charges falling into the centre of the furnace, although the difficulties arising from that cause had since been entirely obviated by the addition of the internal distributing cone for directing the materials outwards towards the sides of the furnace. At a neighbouring furnace however in the Middlesbrough district, where the same construction of closed top with lifting valve had been adopted, the valve had been made 9 ft. 6 ins. diameter instead of only 6 ft. 6 ins.; and the consequence of this increase in its size was that the charges were distributed sufficiently towards the sides of the furnace, instead of shooting into the centre, and the furnace was working admirably without any need of an internal distributing cone such as it had been necessary to have recourse to in the furnace described in the paper.

The PRESIDENT enquired what was the difference of size in the Staffordshire blast furnaces as compared with those in the Middlesbrough district.

Mr. J. E. SWINDELL said that the furnaces in the Staffordshire district were from 13 to 18 feet in diameter as a maximum, and not exceeding 45 to 50 feet in height.

The PRESIDENT asked whether the materials of the charges for the close-topped furnace described in the paper were broken to any particular size before charging.

Mr. COCHRANE replied that the limestone was broken by hand labour to a size of about 4 to 6 inches cube; but the ironstone was taken as it came from the kilns, and no attempt was made to break it at all, as that had not been found to pay.

The PRESIDENT enquired whether the high temperature of 1150° Fahr., which had been mentioned as the heat of the hot blast at the Ormesby furnace, was the average temperature of the blast, and what was the extent of fluctuation in the temperature.

Mr. COCHRANE replied that the blast was heated by means of Mr. Cowper's regenerative hot-blast stoves, and the average temperature of blast obtained was 1150° in regular working. The very outside fluctuation was about 200° during the four hours that each stove alternately heated the blast, the maximum temperature being nearly 1250° when the newly heated stove was first turned on, and the minimum temperature not less than 1050° at the end of the four hours' working of the same stove.

The PRESIDENT asked what had been the experience with reference to the durability of the regenerative hot-blast stoves, and whether any difficulty had occurred with any part of them.

Mr. COCHRANE said he had now had these stoves in regular work for upwards of three years, and as regarded their durability they did not show the slightest signs of wear or deterioration, but appeared likely to last for an indefinite length of time. The only parts in which any difficulty had been experienced were the stop gas valves of the stoves; these gave some trouble at first in consequence of a condensation of tar upon them, which prevented them from fitting as tightly as was necessary to avoid leakage, and the tar afterwards ignited and cracked the valve seats; but that difficulty was now entirely got over by not allowing the gas to come into contact with the valve at the time the blast was passing

through the stove, so that any leakage of blast, instead of escaping into the gas, was now discharged into the open air.

Mr. E. A. COWPER remarked that the regenerative hot-blast stoves heating the blast for the Ormesby furnace were the same that he had described at a meeting of the Institution four years previously, (see Proceedings Inst. M. E., 1860, page 54); and the advantages then anticipated from heating the blast in that manner to the high temperature of 1150° Fahr. had been fully realised in actual working. The temperature of 1150° was not attainable with common stoves, in which the heat of the blast seldom exceeded 650° , and could not be increased much beyond that amount on account of the heating being done by means of cast iron pipes. The regenerative stoves however afforded the means of raising the temperature to as much as 1250° or more, the blast being heated by direct contact with the hot mass of firebrick contained in the stove, which had previously been heated by direct contact with flame. The result of employing a blast of that high temperature had been as stated in the paper, that 17 to 18 per cent. of coke was saved in the blast furnace: and there was also an increase of about 20 per cent. in the quantity of iron made, while the quality of the iron was better than previously, more of No. 1 being made.

Mr. F. J. BRAMWELL observed that the arrangement of close-topped blast furnace described in the paper was one of the plans by which the whole of the gas was taken off from the furnace, and there was no combustion of gas out of the mouth of the furnace; and in connection with that arrangement it appeared to be considered that the sole object to be attained was that the materials in the upper part of the furnace should absorb as completely as possible the heat generated lower down. He believed however there was a general opinion that a certain beneficial chemical effect was produced by allowing some of the gas to burn out of the furnace mouth, so that its combustion there might operate in preparing the newly charged materials and rendering them more ready to be acted upon and deoxidised as they descended in the furnace. An open-topped arrangement, similar to that employed

at Messrs. Schneider's furnaces at Ulverstone, had been described at the Liverpool meeting of the Institution last year (see Proceedings Inst. M. E., 1863, page 227), a large portion of the gas being taken off by a vertical tube inserted in the centre of the furnace throat, while the annular space surrounding the tube was left open for the rest of the gas to burn out freely at the mouth of the furnace; and that plan appeared to him to satisfy all the requirements, for while allowing so much of the gas to be taken off as was required for working the blast engine and heating the blast, it still left gas enough burning out of the furnace top to produce the heat necessary for the proper preparation of the materials, and also left the mouth of the furnace open so that the charging was done in the ordinary manner by hand. He thought therefore that an arrangement which allowed of combustion at the furnace mouth and of charging in the ordinary manner fulfilled the required conditions of a blast furnace better than one in which the combustion at the furnace top was entirely stopped by taking off the whole of the gas, and where the charging had to be done by special means in consequence of the top of the furnace being closed.

In reference to the irregular quality of the iron produced where there was any irregularity in the charging of the materials, he thought it most important that great attention should be paid to having the materials all broken to a uniform size for putting into the furnace. For where a chemical process had to be carried on, such as the reduction of the ironstone and other materials of the charge, it was impossible to expect uniformity of results without uniformity of mixture; and if large masses of ironstone and limestone were put into the furnace, they could not be so thoroughly and uniformly acted upon by the heat as if smaller pieces broken to a uniform size were used. A stone-breaking machine for breaking the limestone and iron ore for blast furnaces had been seen in operation by the members at the Liverpool meeting in last year, and had also been described at a subsequent meeting (see Proceedings Inst. M. E., 1864, page 20); which effected the breaking of the materials with great economy, and with a rapidity sufficient for all the purposes of a large ironworks; and he thought such a

machine would be productive of great advantage by conducing to uniformity in the quality of iron made with a given burden.

He had not had an opportunity of seeing the regenerative hot-blast stoves at work for heating the blast, but they were an admirable adaptation of Mr. Siemens' regenerative system: he had seen the regenerative furnaces applied to other purposes where a very high temperature was required, and certainly nothing could exceed the success of their application in such cases. There was no doubt that the mass of firebrick in the regenerative stoves gave the means of heating the blast as high as 1150° Fahr. or upwards, and of maintaining it easily at that temperature, which it would be impossible to accomplish in the ordinary mode of heating the blast through cast iron pipes. Moreover in the regenerative stoves every particle of fuel was utilised, since the heat given out by it was taken up so completely by the firebrick in the regenerators that the chimney flue remained cool enough to allow of the hand being held in it; and the blast being afterwards heated by passing in the reverse direction through the same mass of firebrick, the heat was carried forwards by it into the blast furnace, and great economy was thus effected, the whole of the heat being thereby utilised, instead of a large amount of waste heat escaping to the chimney. There appeared no reason to doubt that the increase in the temperature of the blast from the ordinary heat of 650° to the high temperature of 1150° maintained at Ormesby was attended with the beneficial results that had been mentioned, as regarded economy of fuel in the blast furnace; and that being the case, it might be expected that a still higher temperature of blast would be found productive of yet greater economy. As to what temperature of blast would give the maximum of economical effect, if the question were one of merely melting the ore, no doubt the process of heating the air by means like the regenerative stoves, which utilised nearly the whole of the fuel, might be advantageously carried on until the air was made sufficiently hot to do the whole work of melting the ore without the use of any fuel at all in the furnace; unless indeed before that point were reached the highly heated blast should have an injurious effect on the walls of the

furnace, which however he did not at all fear. But it must be borne in mind that the use of the fuel in the furnace was not merely to generate heat for melting the charge, but that one of its most important functions was to act chemically on the ore so as to fit it for reduction. It seemed to him probable therefore that the limit of useful effect in heating the blast would be reached at that point where its increased temperature would admit of the fuel in the furnace being reduced to the minimum quantity requisite to act chemically on the ore. What that quantity might be was a chemical question: but he had little doubt that the limit was sufficiently far off to allow of the temperature of the blast being still further increased with advantage; and he believed this increased temperature could be obtained by the use of the regenerative stoves, which he was very glad to hear had worked so successfully during the four years they had been in action.

Mr. COCHRANE remarked that, as regarded the burning of the gas in the throat of the blast furnace, he was led to believe that the temperature of the ascending gas on reaching the top of the furnace was not sufficient to produce any chemical effect upon the materials, and the addition of a few feet height at the top of the furnace was only a question of absorbing the heat more completely from the gas before it escaped from the furnace. He had at one time considered that the combustion of the gas in the throat of an open-topped furnace had something to do with dispelling any foreign matter in the coke or the ironstone, or possibly finishing the calcining of any portion of the ironstone that had been imperfectly burned, or drying the materials and warming them more thoroughly previous to their descent in the furnace. But the results of subsequent experience had now led him to conclude that there was not any appreciable difference in yield between a furnace working with a totally closed top and one which allowed the combustion of the gas in the throat. The explanation of this fact appeared to be the same as that which applied to the burning of an ordinary candle, where the gas in the interior of the cone of flame remained so cold that gunpowder might be placed in it without being exploded; and in the same way in an open-topped blast furnace,

the gas by the time it reached the top of the materials was at its lowest temperature, and it had still so much further to ascend before it came in contact with the oxygen of the air necessary to burn it, that the heat generated by its combustion at the furnace mouth, although large in amount, could not radiate back again through the ascending column of gas so as to impart any of its temperature to the materials lying in the throat of the furnace.

As regarded the breaking of the materials previous to charging, there could be no question that if they could be always broken to a uniform size it would be very advantageous to the working of the furnace. This was already accomplished to a considerable extent in the case of the limestone, which was broken by hand labour for the purpose; but in respect to the ironstone, he had no hesitation in saying that any attempt to break it into pieces of uniform size would be frustrated in the Middlesbrough district by the amount of waste made in crushing it, on account of the friable nature of the Cleveland ironstone.

Mr. J. E. SWINDELL mentioned that an attempt had been made eighteen years ago in a blast furnace at Wingerworth in Derbyshire to get the gas ignited and consumed close to the surface of the materials in the furnace throat, in order that the whole of the heat generated by the combustion might be utilised in the furnace. The furnace was about 25 or 30 feet high, with the top entirely closed, the charging of the materials being done through doors provided for the purpose; and a small opening furnished with a damper admitted air to the top of the furnace for the combustion of the gas. The result was that the gas was entirely consumed in the top of the furnace, and the heat produced was so great that the materials at the top were almost in a melting state. The furnace had been worked in that manner for a considerable length of time, but the results were altogether unsuccessful as to quality of iron made and economy of fuel, and the plan was therefore abandoned.

Mr. J. FERNIE had been much struck with the very great waste of heat that must take place at the open-topped furnaces of Gartsherrie and other places in the neighbourhood of Glasgow,

where the quantity of waste gas burning out of the furnace tops appeared largely in excess of what was observed in many English open-topped furnaces; and he could not help thinking the closed top or some other mode of taking off the gas and utilising it might be applied with great advantage to many of the Scotch blast furnaces.

The PRESIDENT enquired whether the iron produced was found to be stronger or better in quality in consequence of the high temperature of the hot blast described in the paper. He remembered that formerly iron used to be produced so strong that the pigs had to be cast with nicks in them for breaking, but latterly the strength had so much deteriorated that a pig would break by merely falling on the ground; and he feared that more attention was now paid to cheapness than to quality of iron.

Mr. COCHRANE said he had not made any experiments to ascertain the actual increase of strength in the iron produced with the very hot blast employed at Ormesby, but he could state positively that there was an increase of strength, as shown by the fact that the work of breaking the pigs after each cast was now much heavier, which was a rough test of the increased strength. There was a decided improvement in the purity of the iron made with the hotter blast, which would no doubt explain its increased strength. In the Middlesbrough district it was found that a little scum of impurities rose to the surface of the melted iron in the blast furnace, which was sometimes very objectionable in casting; but with the hotter blast there was less of this scum rising, showing that there was increased purity of the iron produced. In fact as the greater part of the impurities in the iron arose from the coke, the smaller quantity of coke used with the hotter blast gave less opportunity for these impurities to pass into the iron.

Mr. J. ANDERSON thought it strange that makers of iron on a large scale should allow the question of quality to occupy so little of their attention. The fact that the tensile strength of different descriptions of iron in the pig ranged from as low as only 4 tons per square inch up to 15 tons, with all the strengths between, showed that there was something to be done by the iron maker, and that

the founder had very little to depend upon previous to trial as to the kind of iron that should be used for any purpose, since with the inferior irons the strains to which they would be subjected in use must often approach very nearly to their breaking strength. He thought the iron maker should ascertain the exact quality of the iron which he made, so as to be able to state definitely how good it was in respect to toughness, elasticity, and ultimate tensile strength. If these points were more attended to, instead of merely the production of iron in great quantities, it would in the long run be the better for the country at large.

Mr. W. HADEN remarked that if a superior quality of iron were desired it could always be obtained if a proportionate price were paid for it. But there were many other requirements also for which a very inferior quality of iron was quite suitable; and if these were to be overlooked, a large amount of the material in the various iron making districts would lie worthless. The great object to be aimed at in every district was to utilise the material of that district to the utmost extent.

Mr. J. ANDERSON thought that, if there were greater facilities for getting good iron, a proportionate diminution might be made in the dimensions of castings, compared with those made of the inferior iron at present employed; and if more care were bestowed upon getting the greatest strength from the ironstone of a district, and the chemical constituents of the iron were attended to, the minimum tensile strength of the iron in the pig might probably be brought up to 8 tons per square inch or upwards. Thus only half the weight of iron would have to be used in those structures for which the inferior iron was at present employed.

Mr. J. E. SWINDELL thought the only excuse for not using the better qualities of iron was their high prices; but the tensile strength of 8 tons per square inch that had been mentioned appeared to him to be considerably below the actual strength that was generally obtained from the best makes of pig iron. At his own works in the South Staffordshire district the tensile strength of bars 1 inch square of cold-blast iron cast direct from the blast furnace was found to be 14 tons in the regular make, though it

was not possible for that strength to be guaranteed in all castings made from such pigs, because the metal might be so treated subsequently in the foundry as to have much of its strength destroyed. The mechanical qualities of any sort of iron, its strength, toughness, and elasticity, were the principal points to be regarded, he considered; and the question of chemical composition and the minute proportions of foreign ingredients mixed with the iron appeared to him of very secondary importance.

Mr. F. J. BRAMWELL concurred in thinking that the chemical composition of iron should be viewed as of secondary importance in comparison with its mechanical qualities. If a number of inferior descriptions of iron were found by chemical analysis to contain a certain foreign ingredient which was found to be absent from other irons of a better class, that afforded a presumption that the particular ingredient in question deteriorated the quality of any iron containing it: but the exceptions to this inference were found to be so numerous in practice that it would be a mistake to reject any iron merely on the ground of its containing some special ingredient, while its mechanical properties might notwithstanding be such as to place it among the class of good irons. He therefore considered the mechanical qualities were in every case those which should be first regarded. In describing the strength of any make of iron, one thing to be stated was the condition that the iron was in, whether in the pig or after a subsequent process of casting, as the strength was much affected by difference of the conditions in that respect. In the case of some iron from Nova Scotia which he had had occasion to test, he had found that in the pig it bore a tensile strain of only $7\frac{1}{2}$ tons per square inch; but after repeated fusion and mixing with its own scrap, the same iron bore an average tensile strain of $18\frac{1}{2}$ tons per square inch, while the highest strength obtained by that means was as much as $19\frac{5}{8}$ tons per square inch, as proved by the testing machine at Woolwich, showing how greatly the original strength in the pig might be increased by subsequent treatment.

Mr. J. ANDERSON remarked that having lately given a good deal of attention to the properties of iron in its different characters

of wrought iron, cast steel, and cast iron, he had come to the conclusion that the chemical composition of the metal was the great question. He had found that wrought iron which was most nearly pure, containing the least amount of carbon, had a tensile strength of about 20 tons per square inch, and in the irons of Scotland and the steely irons of Yorkshire the strength varied from that amount up to 28 tons per square inch, while cast steel containing $1\frac{1}{2}$ per cent. of carbon had an ultimate tenacity as high as 75 tons; whereas in cast iron, containing the largest proportion of carbon, the strength declined to 8 tons and downwards as low as 4 tons per square inch. All these descriptions of iron, excepting the purest with the tensile strength of about 20 tons, had their strength increased by plunging them while in a heated state into cold water. He had also found that the facility of welding any description of iron was in proportion to its freedom from the chemical constituent, carbon, which increased its tenacity; so that the purer and weaker irons welded more readily than those containing more carbon and possessing greater tensile strength. Thus the steely irons of Yorkshire became very difficult to weld in the stronger qualities, and the next gradation in the scale was the mild steels which he was now using for guns. These had very nearly the same constituents as the Yorkshire iron, and were affected to nearly the same extent by being made red-hot and plunged into water. The various mechanical properties of the different descriptions of iron were now becoming generally understood, but the great question that still remained for solution was altogether a chemical one: namely, what it was that produced such great changes of quality in the different sorts of iron, and particularly what it was that caused iron to become so much stronger when heated red-hot and plunged into water.

Mr. P. D. BENNETT thought the subject of the different qualities of various descriptions of iron was of the greatest importance to the makers of iron, and he would be very glad if an explanation could be given as to why there was so much difficulty in getting Staffordshire iron to stand tests which were borne by Scotch iron of much less cost. His own practice in testing iron was to have a

test bar cast 2 inches deep by 1 inch wide with 3 feet between the bearings, which ought to carry a load of 28 cwts. in the centre before breaking, if the iron were of at all a good quality. But in the case of the Staffordshire district he had found it difficult to get any of the cheaper iron to stand that test, while Scotch iron would readily stand 32 cwts.; and to get Staffordshire iron to stand the same test as the Scotch, the price would be as much as 20s. to 30s. per ton higher than the Scotch. In some recent experiments with the best cold-blast Staffordshire iron he had succeeded after much difficulty in getting a test bar to stand a weight of 37 cwts., which was the highest test he had been able to attain with it; but the price in that case was as much as £5 10s. per ton as compared with only £3 10s. for Scotch iron of the same strength. He hoped therefore that the reason of this great difference would be more satisfactorily explained than had yet been done.

Mr. E. A. COWPER thought there was still much to be done in respect to the chemical investigation of the different qualities of iron, in order to ascertain clearly what was the cause of the differences that were met with; for when this was known, so that the quality of any desired sort of iron could be fully described, he had no doubt the iron makers would find the means of producing that quality of iron readily enough. At present chemistry had not gone far enough in this subject; for in a recent case one of the strongest irons known had been rejected on chemical reasons alone.

In reference to increasing the strength of iron by heating it red-hot and plunging it into cold water, it was found very advantageous, in the case of casting chilled rolls, to melt and cast the iron into cold water two or three times beforehand. He did not know what change this made in the nature of the metal, but it had the effect of causing the iron to chill more completely in the final casting, and thus increased the hardness and durability of rolls cast in that way.

Mr. J. ANDERSON observed that a great deal had already been accomplished and was still in process of being done by government towards ascertaining the chemical qualities of iron, and to a certain extent these endeavours had been successful; but because chemical

investigation had not always led to correct results at present, it ought not on that account to be disparaged.

Mr. F. J. BRAMWELL thought the value of chemistry in connection with the properties of iron should not be depreciated ; but on the other hand, when the sole object was to get iron that should satisfy certain mechanical requirements, if the chemical test and the mechanical test were at variance, it was a mistake to accept the chemical test in lieu of the mechanical. In any case of a discrepancy between the two, the test which was practical should be adopted, and not that which was only a means of arriving at the practical by another road.

The PRESIDENT considered the experiments and researches that had been referred to as being made by the government must tend to a good result ultimately, and were leading the way for further investigations by individual makers and consumers of iron, who were all anxious to get better iron. A very elaborate machine was now in course of construction by Mr. Kirkaldy, for the purpose of testing iron in respect to all its various mechanical properties, which would enable the makers of iron to ascertain with great accuracy the quality of the metal which they produced.

He proposed a vote of thanks to Mr. Cochrane for his paper, which was passed.

The Meeting was then adjourned to the following day. In the afternoon the Members were conveyed by special train, granted for the occasion by the Edinburgh and Glasgow Railway Company, to visit the Mugdock Reservoir of the Loch Katrine Water Works, with the Straining Well, the Outlet of the Loch Katrine Aqueduct, and the Delivery Sluices for the supply of Glasgow. The Members were received at the Milngavie Station and accompanied over the works at Mugdock by the Lord Provost of Glasgow and the authorities of the Water Works ; and returned to Glasgow in the evening by special train.

The Adjourned Meeting of the Members was held in the Institution Rooms, St. George's Place, Glasgow, on Wednesday, 3rd August, 1864; ROBERT NAPIER, Esq., President, in the Chair.

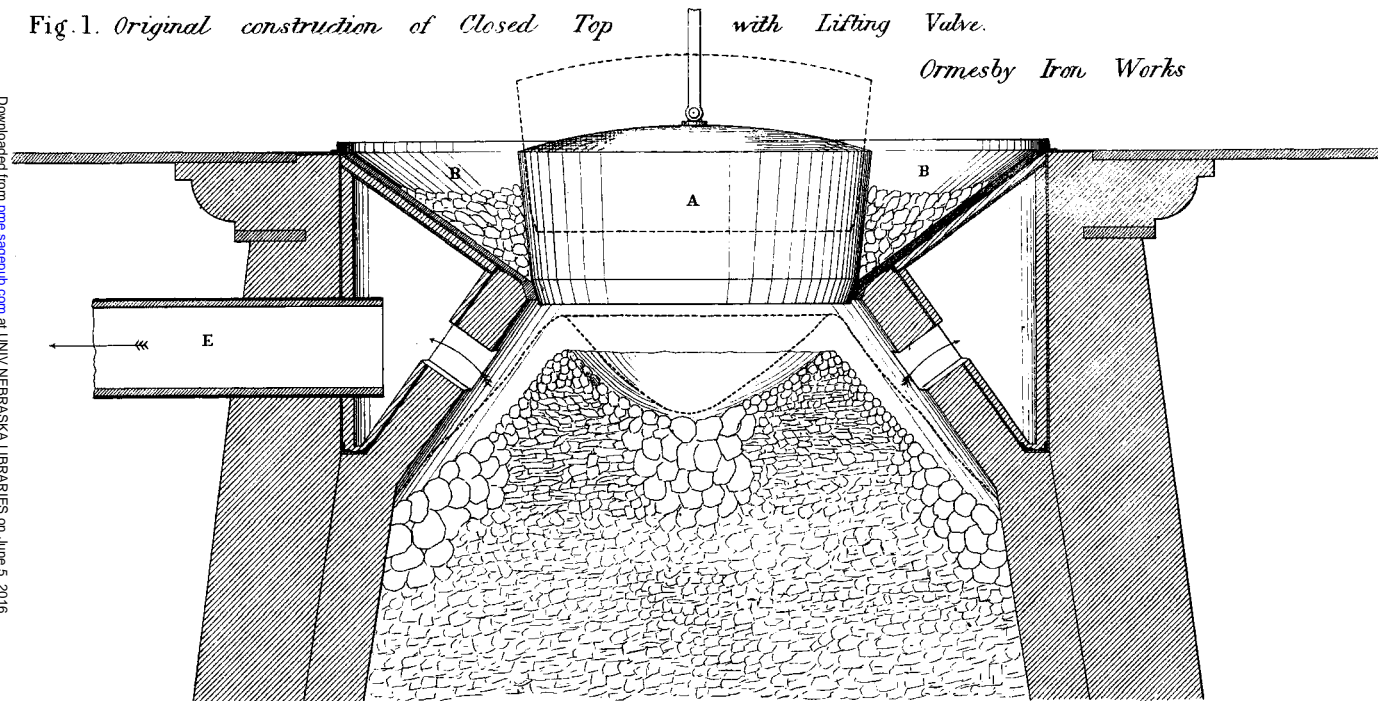
The following paper was read :—

BLAST FURNACES.

Plate 56.

Fig. 1. Original construction of Closed Top with Lifting Valve.

Ormesby Iron Works



(Proceedings Inst. M.E. 1864. Page 163) Scale $\frac{1}{50}^{th}$

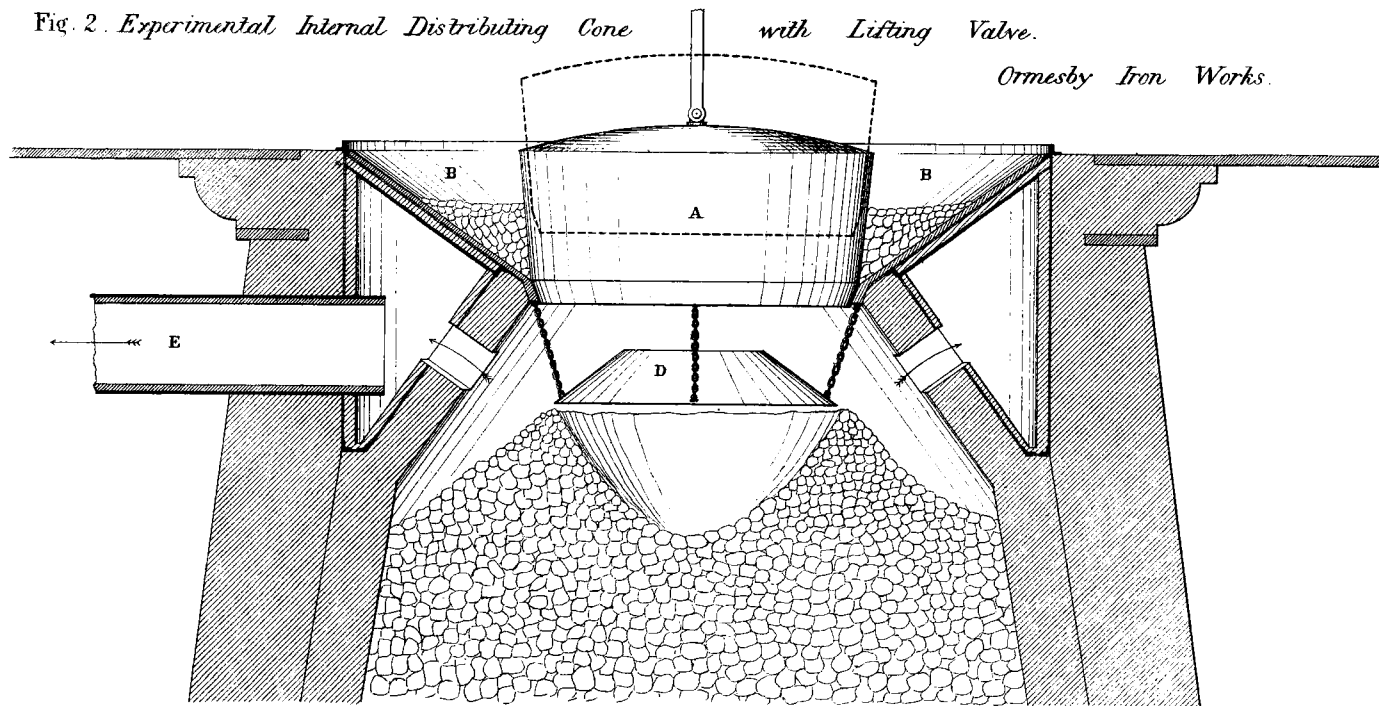
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BLAST FURNACES.

Plate 57.

Fig. 2. *Experimental Internal Distributing Cone with Lifting Valve.*

Ormesby Iron Works.



(Proceedings Inst. M.E. 1864. Page 163.) Scale $\frac{1}{50}^{th}$

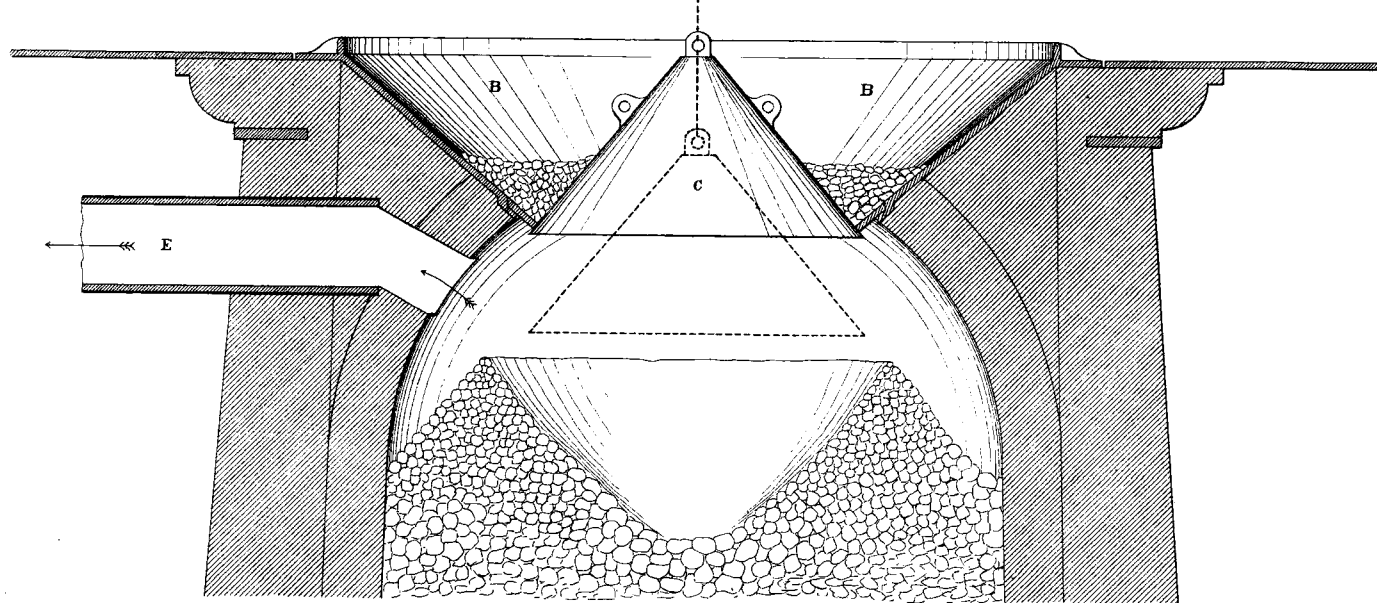
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BLAST FURNACES.

Plate 58.

Fig. 3. *Ordinary construction of Closed Top
Final arrangement*

*with Lowering Cone Valve.
at Ormesby Iron Works.*



(Proceedings Inst. M.E. 1864. Page 163.) Scale $\frac{1}{50}^{th}$

0 5 10 15 Feet.