II. ACCOUNT of certain PHENOMENA *observed in the AIR VAULT*
*of the FURNACES of the DEVON IRON WORKS**; together
with some practical REMARKS on the MANAGEMENT of
BLAST FURNACES. By Mr ROEBUCK, in a LETTER to Sir
JAMES HALL, Bart. Communicated by Sir JAMES HALL.

[Read, July 2. 1798.]

S I R,

I HAVE examined my memorandums, concerning the observations I made on the condensed air in the *air vault* of the Devon Iron Works, near Alloa; and, according to your request, I now transmit you an account of them; and also of an experiment I made, when a partner and manager of these works, in order to increase the produce of blast furnaces.

THE two blast furnaces at Devon are of large dimensions, each being 44 feet high, and about 13 feet wide in the bolhes, or widest part, and are formed on a steep bank, by two pits sunk in a very solid stratum of coarse grained freestone.

THESE pits were afterwards shaped and lined in the usual manner of blast furnaces, with common bricks and fire bricks, and the hearth was laid with large blocks of the stone that had been dug out, and which serve the purpose of fire stones. At the back of the two furnaces, next the bank, the air vault is excavated

* THESE iron works are on the banks of the river Devon, which runs into the Frith of Forth near Alloa. They are 3 miles from Alloa, and 8 from Stirling.

cavated, and formed by a mine drove in the solid rock, distant from the furnaces about 16 feet. The bottom of the air vault is only about 4 feet higher than the level of the bottom of the furnaces. This vault has an aperture at one end to receive the air from the blowing machine, and has two at the opposite end, one of which receives the eduction pipe, and the other is a door to give admittance occasionally into the vault. As the rock is extremely close and solid, the vault is dry, except that a little water ouzes very gently from the side next the bank in small drops, and does not appear to exceed an English pint in 24 hours.

THESE furnaces are provided with air, or blast, as it is termed, by the means of a fire-engine of the old, or NEWCOMEN'S construction. The diameter of the steam cylinder is $48\frac{3}{4}$ inches; and the square area of its piston being about $1866\frac{1}{2}$ square inches, the power of this sort of engine cannot be rated at more than 7 lb. to the square inch, amounting in all to about 13062 lb. This power was employed to work an air pump, or blowing cylinder, of 78 inches diameter, and about 7 feet long. The number of square inches on the piston of the air pump is 4778, and therefore this area, being multiplied by $2\frac{3}{4}$, will produce 13139, being a resistance that nearly balances the above-rated power, and shows that the air, which was expelled from the air pump, could not be condensed more in the ordinary way of working, than with a compressing power of about $2\frac{3}{4}$ lb. on each square inch. As the engine was not regulated, at first, to make a longer stroke than about 4 feet 8 inches, only one furnace being used, the quantity of air expelled at each stroke of the machine was about 155 cubic feet, which it discharged through a valve into the air vault, about 16 times in a minute. When two furnaces afterwards were blown, the engine was regulated to work much quicker, and with a longer stroke. The air vault is 72 feet long, 14 feet wide, and 13 feet high; and contains upwards of 13,000 cubic feet, or above 80 times the
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contents of the air pump. The top, sides, and bottom of this vault, where the least fissure could be discovered in the beds of the rock, were carefully caulked with oakum, and afterwards plastered, and then covered with pitch and paper. The intention of blowing into the vault is to equalize the blast, or render it uniform, which it effects more completely than any machinery ever yet contrived for the same purpose. The air is conducted from the vault by the eduction pipe, of 16 inches diameter, into an iron box or wind chest, and from this it goes off to each furnace, in two smaller pipes that terminate in nozles, or blow-pipes, of only $2\frac{1}{2}$ to $3\frac{1}{4}$ inch diameter, at the tweer of the furnace.

WHEN the furnace was put in blast, after having been filled with coakes, and gently heated for more than six weeks, the keepers allowed it to have but little blast at first, giving it a small blow-pipe of about $2\frac{1}{4}$ inch diameter, and likewise letting off a very considerable quantity of air, at the escape, or safety valve on the top of the iron wind chest, as it is a received though erroneous opinion among them, that the blast must be let on very gradually for several months. From the construction of this valve, it was impossible to ascertain the exact proportion of the blast they thus parted with, but I believe it was very considerable. The consequence was, that the furnace, after it had been in blast for several days, never seemed to arrive at its proper degree of heat, but was always black and cold about the tweer in the hearth, and appeared in danger of choking, or gobbing, as it is termed.

AFTER various experiments tried in vain, by the keepers and the Company's engineer, and others, (indeed they tried every thing, except giving the furnace a greater quantity of air, which, as I afterwards ascertained, was all that it wanted), they concluded, that the air vault was the cause of the whole mischief; and, to confirm their opinion, they said they had

now discovered that water was, in considerable quantities, driven out of the air vault through the blow-pipe, which cooled the furnace; and they insisted, that the power of the engine was such as to force water out of the solid rock; so that this method of equalizing the blast never would succeed. The other managing partner was so much alarmed by these representations, that he began to consult with the engineer, and others, about finding a substitute for the air vault at any expence.

As the plan of the blowing apparatus had been adopted at my recommendation, and was now so loudly condemned on account of the water, I had other motives, than mere interest, for trying to become better acquainted with the phenomena attending it. I accordingly determined to go into the air vault, and to remain inclosed in the condensed air while the engine was blowing the furnace. It is an experiment that perhaps never was made before, as there never existed such an opportunity. I could not persuade the engineer, or any other of the operative people about the work, to be my companions, as they imagined that there was much danger in the experiment. Mr NEIL RYRIE, however, one of the clerks of the Devon Company, had sufficient confidence in my representations to venture himself along with me.

THE machine had been stopped about two hours previous to our entering the vault, and we found a dampness and mistiness in it, which disappeared soon after the door was shut fast upon us, and the engine began to work in its usual manner. After four or five strokes of the engine, we both experienced a singular sensation in our ears, as if they were stopped by the fingers, which continued as long as we remained in the condensed air. Our breathing was not in the least affected. I had no thermometer with me, but the temperature of the air felt to us the same as that without the vault. Sound was much magnified, as we perceived, when we talked to each other, or struck any thing;

thing ; particularly, the noise of the air escaping at the blow-pipe, or waste valve, was very loud, and seemed to return back to us. There was no appearance of wind to disturb the flame of our candles ; on the contrary, I was surprised to find, that when we put one of them into the eduction pipe, which conveys the wind from the vault to the furnaces, it was not blown out. There was not the smallest appearance of any drops of water issuing out of this pipe. The ouzing and dropping of water from the side of the rock, next the bank, seemed the same as before the condensation was made in the vault. In short, every thing appeared, in other respects, the same as when we were in the common atmosphere. Having remained about an hour in the condensed air, and satisfied ourselves that no water, during that time, that we could in the least discover, was agitated and forced out of the rock and vault by the power of the blast, as was imagined and insisted on, we gave the signal to stop the engine. As soon as it ceased to work, and the condensation abated, and before the door of the vault was unscrewed, *the whole vault, in a few seconds, became filled with a thick vapour, so that we could hardly see the candles at four or five yards distance.* The door being now opened, the work people, anxious to know our situation, and what had occurred, came into the vault, and prevented any further observations.

I now endeavoured to account for this curious appearance of the water, which only shewed itself occasionally, in very small quantities, at the tweer, and at a hole I ordered to be made in the bottom of the wind chest to collect it more accurately, for it never was observed, but either when the engine, after working slowly, was made to work quicker, or, after having been stopped for a few minutes, was set to work again.

I CONSIDERED the vapour which we had discovered in the vault to arise from the moisture of the side of the rock next the furnace, which being expelled by the great heat of the furnace,

and converted into vapour, was able to force its way through the pores of the rock into the vault, but that being in a manner confined within the rock, by the pressure of the condensed air, it found itself at liberty to come into the vault, only when the condensation abated considerably, or was totally removed by the going flow, or stopping of the engine. It also occurred to me, that the air, in a state of condensation, might possibly be capable of holding a greater quantity of water in solution, which might precipitate suddenly into vapour or mist when the condensation abated. I imagined, therefore, that the very small quantities of water we at times discovered, proceeded from nothing else but this vapour, in its passage to the furnace along with the blast, being condensed into water, by the coolness of the eduction pipe and iron wind chest. The quantity of water did not appear to amount to a gallon in twenty-four hours.

A FEW days after I had made this experiment, the water ceased entirely to make its appearance, either at the tweer, or at the hole in the wind chest ; but the furnace did not come into heat for a long while after, and indeed not till the keepers let much more air into it by a larger blow-pipe, and allowed less air to escape at the safety valve. It is probable that the rock was now become perfectly dry by the continued heat of the furnace.

MY experiment had the good effect to remove all the prejudices against the plan I had adopted of blowing the furnaces, and likewise prevented the other partner from laying out a large sum of money, by stopping the works, and altering the blowing machinery. Indeed, it has since been admitted, by all who have seen it at work, to be the most simple and effective method of equalizing the blast of any yet put in practice.

THIS experiment led me, some time afterwards, to apply a wind guage that I contrived, to ascertain precisely the state of the
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the condensation of the air thrown into the furnaces. I found that a column of quick silver was raised five inches, and sometimes, though seldom, six inches, and, in the interval of the return of the engine to receive air into the air pump, it fell only half of an inch. At this time only one furnace was worked. But when two furnaces were in blast, the engine only raised the mercurial guage about 4 inches, because the Devon Company, for certain reasons, did not, while I continued a partner, think proper to allow the blowing machinery to be completed, by the putting to work their second boiler of 20 feet diameter for the fire engine, according to my original design, which, by adjusting the machinery, would have enabled us to blow two furnaces, with two boilers, with as much effect, in proportion, as one furnace with one boiler. This instrument had the advantage of enabling the work people to discover the real power of their blast, and know the exact condition of the air valves, and the gearing of the blowing piston; for if these were not tight, and in order, (although the engine might, to appearance, be doing well, by making the same number of discharges of the air pump as usual *per minute*), yet the wind guage would not rise so high, and would shew that there was an imperfection some where, by reason of a quantity of air escaping at the valves, or piston, that could not so easily otherwise be known. This contrivance was considered as of much use, and was afterwards always quoted in the Company's journal books, to shew the actual state of the blowing machine, in comparing the daily produce of the furnaces.

I HOPE you will not think me tedious, when I explain to you another experiment, which appears to me to be of considerable importance to all manufacturers of cast iron.

I HAD reason to conjecture, from my own observations on the effects of blowing machinery on blast furnaces, as well as
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from the knowledge I had acquired from my father Dr ROEBUCK, and from my communications with other experienced iron masters, that a great part of the power of such machinery was misapplied in general practice, by throwing air into furnaces with much greater velocity than necessary, and that, if this velocity was, to a certain degree diminished, the same power, by properly adjusting the blowing machinery, of whatever nature, would be capable of throwing into the furnace a proportionally greater quantity of air. For, “*Since the quantities of any fluid, issuing through the same aperture, are as the square roots of the pressure;*” it follows, that it would require four times the pressure, or power, to expel double the quantity of air, through the same aperture, in the same time: But if the area of the aperture was doubled, then the quantity of air expelled by the same power, and in the same time, would be increased in the ratio of the square root of 2 to 1, though its velocity would be diminished exactly in the same proportion. Again: I considered that the quantity and intensity of heat, produced in blast furnaces, and consequently its effects in increasing the produce, might be only in proportion to the quantity of air decomposed in the process of combustion, without regard to its greater velocity; that is to say, whether or not the same quantity of air was forced, in the same time, into the furnace through a small pipe, or through one of larger dimensions; for, in attending to the process of a common air furnace for remelting of iron, where there is a very large quantity of air admitted through the large areas between the bars, it is well known, that a much greater intensity of heat is produced than takes place in a blast furnace, and yet the air does not enter into the fire through the bars with increased density or great velocity. I therefore thought it probable, that increasing the *quantity* of air, thrown into the blast furnace in a considerable degree, although the *velocity or density* might be much

much less, would have the effect of increasing its heat, and operations, and produce. And as, from the principles above stated, with regard to the machinery, I saw I could greatly increase the quantity of air thrown into the furnace, by enlarging the diameter of the blow-pipe, and regulating the engine accordingly, without being obliged to employ more power, I was anxious to make this experiment.

A system of management, of which I did by no means approve, was adopted by the other partners of the Devon Company, soon after the works were begun to be erected; and, in the prosecution of it, they ordered their second furnace to be put in blast, without permitting those measures to be taken that were necessary to provide and maintain a sufficient stock of materials; and also without allowing their blowing machine to be completed, according to the original design, by the addition of its second boiler. As might have been expected, a trial of several months to carry on two furnaces, with only half the power of steam that was necessary, and an inadequate stock of materials, proving unsuccessful, the Company, as a remedy, instead of making up the above deficiencies, ordered one of the furnaces to be blown out, and stopped altogether. This improper measure, however, afforded me the opportunity of immediately putting in practice the plan I have mentioned.

WHEN one of the furnaces was stopped, the other continued to be blown by a blow-pipe of $2\frac{3}{4}$ inches diameter, and the produce of the furnace, for several weeks thereafter, was not 20 tons of iron *per* week at an average. The engine at this time was making about 16 strokes a minute, with a stroke of the air pump, about 4 feet 8 inches long; but when I altered the diameter of the blow-pipe, first to 3, and immediately after to $3\frac{1}{4}$ inches diameter, and regulated the working gears of the engine, so as to make a stroke of 5 feet 2 inches long, and about 19 strokes in a minute, on an average, the produce was immediately

ly increased. It continued to be, on an average of nine months immediately after this improvement, at the rate of 33 tons of iron *per week*, of as good quality as formerly; for during this period, from the 21st November 1795 to July 30. 1796, this one furnace yielded 1188 tons of iron. No more coals were consumed in working the blast engine, or other expences about the blowing machine incurred, and therefore no more power was employed to produce this great effect. It is also of much importance to remark, that the consumption of materials, from which this large produce was obtained, was by no means so great as formerly. The furnace required very considerably *less fuel, less ironstone, and less limestone*, than were employed to produce the same quantity of iron by the former method of blowing; and according to the statements made out by the Company's orders, as great a change was effected in the æconomical part of the business.

FROM the success of this experiment, so well authenticated, and continued for several months, I am led to be of opinion, that all blast furnaces, by a proper adjustment of such machinery as they are provided with, might greatly and advantageously increase their produce, by assuming this as a principle, *viz. "That with the given power it is rather by a great quantity of air thrown into the furnace, with a moderate velocity, than by a less quantity thrown in with a greater velocity, that the greatest benefit is derived, in the smelting of ironstones, in order to produce pig-iron."* However, it is by experiment alone, perhaps, that we can be enabled to find out the exact relations of power, velocity, and quantity of air requisite to produce a *maximum* of effect*.

BUT, an unfortunate disagreement among the partners of the Devon Company, put it out of my power to make further progress

* If Q be the quantity of a fluid, issuing in a given time through an aperture of the diameter D , V its velocity, and P the power by which it is forced through the aperture: then the area of that aperture being as D^2 , the quantity of the fluid issuing in the given time will be as VD^2 , or $VD^2 = Q$.

grefs in this matter, by laying me under the necessity, two years ago, of withdrawing myself entirely from the concern.

I have the honour to be, respectfully,

S I R,

Your most obedient servant,

JOHN ROEBUCK.

June 30. 1798. J

To Sir James Hall, Bart.

IN order to illustrate what is said above, a ground plan of the air vault and furnaces of the Devon Iron Works is given in Plate I. ; of which the explanation follows :

EXPLANATION OF FIG. 2. PL. I.

- A The air vault, formed by a mine drove in the solid rock of coarse grained freestone.
- B The blowing cylinder.
- C The pipe that conveys the air from the blowing cylinder to the air vault.
- D The eduction pipe that carries the air from the air vault to the iron wind chest.

PART I.

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AGAIN, this quantity multiplied into its velocity, will be as the *momentum* of the fluid expelled, or as the power by which it is expelled, that is, $V^2 D^2 = P$, or $VD = \sqrt{P}$.

HERE, therefore, if D is given, V is as $\sqrt{P}$, as Mr ROEBUCK affirms. Also, because $V = \frac{Q}{D^2}$, and also $V = \frac{\sqrt{P}}{D}$, $Q = D\sqrt{P}$, so that, while P remains the same, Q will increase as D increases, and V will diminish in the same ratio.

THE problem, therefore, of throwing the greatest quantity of air into the furnace, with a given power, strictly speaking, has no *maximum*, but the largest aperture of which the engine can admit must be the best. It is probable, however, that there is a certain velocity with which the air ought to enter into the furnace ; this will produce a limitation of the problem, which, as Mr ROEBUCK suggests, is not likely to be discovered but by experiment. J. P.

- E The iron wind chest, (about $2\frac{1}{2}$ feet cube), in which is inferted a wind-gauge, represented in fig. 3.
- F F The two blow-pipes for each furnace, which terminate in apertures of $3\frac{1}{4}$ inches diameter at the tweers of the furnaces.
- G G The two blast furnaces, placed in two pits sunk in the solid rock.
- H H The tumps of the furnaces from whence the cast-iron is run off into the casting room, I I.
- O The door to give occasional admittance into the air vault.
- M The excavation, in which is placed the blowing machine.

EXPLANATION OF FIG. 3.

- A The end of the wind-gauge, (about 12 inches long), which is open to the atmosphere, being half filled with quicksilver.
- B The end that is inferted in the iron wind chest, and exposed to the pressure of the condensed air of the air vault.