April 13th, 1916.

NOTES OF SOME EXPERIMENTS ON THE FLOW OF AIR IN LEAD BLAST FURNACES.

(By A. W. TOURNEY-HINDE.)

I propose this evening to describe some experiments made about the end of the year 1911 at the Cockle Creek Smelting Works, for the purpose of ascertaining the behaviour of the air entering the tuyeres of a lead smelter.

Before doing so, however, a short resume of the history of the smelting of Broken Hill lead ores will not be out of place.

The immensely rich silver lead ore body of Broken Hill was discovered in 1883, and smelting at Broken Hill commenced about 1885-1886. From that date onward, the ore treated was from the upper part of the lode, and consisted of oxidised ore. Lead-silver ore in this form is easily smelted, and no difficulties were encountered till about 1894 to 1896, when the large bodies of oxidised ore in the deposit gave out. The ore body below the depth then attained was found to be principally lead sulphide, with only small bodies of oxidised ore. The lead sulphide proved incapable of satisfactory commercial treatment by the methods then in vogue.

To most persons Broken Hill is known as a silver and lead mine. By far the largest proportion of the metals in the lode is, however, zinc. Fig. 1 shews in graphic form the relative proportions of zinc, lead, and silver contained in the ore, which is from the Central Mine at Broken Hill, belonging to the Sulphide Corpora-

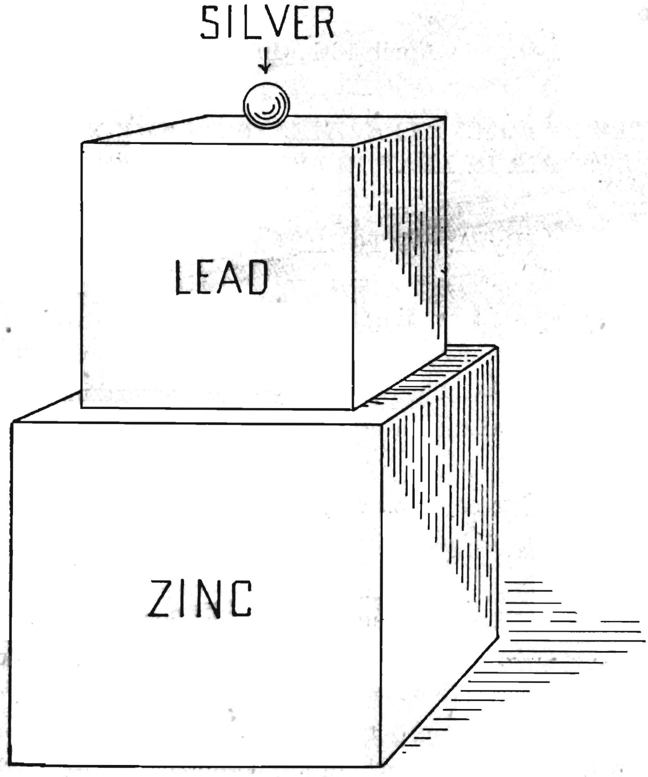

Fig. 1.

tion, Ltd.. The large cube at the base represents zinc, the upper cube, lead, and the small sphere on the top is the silver, there is also a small trace of gold.

The presence of so much zinc, coupled with the sulphide nature of the ore, made smelting, as then known in an ordinary lead smelter, practically impossible, and various methods of considerable ingenuity were introduced to remove as much of the zinc as possible so as to permit of smelting. This proved an extremely difficult problem. One of the most noteworthy attempts, which after the expenditure of nearly a quarter of a million pounds, proved a failure, was that of E. A. Ashcroft, who attempted to remove the zinc by electrolysis. This was, in the years 1896-1897. Separation of the zinc by means of fine crushing and Wilfly tables had been tried, and, about the same time or soon after, was developed sufficiently to prove instrumental in producing a concentrate which, whilst it was not ideal, contained a sufficiently small amount of zinc to permit of practical smelting. Unfortunately, however, the zinc portion which was separated out still contained a considerable portion of lead and silver, and at that time was untreatable, either for its zinc, lead, or silver contents, and was therefore dumped. In the course of time these dumps assumed enormous proportions, and their value in metal content per ton of dumped material, could it be recovered, was practically equal to the value per ton of the original ore in the mine.

Since that time, however, improvements in methods of separation, though of gradual development, have been amongst the most noteworthy of metallurgical achievements in recent years. At the present time by means of the flotation process, the ore is separated into two high-class concentrates, one containing nearly all the lead and most of the silver, and the other containing nearly all the zinc, together with a little of the lead and silver. To such a degree of excellence have the processes been brought, that the total metal recoveries in the concentrates produced represent 90 per cent. of the silver, 94 per cent. of the lead, and 92 per cent. of the zinc contained in the original ore.

In the year 1897, shortly after the failure of the Ashcroft Process, successful smelting of the zinc-lead concentrates then produced was, I believe, first accomplished at Cockle Creek, by A. E. Savage. The smelters in use at that period had a height of about 18ft. from feed floor to tapping floor, and were of the usual water jacketed type, and were operated with a blast pressure of 8 to 10 oz. per square inch. The air was supplied by rotary blowers, of the Baker type. Owing to the fine powdery condition of the charge in the furnace, and to the imperfect elimination of the sulphur and the presence of so much zinc, the difficulties were great.

About 1900 an improvement was effected by Huntingdon & Hebbelein, who introduced the method of blowing up the fine powdery ore, after roasting, and while still red hot, in a converter. This removed practically all the sulphur and left the ore ready for the smelter—matted or semi-fused together in large lumps, thus giving a freer passage for the air through the charge of ore in the smelter.

From this period on, assisted from time to time by the gradual development and production of a higher class of lead concentrate at Broken Hill, there has been a steady and regular improvement in the smelting operation, and to-day very high-class work indeed is attained in a lead smelter of modern type on these concentrates.

As already mentioned, the earlier types of lead smelters were about 18 feet in height, and worked at a blast pressure of about 8 to 10 oz. per square inch. Owing to the improved condition of the smelting charge occasioned by the introduction of the converter process, it become possible to increase the depth of the ore body in the smelter. This was done gradually. Each new smelter, as necessity for the construction of new ones arose, was built with a higher shaft, until at the present time a height of 36 feet from tapping floor to feed floor is not uncommon. This increase in height necessitated higher blast pressures, and as about 15 to 20 oz. per square inch is about the limit of the rotary type of blower, it was decided at Cockle Creek to introduce the piston type

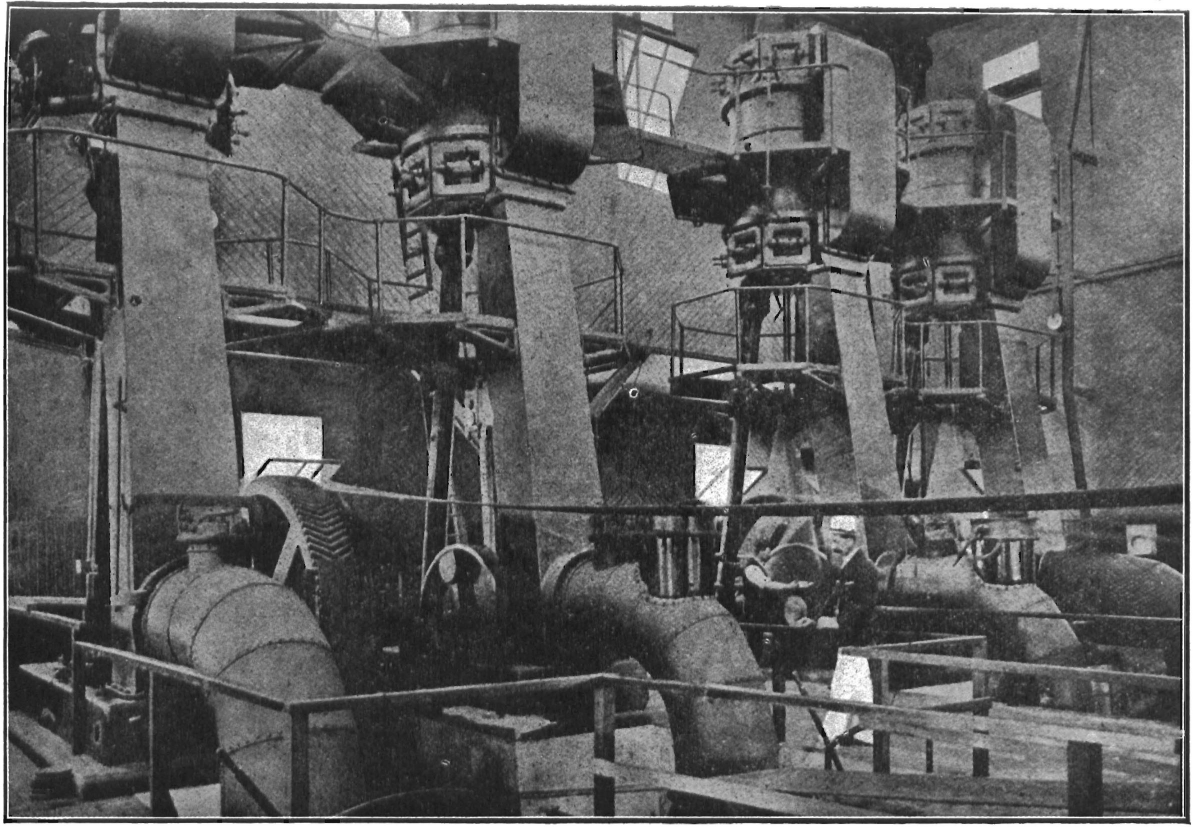

Fig. 2.

of blower. Enquiries were made in Europe and America for blowing engines. A consideration of the prices received, led to a decision that it should be possible to build a set of blowing engines suitable for the work for less money in Australia. Plans were prepared by the author, and a contract let to Mort's Dock in 1904, who built the two pairs of blowing engines, a photo of which in shewn in Figure 2. There are many features in these engines which are a distinct departure from ordinary blowing engine practice, but time does not permit of a reference thereto in the present paper.

The engines are belt-driven from 250 volt direct current electric motors of about 150 h.p., with a speed regulation of 390 to 650 r.p.m. by means of shunt control. The cylinders are 51in. diam. x 4ft. 6in. stroke, and the volume of air discharged is about 6820 cubic feet per min. per pair of engines at 30 r.p.m., and 4550 at 20 r.p.m. The maximum pressure per square inch is 90 oz. They were installed in 1904, and have been in continuous successful operation up to the present time, and are still good for many years' service. They have often made continuous non-stop runs for periods of three months night and day, and have proved remarkably free from breakdown, and are economical in operation.

Most engineers are more or less familiar with the general construction of a water-jacketed smelting furnace. Lead smelting furnaces, though they differ in detail, conform to the general features present in all smelting furnaces. Fig. 3 shews a longitudinal and cross-section of a modern lead smelter. At the base is a crucible which contains the molten metal, viz., lead bullion which is drawn off from time to time through the lead spout. The crucible is constructed of fire bricks, enclosed in a strongly reinforced steel casing. On the top of the molten metal floats a layer of slag, which rises to the

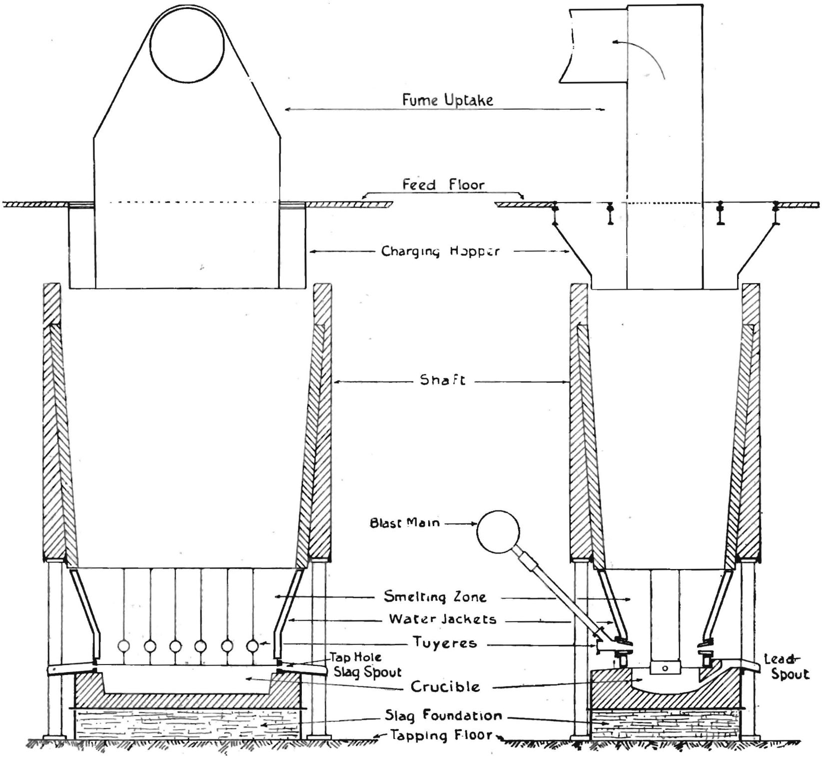

Fig. 3.

top owing to its lower specific gravity. The slag is removed as often as necessary through the tap holes and slag spouts at each end of the furnace. Above the crucible are the water jackets, and through openings left between them and projecting into the furnace are the tuyeres through which the air for the combustion of the fuel is forced into the furnace. The space surrounded by the water jackets is the smelting zone, where all the solids put in at the top of the furnace are reduced to liquids. Extending above the water jackets, and supported independently of them by columns, is the shaft.

This is constructed of brickwork, and has a fire-brick lining. Above the top of the shaft is the fume uptake, constructed of steel plates, the sides of which are so constituted as to form the charging hopper into which the material to be smelted is tipped.

The smelting charge consists of the ore, fuel, and fluxes in suitable proportions, and is brought to the feed floor and over the charging hopper in self-tipping waggons that run along rails on the floor. I beams support these rails over the charging hopper.

Those of you who have occupied positions as engineers at works where there is also a chemical staff, are doubtless quite familiar with the ever-present controversy between the engineering and chemical staffs. In the case of a smelting works it is just the same, the metallurgical staff could do wonders if they were only engineers, and the engineers could do excellent metallurgical work if they only knew enough to run the furnace. Such controversy is usually, or ought to be, quite friendly, and where the good-humoured banter between the staffs is taken in the proper spirit, it often leads to mutual advantage on both sides.

The experiments on the flow of air in lead blast furnaces with which this paper is concerned, and to which I will now refer, may be described as the result of such verbal interchanges between the staffs as have just been referred to.

With the gradual increase in the height of the lead smelter it became necessary to always provide for correspondingly increased pressure of blast. Sometimes the metallurgical ideas as to pressure required would be ahead of that which it was possible for the engineering staff to provide, when any shortcomings in the smelting equation were laid upon the broad backs of the engineering staff, and at other times, rarely it should be stated, the engineering staff were in the pleasant position of being able to provide more blast than was required, and on such occasions should the working of the smelter be not all that it should, the metallurgical staff had to carry it.

A digression is permissible here to attempt to describe what probably takes place in the shaft and smelting zone of a blast furnace during its operation. Fig. 3 already referred to shews a longitudinal and cross section of a modern lead blast furnace. At the top of the shaft the furnace charge is cool, and, as it gradually descends, becomes more and more heated by the ascending products of combustion from the smelting zone at the lower part of the furnace. I might say here, that it takes about 10 to 12 hours for any section of the charge to descend from the top to the bottom of the furnace. When the charge has reached the position just above the top of the jackets, it is, more or less, in a semi-plastic or pasty condition, and it is essential that its descent should be regular and uniform, otherwise there is a risk of its chilling slightly, and solidifying into a more or less solid lump. If this occurs partially or wholly, there is considerable risk of the smelting operation stopping, which means that the charge in the furnace after it has been allowed to cool down, has to be removed by the laborious method of hammer and gad.

An increase in the blast pressure, in other words the introductoin of more air into the smelting zone tends to increase the rate of smelting, and enlarges the smelting zone, the upper section of which usually then occupies a slightly higher position in the furnace.

Such increase in the blast pressure is generally resorted to when danger threatens, due to the charge solidifying above the smelting zone, and the raising of the position of the smelting zone within the furnace has the effect of softening the refractive charge, permits it to continue its descent, and thus overcomes the difficulty.

One of the principal sources of controversy between the metallurgical and engineering staffs was on the vexed question of the diameter of tuyere opening. It was held by some of the metallurgists that a tuyere, whose interior was conical in shape, and having a comparatively small aperture at the furnace end, produced a better result than a similar tuyere with a larger aperture, of, say, double the diameter. The idea was that the small opening produced a more intense or jet line action to the entering air, and therefore tended to improve the combustion in much the same manner as the air issuing from a pair of bellows does in blowing up a fire.

A consideration of the facts, however, from a scientific point of view, hardly bore out this theory. The air pressure at the tuyere was presumably practically that in the blast main, and if the interior of the furnace carried no greater pressure than that of the outer air, or at any rate very little more, as was claimed by the advocates of the air jet theory, the quantity of air delivered to the furnace, due to the difference of pressure, would be infinitely more than the blowing engines were capable of pumping.

In order to set the question at rest, the following experiments were made. The pressure of the air inside the smelting zone was ascertained by fixing a gland attachment to the sight hole of the tuyere caps, so that a ½-in. diam. iron pipe could be passed to and fro through it like a piston rod in a cylinder. This was essential, as it was impossible to keep the inner end of the pipe in the smelting zone for more than about ten to twelve seconds at a time, otherwise it would have melted off. The outer end of the iron pipe was connected by means of a rubber pipe to a mercurial gauge.

On the day the experiments were made, the pressure in the blast main was 46oz. per sq. inch. The readings of the mercurial gauge shewed that the actual pressure in the tuyere was from 40 to 41 ozs., at six inches beyond the tuyere in the furnace the pressure varied from 38 to 41 ozs., and at 2ft. into the furnace, or practically at the centre of the smelting zone the pressure varied from 35 to 41 ozs. These tests were made with tuyeres having an opening into the furnace of 3in. diam. The volume of air delivered to the furnace at the time through the tuyeres was 6340 cubic feet as ascertained by the displacement of the pistons in the cylinders of the blowing engines.

Other tests were made with the noses of the tuyeres closed to 2in. diam., by inserting annular pieces in the nose, and it was found that to produce the same conditions of pressure in the smelting zone, necessitated the raising of the blast pressure to 51oz. in the blast main, or in other words it required 5oz. more pressure per square inch, or an increase of 9 per cent. in the blast pressure, to force the same volume of air into the furnace.

As the amount of smelting performed, and the intensity of the temperature in the furnace, depends upon the rapidity with which the coke fuel can be consumed, it follows that the method that permits of the freest ingress of air at the lowest pressure is the most economical when the cost of power to operate the blowing plant is taken into consideration.

Therefore the large diameter tuyere carried the day. The experiment clearly proved that most of the kinetic energy in the air was dissipated in overcoming the resistance through the charge in the upper part of the furnace, and that only about 2 to 3 oz. per square inch was expended in actually forcing the volume of air into the smelter.

It should be noted that in arriving at the results stated, the mean value of a number of readings was taken.

Owing to the constantly changing conditions in the smelting zone and shaft of the furnace, as the body of ore gradually moves downwards, and also owing to the melting of the mass of material, continual variation in the sizes of such cavities as may exist in the smelting zone, the pressures are continually changing. For instance, the opening of one or more tuyeres may be momentarily blocked by the descending mass, so that sometimes a tuyere may be clear and supplying air freely to the interior of the furnace, and at other times may be partially or wholly ineffective owing to its operating in a zone of particularly high resistance to the passage of the air. The figures given shew that in some cases the pressure per square inch at the tuyere and at a point two feet into the furnace was the same, thus demonstrating conclusively that at that particular moment the tuyere was delivering no air, although quite free, so far as appearance went. In another instance there was as much as 5oz. difference in pressure between that at the tuyere and a point two feet into the furnace, shewing that that tuyere was operating well and delivering a large quantity of air.

The result of the experiments would appear to shew that the air enters a smelting furnace at each tuyere in a constantly varying quantity, depending on the resistance offered at the moment to the passage of the air through the material situated opposite or adjacent to the tuyere.

The sizes of tuyere openings during the experiments were 3in. and 2in. diam., respectively, as has already been stated. Theoretically, at any given air pressure, a two-inch diameter opening should deliver approximately about half the volume of air as compared with a 3in. opening. But the placing of an annular stopping or nozzle in the nose of a tuyere introduces other factors that modify the theoretical discharge. The air is supplied to the tuyere through a comparatively long pipe from the "Bussel Pipe" or air main surrounding the furnace. In the case under notice these pipes were 4½in. diam., and 9ft. 6in. long. And as the air in this pipe is travelling at a high velocity, there is a relatively greater drop in pressure in the length of the pipe when the tuyere opening is 3 inches, than when it is 2 inches diameter. That is, with any given pressure in the blast main. The actual pressure per square inch in the tuyere with the 2in. opening is therefore slightly higher than in the case of the tuyere with the 3in. opening, and therefore the 2in. opening passes rather more air than half the quantity that a 3in. tuyere would do.

The condition of the material in the upper shaft of the furnace is mainly responsible for the pressure required to force sufficient air into the furnace to maintain smelting. If this material be in large lumps and loosely packed, the resistance is much less than when the reverse is the case, and much can be done by the skill of the metallurgist and men operating the charging of the furnace, to avoid the necessity for an unduly high blast pressure. Care is usually taken to feed the coarser material to the centre, and the finer to the sides, thus ensuring a more or less central draft to the furnace.

From 3oz. to 5oz. difference of pressure per square inch between that in the tuyere and that in the furnace itself would appear, both by calculation and by experiment, sufficient to force the requisite quantity of air into the furnace. Suppose that a furnace was operating at 45oz. per square inch, and that it was desirable for some metallurgical reason to increase the blast pressure to 55oz. This does not mean that there will be 10ozs. more pressure forcing air into the furnace, or that proportionately more air will flow, for the interior pressure in the smelting zone will rise proportionately with the increase in the external pressure. There will, of course, be a slightly higher difference of pressure between that in the tuyere and the smelting zone, and slightly more air will be forced in. So far as it was possible to ascertain, an increase of 10oz. in the blast pressure produced only an increase of about .5oz. to 1oz. effective difference of pressure for forcing air into the furnace.

If the foregoing notes seem to lack academic accuracy, I would point out that they are data obtained in a comparatively rough manner, under everyday working conditions, merely in order to set at rest a very vexed question between the metallurgical and engineering staffs of a certain smelting works. They are, at any rate, sufficiently accurate to shew what really happens.

To summarise the foregoing data, it may be postulated that:—

1. The volume of air delivered to a blast furnace at any given pressure virtually depends entirely on the resistance offered by the condition of the charge in the smelting zone and shaft.

2. The pressure of the air in the smelting zone of the furnace with any given blast pressure is dependent on the tightness of the charge in the shaft, and is indepen-

dent of the size of the tuyere opening, so long as the tuyere area available will permit of sufficient air passing into the furnace for smelting.

3. The pressure in the smelting zone is usually only 2oz. or 3oz., and should not be more than 5oz. or 6oz. below the pressure at the tuyere, as these differences of pressure are ample to pass into the furnace all the air required.

4. Variations in the pressure of the air in the blast main, cause almost equal variations in the pressure of the air in the smelting zone.

5. Variations in the size of the tuyere opening only vary the amount of energy required to force a given volume of air into the furnace, and do not materially vary the conditions of volume or pressure or smelting within the furnace.

Discussion

MR. SINCLAIR (in moving a vote of thanks to Mr. Tourney-Hinde for his paper) said:

Mr. Tourney-Hinde's paper appeals to me because it is just one of those papers which has a personal touch about it that we in this Association like to hear, as men who have actually measured things and done things themselves make interesting speakers. Personally, I am not on familiar ground in dealing with smelting furnaces and mining matters, and there are probably others here of the same way of thinking, and there are some things upon which I think Mr. Tourney-Hinde might give us a little more information.

I am not quite clear as to whether the air is heated before going into the furnaces or not, and if it is heated, to what temperature is it raised? Then, again, there is