Mr. GLYNN said, there was one circumstance connected with the subject of explosions in coal mines, which struck him as being well worthy of consideration. He alluded to the fact of almost all accidents taking place after the pit had ceased working. The comparative freedom, during the period of working, might be due to the passage of the trains of waggons along the workings, and of the skips up the shafts, forming a sort of pump. Again, the state of the atmosphere was known to have a most important influence on all underground workings; the barometer should therefore be carefully watched, and according to its indications precautionary means might be adopted. When the atmosphere was heavy, coal mines were invariably what was termed "fiery;" but when the atmosphere was light, the fire damp was more effectually removed by the ordinary ventilation, as the gases did not then accumulate in dangerous quantities, as was the case when they ascended to the roof. These were matters of every-day notoriety, and should be taken into consideration when any measures were to be introduced for the removal of those accidents which had formed the subject of Mr. West's paper.

November 19, 1850.

WILLIAM CUBITT, President, in the Chair.

No. 842.—"The Ventilation of Collieries, theoretically and practically considered." By William Price Struvé, M. Inst. C. E.*

IN the ventilation of mines it is essential to lay down certain general rules, the proper application and modification of which, to meet given circumstances and localities, must depend on the judgment and practical experience of the Engineer. These rules are,—

1st. That a current of air, through the channels of collieries, at a velocity of 5 feet per second, is sufficient for almost all purposes.

2nd. That a current exceeding that velocity will be obtained at the expense of leakage and other evils.

3rd. That in order to obtain the requisite supply of fresh air, the channels of a mine ought to be enlarged, according to the exigency.

The limitation of currents of air, to the velocity stated in the first proposition will, among other advantages, enable the workmen to carry naked lights. This may be easily tested, by moving a lighted candle at the rate of 5 feet per second, through a still atmosphere. It will be found, that it is practicable to retain the

* The discussion upon this subject was extended over a portion of four evenings, but an abstract of the whole is given consecutively.

light at such a velocity, but that it is impossible to do so, if a current of equal velocity has to be encountered.

In the first process, of laying open a coal field, after the pits are sunk, a pair of drifts, or levels, a few yards apart, are driven forward in opposite directions from the pits, along the strike, or level line of the seam, and similar branch levels are carried off at right, or sloping angles from the before-mentioned levels, according as the seam of coal may be level, or inclined. Communications are established at intervals, between these parallel drifts, for the purpose of ventilation, and the currents of air are made to pass, inwards by one drift, and outwards by another.

One of the levels serves the double purpose of a horse road, and air-way, and the other is the return air-channel and, sometimes, the water-course.

In this manner, a colliery becomes divided into numerous compartments, or subordinate collieries; and the included solid masses are either worked out at once, or, on the plan of "stall and pillar" work of the north, are only partially worked at first; pillars of considerable dimensions being left to be cut away by a subsequent process.

If, at this stage of the proceedings, it is assumed, that a given exhausting power at the upcast pit is sufficient, without due reference to the length and sectional area of the air-channels, on which the needful supply of air to the mine should depend, serious consequences may ensue: indeed to the want of attention to these two elements, in the problem of ventilation, may be attributed, in a great degree, its inefficient state in numerous collieries.

In mines evolving fire-damp, it has been found necessary, in practice, to have as large a ventilation as 300 cubic feet per minute per man; and if it be assumed, that about eighty men and boys are required to work 100 tons per day, a mine working 200 tons per day would require 48,000 cubic feet per minute; and a mine producing 400 tons per day, would demand a ventilating power of 96,000 cubic feet per minute. Taking, as an example, a colliery producing 200 tons per day; if 5 feet per second be taken as the standard velocity of the air, it follows, that the intake and return air-channels should have a sectional area of 160 square feet; or about 6 feet high by 27 feet wide: dimensions which would be found too expensive, and possibly in many cases, impracticable. This assumes, that the air would have to pass, in one undivided channel, through the whole of the mine, and in that case it would, in some large mines, have to travel as much as thirty miles.

But in practice it is not usual, even in the best-conducted mines, to give to the air-channels a sectional area of more than 50 square

feet; and, in many cases, particularly in South Wales, not more than 16 square feet. It follows, therefore, that if it were attempted to course the air, in one continuous channel, the current, in the former case, would be 16 feet per second, and in the latter case, 50 feet per second: velocities which it will be demonstrated, by reference to experiments, it would be impracticable to keep up through the workings; because the rarefaction, necessary to produce such a current, would cause the air-channels to leak, and the air to find a shorter course, through the excavated portions of the mine, to the upcast shaft.

Science and practice have, however, taught better things with regard to the ventilation of mines; and, therefore, instead of attempting to course the air through one continuous channel of the mine, from the downcast to the upcast shaft, it is now usual, in the best-arranged mines of the North, to take advantage of the separate compartments, or subordinate collieries of the mine; and, in the same manner as they form distinct workings, so has it at last been found practicable to ventilate each separately. Therefore, if a panel, or compartment of work, contains twenty-seven men, the provision to be made in the ventilation, for this section of the colliery (at the rate already proposed, viz., 300 cubic feet per minute per man), would be 8,100 cubic feet, or one-sixth of 48,600 cubic feet per minute: and, if this ventilation is kept separate from the remainder of the colliery, the air will necessarily be much purer, and will have to travel a proportionably less distance. Moreover, the velocity through the air-channels will be reduced, in a passage having an area of 50 feet, from 16 feet per second to $2\frac{2}{3}$ feet per second; or, in a passage of 16 feet area, from 50 feet per second to about $8\frac{1}{3}$ feet per second. This latter velocity would still be too high; but, by the splitting system, a multiplication of air-tubes may be obtained, for the intake and return air-currents of the mine, producing the same result as would be obtained from one large tube, of the aggregate area of the several splittings, with a diminished distance for the air to travel, in the same proportion.

The annexed simple diagrams of the two systems will demonstrate, that the splitting system, carried out to the extent described, will give to the ventilating power at the upcast shaft the greatest efficiency, whether the rarefaction is produced by a furnace, a pump, or a steam jet.

The four diagrams (Figs. 1, 2, 3 and 4) are intended to illustrate this proposition. **B, B**, (Fig. 3) are two parallel drifts, carried forward in the coal. **C, C**, are the downcast and upcast pits.

D, D, D, D, D, D, (Fig. 3) are six parallel drifts, driven off at right angles to the parallel drifts **B B**.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Now, if the air descending the downcast shaft is distributed, in quantities of 8,100 cubic feet each, through the parallel drifts **D**, **D**, &c., and is returned through the return drift **B**, by passing over the drifts **D**, **D**, **D**, &c., the current will run the course represented in Fig. 4, which shows six tubes, leading from the downcast to the upcast shaft, each conveying 8,100 cubic feet per minute from shaft to shaft, or a total of 48,600 cubic feet. Now, if the areas of these tubes are each respectively 50 feet, and the length one mile, the velocity will be about $2\frac{2}{3}$ feet per second; and, if they are larger, the velocities will be proportionably less, and will require less power to accelerate the air through them. But if, instead of splitting the current into six columns, it is made to pass in a single current along the intake drift **B**, to the farthest extremity of the mine; and then into the drift **D**, through the stalls of that panel, or compartment of the works, back to the return air-drift **B**, thence into the next panel **D**, and so on continuously, the air-channel will resolve itself into a tube, six miles long by 50 square feet sectional area (Fig. 2). If it were practicable to pass 48,600 cubic feet of air through such a tube, it would have to travel at the rate of 16 feet per second, instead of at the rate of $2\frac{2}{3}$ feet per second, through a tube one mile long by 300 feet area (Fig. 1). It must however be borne in mind, that if the air were coursed through the channel, six miles long by 50 feet area (Fig. 2), with the same exhausting power at the upcast shaft, the quantity obtained would be barely one-sixth, or 8,100 cubic feet per minute: but the power at the shaft being sufficient to overcome a resistance, through the mine, generated by a velocity of $2\frac{2}{3}$ feet per second, the power necessary to overcome the resistance for 48,600 cubic feet through six tubes of 50 feet area each, by one mile in length (Fig. 4), will be nearly the same as for 8,100 cubic feet per minute, through one tube of six miles long and 50 feet area (Fig. 2). Too much importance, therefore, cannot be attached to splitting the current of air; but the limit must be governed by the velocity which can be attained in the upcast shaft. If a velocity of 9 feet per second is attainable, and the shaft is 6 feet in diameter, or 28 feet in area, it would be practicable to have three splittings of 28 feet area each, at 3 feet per second, or three currents of air of about 5,000 cubic feet each per minute.

Although the advantage of splitting the current of air is unquestionable, in a dynamical point of view, with reference to the ventilating power at the upcast pit, the system of coursing the air through one continuous channel is still continued in many collieries.

It is important to consider attentively the circumstances and accidents, affecting the velocity of the air-current in a mine.

After an extensive excavation has been made, the stratification above and below the seam is generally found to be much ruptured for many yards; and the space, which previously contained the seam of coal, becomes filled up with broken materials, from the roof and the floor of the mine; and it often happens, that the return air-current has to be maintained, for a long distance, under these unfavourable circumstances. Or if the district, through which the air-channel is constructed, has been only partially worked, the walls, or sides necessarily consist of pillars of coal, with intermediate brattices, made either of planks, of rubbish, or of dry masonry; but in all cases presenting innumerable small spaces, through which the air may leak. These fissures are constantly enlarged by the pressure of the ground, or the perforations made by rats. Therefore, if a high degree of rarefaction is attempted, although a considerable quantity of air may be withdrawn from the orifice of the tube, near the exhauster, a similar quantity will not pass through the other extremity, but will find a shorter escape, through the cracks and fissures, already alluded to.

A colliery air-channel may therefore be compared to a gas main in a street, with numerous perforations, through which the gas is supplied to the various adjoining lamps. It would be unreasonable to expect, that the same amount of gas which entered the main from the gasometer, should be discharged at the other extremity, when all the lights are burning: or that there would be the same pressure of gas at the last light, as there is near the gasometer, or at the first light. In order to obtain the necessary discharge of gas at the last light, the main ought to be of suitable dimensions; and so in the air-channel of a mine, the best preventive against leakage is to make it of large dimensions, so as to insure the requisite amount of ventilation, at its farthest extremity.

In order to still further illustrate this proposition, it is necessary to refer to two experiments, which were conducted with great care, at separate collieries in South Wales: both of them probably possessing in the upcast shaft, a larger amount of exhausting power per square foot, than any colliery in the kingdom.

One experiment was tried at the Eaglesbush Colliery, where the Author's Mine Ventilator has been incessantly at work for nearly two years. The general condition of the ventilation of this colliery is very simple. The air descends a sloping drift about 700 yards long, with a sectional area of about 50 square feet; it then proceeds along a level heading of about 600 yards in length, and of 36 feet area; thence into an air-channel of 350 yards in length, and 16 feet area, where it reaches the extreme end of the colliery. It returns

thence through the stalls, coursing through each of them, and passing from one to the other, through channels of about 16 feet area, for a distance of about 400 yards; it then passes through an air-channel of about 12 feet sectional area and 1,200 yards long, which is surrounded by an extensive goaf, and thence it ascends an upcast shaft, 60 feet deep and 9 feet area, communicating with the mine ventilator.*

The air-tube of this colliery might be reduced to a simple figure of the following dimensions, viz. :—

Velocities for 13,500 cubic feet per minute for the annexed areas.		
700 yards long,	50 feet area,	4½ feet per second.
600 ,,	36 ,,	6½ ,,
350 ,,	16 ,,	14 ,,
400 ,,	16 ,,	14 ,,
1,200 ,,	12 ,,	19 ,,
20 ,,	9 ,,	25 ,,

3,270 = 1 mile and ¾ths.

The quantity of air going into the mine was estimated at 7,000 cubic feet per minute, whilst the discharge through the upcast pit was 13,500 feet; the difference must therefore have been supplied from leakage. This is not surprising; because, in order that this quantity of air should pass the last 1,200 yards, it must have acquired a velocity of 19 feet per second. Hence a large portion is drawn from the extensive goaf, already alluded to, which communicates with the cross workings, where there are several old pits and levels. The water gauge at the top of the pit constantly marks 2½ inches, indicating the drag, or the duty which the apparatus performs.

The other experiment was tried at the Cwm Avon Iron and Coal Works, at Taibach, in Glamorganshire, belonging to the Governor and Company of Copper Miners; but at present carried on by the Directors of the Bank of England, under the management of Mr. John Biddulph.

A large culvert, of about 200 feet sectional area, has been constructed along the surface of the Voel Mountain, up to its summit, which is about 1,300 feet above the bottom of the valley. This culvert, which is about 1,500 yards long, was constructed for the purpose of conveying the smoke and noxious vapours from the copper smelting works, where the average consumption of coal is about 30

* This apparatus, which draws out of the upcast pit 13500 cubic feet of air per minute, will be hereafter described.

tons in twenty-four hours. The temperature at the bottom of the culvert is about 350° and near the top 150° , being an average of 200° ; the expansion due to these temperatures would be a column of air of about 358 feet; and, as air is eight hundred and twenty times lighter than water, a water-gauge at the bottom of the culvert ought, when the culvert is closed, to exhibit about $5\frac{1}{6}$ inches. This enormous culvert, besides performing the office of an upcast for the copper works, is made to ventilate several of the collieries belonging to these extensive works.

An experiment was tried upon the Ynisdavid Colliery, in order to compare the quantity of the intake air with the return air into the great culvert. An accurate observation was made in a culvert of 17 feet sectional area, which conveys the return air of the Ynisdavid Colliery into the great culvert, and the supply was found to be 21,800 cubic feet of air per minute; the water-gauge stood at $1\frac{1}{2}$ inch; and the velocity was ascertained by Biram's anemometer to be $24\frac{1}{2}$ lineal feet per second.

The same observation was then made at the commencement of the intake, and in various parts of the colliery, and was found to be only about 5,000 cubic feet per minute. The air-channels, if reduced to a simple figure, will be of the following dimensions:—

Downcast pit	50 yards long,	100 feet area,	Velocities for 21,800 cubic feet per minute.	
			3 $\frac{1}{2}$ feet per second.	
500	„	39	9 $\frac{1}{2}$	„
600	„	16	23	„
50	„	30	12	„
300	„	64	5 $\frac{3}{4}$	„
600	„	16	23	„
150	„	30	12	„
100	„	39	9 $\frac{1}{2}$	„
200	„	16	23	„
200	„	9	40	„
600	„	30	12	„
<hr/>				
3,300 = 1 mile and $\frac{3}{4}$ ths.				

The air, in the course of the last 600 yards, passes through an old working, which probably communicates with the crop, where the seam has been worked; and it also passes up a pit, with a wooden brattice, which is not air-tight.

In both these instances, most important results would follow the

enlargement of the air-channels, so as to bring the velocities down to about 3 feet, or 4 feet per second. In the first place, an increased quantity of air would flow into the exhausters. In the case of the mine ventilator, at Eaglesbush Colliery, the pistons of which now only move at the rate of 1 foot per second, this rate might be readily increased to 3 feet per second, when the machine would discharge three times the quantity of air. With respect to the upcast culvert of the Ynisdavid Colliery, the quantity there might also be greatly increased, and the increase at the extremity of the intake would be in a much larger ratio, because nearly the same volume would come in as would be withdrawn, instead of being supplied, in such large quantities, from the intermediate portions of the tube.

If the mines of Great Britain were examined, it would be found, that in numerous instances these principles have been altogether lost sight of; and in order to bring the mines to a proper condition, a work must be commenced, something like relaying the pipes for the better supply of gas, where a town has outgrown the original scheme, and the dimensions of the pipes.

The next consideration is that of the motive powers in most general use, for accelerating the air-currents of mines.

That which has obtained the most universal adoption, is the rarefaction caused by the expansion of air, through the application of heat. In some cases the acceleration is caused solely by the natural temperature of the mine, the burning candles, and the animal heat derived from the men and horses employed in the workings; the difference of temperature thus established between the upcast and the downcast pits, being sometimes augmented by the cooling effects of jets of water through the latter. Although all these together scarcely produce an average difference of 13° in winter, and at certain times in summer, occasion no difference at all, yet in some extensive mines the ventilation is attempted to be accomplished entirely by these means. This may be considered the lowest scale of ventilation. The highest standard may be taken from examples in the North, where the average temperatures, in some of the upcast pits, which have been exclusively set aside for that purpose, have reached from 140° to 160° .

The following extracts, with relation to this portion of the subject, are made from the Minutes of Evidence, taken in 1849, before a Committee of the House of Lords, on the Ventilation of Mines.

THE HASWELL COLLIERY.

Depth of shaft, 936 feet.
 Area of downcast pit, 110 superficial feet.
 Area of upcast pit, 58 superficial feet.
 Average temperature in downcast pit, 62° .
 Average temperature in upcast pit, 165° .
 Velocity in upcast pit, $27\frac{1}{2}$ feet per second.
 Quantity of air discharged, 94,000 cubic feet per minute.
 Consumption of fuel, 4 tons in 24 hours.
 There are ten splittings of the current of air: the average area of each is 42 superficial feet, making an aggregate of 420 superficial feet: the distance travelled in each splitting is $3\frac{1}{2}$ miles.
 Mr. John Taylor estimates the power of the upcast pit at $34\frac{1}{10}$ ths H.P.

THE HETTON COLLIERY.

Mr. Nicholas Wood states there are two downcast pits, of $11\frac{1}{2}$ feet and $12\frac{1}{2}$ feet diameter, = 216 superficial feet area.
 One upcast pit 14 feet diameter, = 153 superficial feet area.
 There are sixteen splittings, each 54 feet area, aggregate area, = 864 superficial feet.
 Average length of each splitting, = $2\frac{1}{2}$ miles.
 Quantity of air through the upcast pit, 168,850 cubic feet, being a velocity of 18.3 feet per second.
 Average temperature in downcast pit, 60° .
 Average temperature in upcast pit, 140° .
 Depth of upcast pit, 900 feet.
 Depth of downcast pits, 900 feet and 1056 feet.
 Consumption of coal, 8 tons in 24 hours.
 Mr. Nicolas Wood estimates the power of this upcast at 71 H.P.

SEATON DELAVAL COLLIERY.

Mr. John Taylor states that there are :—
 Four downcast pits, area 179 feet.
 One upcast pit, area $50\frac{1}{2}$ feet.
 Five splittings, area 182 feet.
 Average length $1\frac{1}{2}$ miles each.
 Quantity of air through the upcast pit, per minute, = 48,948 cubic feet.
 Average temperature in downcast pit, $62\frac{1}{2}^{\circ}$.
 Average temperature in upcast, 151° .
 Depth of downcast pit, 636 feet.
 Depth of upcast pit, 538 feet.
 Consumption of fuel by the furnace, in 24 hours, = 4 tons 16 cwt.
 Quantity of air without the furnace, but with the two underground boiler fires, and 25 jets of steam, 77,455 cubic feet, and engine working.
 Consumption of coal, in 24 hours, = 13 tons 4 cwt., or 3,778 cubic feet per pound of coal.

In the instances adduced, a selection has been made of some of the best, as well as of the worst specimens of the ventilation of mines,

and it will appear evident how important it is that the piping of a mine (if such an expression may be used,) should be made as large as possible; and that recourse should be had to splitting, so as to bring down the velocities of the currents below 5 feet per second.

In the instances which have been quoted, of the northern collieries, it will be found, that in the—

HASWELL COLLIERY,

The aggregate area of the air-tube is seven and a quarter times greater than the area of the upcast pit, and the velocity is diminished in the inverse ratio; in the pit it is $27\frac{1}{2}$ feet per second; the average velocity, in the workings, must therefore be about $3\frac{1}{2}$ feet per second.

HETTON COLLIERY.

The aggregate area of the air-tube is five and three-quarters larger than the upcast pit; the velocity in the pit is 18.3 feet per second, therefore the average velocity in the workings must be about $3\frac{1}{2}$ feet per second.

SEATON DELAVAL COLLIERY.

The aggregate area of the air-tube is three and three-fifths larger than the upcast; the velocity in the pit is 26 feet per second, therefore the average velocity in the mine must be about $7\frac{1}{2}$ feet per second.

EAGLESBUSH COLLIERY.

The average area of the air-tube is only one and three-quarters larger than the upcast; the velocity in the upcast is 25 feet per second, and therefore in the mine, the average velocity must be about 15 feet per second, which is the cause of the leakage.

YNISDAVID COLLIERY.

The average size of the tube is only one and three-quarters larger than the upcast; the velocity in the upcast is $26\frac{1}{2}$ feet per second, which is the cause of the great leakage that is found to exist.

Under the old system of coursing the air in one undivided channel, the areas of the upcast pits would, in many cases, exceed the area of the air-tube, and the lengths becoming greatly augmented, the quantity of air travelling through the mine would be proportionably reduced. Thus, reverting to the case of the Haswell colliery, the tube, instead of being $3\frac{1}{2}$ miles long, and 420 feet in area, would be 35 miles long by 42 feet area; and the quantity of air passing through the mine, instead of being 94,000 cubic feet per minute, would be probably under 9,000 cubic feet; that is, assuming the temperature of the upcast pit to be a constant quantity.

HETTON COLLIERY.

In this instance the tube, instead of being $2\frac{1}{2}$ miles long, by 864 feet area, would be 40 miles long by 54 feet area; and the quantity of air passing through the mine, instead of being 168,850 cubic feet per minute, would be probably under 11,000 cubic feet.

It is now necessary to estimate the motive power required for producing the results attained at the Haswell and Hetton Collieries, with a view to determine the power, or size of a boiler, supposing the steam jet to be applied at the top of the upcast shafts; or in the case of air-pumps, worked by a steam-engine in the same position.

It is well understood, that 100 parts of air, taken at the temperature of 32° Fahrenheit, when heated to 212° will expand into 137·5 parts, which gives an expansion of $\frac{1}{480}$ th for every degree of temperature. The following formula will therefore determine the elongation of any column of air in an upcast pit:—

If C = length in feet of the downcast column, and
 T the number of degrees above the temperature of 32°,
 C' the length of the column in the upcast pit, and
 T' its temperature above 32°,
 then $C' = C \left(\frac{480 + T'}{480 + T} \right)$

The effect of heat administered to the upcast pit, is to expel, for every degree, $\frac{1}{480}$ th of its column; and therefore the difference in the columns will be the motive column of ventilation. It follows, therefore, that the length and the temperature are the two elements in the question of power. A pit only half any assumed depth, at the same temperature, will only have half the motive power, or half the pressure on the piston; and if only one-quarter the depth, it will only have one-quarter the pressure.

If this formula be applied to the Haswell pits, which are 936 feet deep, the average temperature of the downcast being 62°, and of the upcast 165°, the motive column of air will be 189 feet, or 27 $\frac{7}{8}$ inches of water; that is, if the bottom of the upcast pit was closed when at that temperature, the water-gauge ought to show 27 $\frac{7}{8}$ inches.

At the Hetton Colliery, the pits of which are 900 feet deep, the average temperature of the downcast being 62°, and that of the upcast 140°, the motive column of air is 137 feet, which is equal to a column of water of 2 inches.

At the Cwm Avon great chimney, which is 1,300 feet high, the temperature of the atmosphere being 62°, and the average temperature of the chimney 200°, the motive column of the current of air is 358 feet, which is equivalent to 5 $\frac{2}{3}$ ths inches of water.

At the Eaglesbush Colliery, the effective column is equal to 2 $\frac{3}{4}$ ths inches.

It has been stated, that in the case of the Haswell Colliery, the effect of the expansion in the upcast pit was to make the downcast
 [1850-51.]

column $2\frac{7}{16}$ inches of water heavier than the upcast column, over the whole area of the pit. Therefore if a piston was made to fit, and was loaded with $2\frac{7}{16}$ inches of water in depth, or 14 lbs. to the square foot, it would be balanced; on the other hand, if this weight was taken off the piston, and the piston itself was imponderable, and there was no friction in the mine or pit, the piston would ascend with a velocity equal to that which a body would acquire, in falling through a space equal to that of the moving column of air.

If, instead of taking the whole weight off the piston, only such a portion was removed as would give it a velocity through the pit of $27\frac{1}{2}$ feet per second, then whatever weight remained, multiplied by the velocity, would be the number of H.P. which a steam-engine would have to exert upon a piston, in order to draw the volume of air passing through the mine. This result was ascertained at the Haswell Colliery by Mr. William Brunton, and, in his evidence before the Lords' Committee, he stated, that he found it to be about $1\frac{1}{2}$ inch of water, or about 8 lbs. to the square foot; and according to Mr. Taylor's evidence, this was, in a pit of about 58 feet area, equal to a load of 464 lbs., travelling at an estimated rate of 27 feet per second, and therefore equal to 23 H.P.

In the Hetton Colliery, the motive column of air has been shown, by calculation, to be 137 feet, or equal to 2 inches of water. If 1 inch of water is adopted as the effective pressure, which is probably very near the truth, then will the pressure, multiplied by the velocity of 18 feet per second in the upcast pit, be equivalent to 26 H. P. applied to a piston.

Another mode of arriving at an approximate estimate of the power required to ventilate the Hetton Colliery, at the rate of 168,850 cubic feet of air per minute, would be the following:—The ventilator at the Eaglesbush Colliery extracts out of a pit 9 feet in area 13,500 cubic feet per minute, with an engine of 5 H. P. If, therefore, there were thirteen such engines and thirteen such pits and air-ways, they would draw out 175,000 cubic feet of air per minute. The area of such upcast pits would then be 117 feet. That at Hetton Colliery is 153 feet: the average area of the passages in the mine at Eaglesbush Colliery would then be 204 feet; that at the Hetton Colliery is 864 feet. From these relative sizes, it appears highly probable, that the Hetton Colliery would be ventilated to the extent of about 175,000 cubic feet of air per minute, by about 26 H.P. At the Eaglesbush Colliery, the real effect of the ventilator is measured by $2\frac{3}{4}$ ths inches of water, and in order that the rarefaction by the furnace in the upcast pit, with its culvert,

which is about 150 feet high, should produce a similar result, it would be necessary to obtain, on the same principle of calculation, a motive column of double the water-gauge, viz., $5\frac{1}{2}$ inches, or a motive column of 335 feet of air, which would require an average temperature of $1,000^{\circ}$.

It will appear from what has been adduced, that furnace ventilation may be made efficient, where the shafts are deep, and where no inconvenience can arise from their being employed solely as upcasts, and therefore requiring no limit in the temperature. But where the shafts are required for pumping and winding coal, or for the passage of men and horses, or where they are shallow, then the furnace becomes limited in its agency, and inefficient as a ventilator.

The following calculations tend further to illustrate the necessity of deep shafts. If the upcast pit of the Haswell Colliery be taken as a standard of ventilation, the following average temperatures will be required in pits of the various depths respectively, viz. :—

Haswell Pit, 156 fathoms deep, temperature 165°				
A pit of	115	"	"	190
"	100	"	"	220
"	75	"	"	276
"	50	"	"	383
"	25	"	"	704

If the Hetton upcast pit be taken as a standard, the following average temperature will be required in pits of the various respective depths, viz. :—

Hetton Pit, 150 fathoms deep, temperature 140°				
A pit of	125	"	"	155
"	100	"	"	178
"	75	"	"	217
"	50	"	"	294
"	25	"	"	527

As in every case, the average is taken, the temperatures at the bottom of the shafts would be much greater.

In considering the Steam Jet as a ventilator for mines, it must be admitted, that steam may be employed to communicate heat, in the same manner as the furnace, to the upcast shaft, and with the same results: the only question being as to its advantages with regard to convenience and economy, when compared with the furnace.

The experiments which bear on this subject, are those of Mr. Nicholas Wood, and Mr. George Elliot, at the Belmont Colliery, and more particularly those of Mr. Henry Hussey Vivian, of Swansea, descriptions of which were published in the Report by the Committee of the House of Lords.

Mr. Nicholas Wood states, that at the Belmont Colliery there is an underground steam-engine, with two boilers, each having a fire; that the amount of air circulating through the mine, was found to be 56,294 cubic feet per minute, the whole of which was due to the effect of heat communicated to the upcast shaft, from the two boiler fires, in conjunction with the steam issuing from a pipe 6 inches in diameter, and the radiation of heat from the surface of the boilers and steam-engine. All the other conditions remaining the same, an alteration was made in the application of the steam, and instead of allowing it to be projected into the pit, in one large jet of 6 inches in diameter, it was distributed into twenty-five jets; and the ventilation was then recorded and found to be 60,000 cubic feet of air per minute, being an increase of 3,706 cubic feet of air per minute, or seven per cent. He also states, that the rarefying effect of the colliery furnace, acting alone, produced a ventilation of 44,000 cubic feet per minute; that of the two boilers alone, including, of course, the radiation of the boilers and engine, was 47,756 cubic feet per minute; and of the colliery furnace, two boiler fires, and the steam, in twenty-five jets, 72,000 cubic feet of air per minute.

Mr. George Elliot tried a similar experiment, at the same colliery, and found the ventilation to be 56,958 cubic feet; this proceeded from the two boiler fires and the steam in one jet, through a pipe of 8 inches in diameter. All other conditions remaining the same, the steam was distributed into twenty-five jets, and the ventilation was then found to be 59,485 cubic feet, being an increase of 2,527 cubic feet per minute. He also states the ventilation from the colliery furnace, taken alone, to be 43,770 cubic feet per minute, and from the two boiler fires, acting without the steam, to be 62,365 cubic feet, and from the colliery furnace, the two boiler fires, and the steam in twenty five jets to be 71,550 cubic feet per minute.

Mr. Henry Hussey Vivian tried the following experiments with reference to the properties of the steam jet. He constructed a horizontal wooden tube 17 inches square, equal to a sectional area of 2 feet, closed at one end, and had vertical tubes of various diameters, made to fit on at the closed extremity. Steam jets of various sizes were also introduced at the lower orifices of the upright tubes; and in order to test the rarefying power of these several jets, under various-sized contractions, up to a perfect closing of the horizontal tube, or box, a door was made to fit the open end, with an arrangement for partially closing it at will. As a preliminary to these experiments, Mr. Vivian tested the powers of producing steam in a boiler of the best construction, 30 feet 4 inches long and 6 feet 2 inches in diameter, having a tube through it of 3 feet 8 inches

in diameter, at a pressure of 50 lbs. to the inch, and found it capable of supplying one jet of $\frac{3}{4}$ inch square. He then instituted seven series of experiments with jets, from $\frac{1}{16}$ inch to $\frac{3}{4}$ inch square, which were introduced at the bottom of the upright tubes, fixed to the horizontal box, which tubes varied in size from 2 inches to 19 inches in diameter. A water-gauge was fixed to the box, and the amount of rarefaction recorded, both when the box was completely closed, and when it was partially open. The velocities of the air passing through the box, at the time of each experiment, were recorded with one of "Biram's" anemometers. The results of these experiments may be applied, to determine the number of steam jets necessary to produce results equal to the furnaces, in the upcast pit of the Hetton Colliery. For that purpose the following selection has been made, and arranged in a tabulated form, having reference to a rarefaction equal to 2 inches of water, when the box was closed, a rate which it has been shown, would be exhibited in the Hetton upcast pit, if it was also closed, with an average temperature of 140°.

MR. VIVIAN'S EXPERIMENTS.			DEDUCTIONS.
Size of Jets.	Diameter of Upright Tubes.	Exhaustion when Box was closed. Column of Water.	Area of the Upcast, if a $\frac{3}{4}$ inch square Jet was employed to produce a Rarefaction of 2 inches of Water, when the Pit was closed.
$\frac{1}{16}$ th inch	3 inches	2 inches	254 square inches.
"	8 "	2 "	452 "
"	11 "	$2\frac{1}{4}$ "	380 } 416 } Mean.
"	12 "	$1\frac{3}{4}$ "	452 }
"	15 "	2 "	397 }
"	18 "	$2\frac{1}{4}$ "	289 } 343 }
"	19 "	$1\frac{3}{4}$ "	408 square inches.
"	17 "	2 "	226 "
"	19 "	2 "	283 "

The mean result of all these experiments shows, that a jet $\frac{3}{4}$ inch square, applied in a pipe of $2\frac{1}{4}$ superficial feet sectional area, would cause an exhaustion equal to a column of 2 inches of water, when the pipe was closed, and therefore, that if steam jets were applied at the top of the Hetton upcast pit, to produce the same results as the furnaces, it would require sixty-one jets, of $\frac{3}{4}$ inch each, or sixty-one boilers, each $30\frac{1}{2}$ feet long by 6 feet 2 inches in diameter, with an internal tube of 3 feet 8 inches in diameter, and steam at a pressure of 50 lbs. to the inch.

These experiments demonstrate, that the results which have been produced by steam, at Seaton Delaval and elsewhere, are due to temperature, and not to the steam jet; that in order to produce

adequate results, by dragging the air along by means of the steam jet, so great a steam power would be required in proportion to the area of the pit, as would render it commercially impracticable. For instance, at Eaglesbush colliery, where the upcast pit is only 9 feet area, and the ventilation is worked by a 5 H.P. engine, if the steam jet was substituted, four boilers of 30 feet each would be required.

The next mode of ventilation to be noticed, is the Author's Mine Ventilator, now used at the Eaglesbush Colliery, near Neath (Plate I.) This consists of two airometers, **E E**, made to balance each other, and to move vertically in the spaces **J J**, by means of the guide-rods, **F F**; the spaces **J J**, are filled with water, forming a packing, or stop to prevent any air passing from the interior of the airometers to the chambers over them; the guide-rods, **F F**, are connected, by short chains, with the arch-heads of the beams, **I I**, and at the other end of these beams the motion is received from a small high-pressure steam-engine, through the cranks **G G**, and the connecting rods **H H**. The apparatus is connected with the upcast shaft **A**, by a culvert **B**, which communicates both with the interior of the airometers and the top chambers through the interior cylinders of masonry **D D**, and the inlet valves **K K**. The operation then is precisely that of a pump. When the pistons ascend, they are filled with air, and at the same time discharge the air out of the top chambers through the outlet valves **L L**, and when they descend, they discharge themselves through the outlet valves **L**, and the top chambers are filled; the supply of air being, in both cases, drawn from the mine.

The apparatus has been incessantly at work for the last two years, without requiring any repair, and gives great satisfaction; but owing to the smallness of the upcast pit and air-ways, the power employed can only move the pistons at the rate of 1 foot per second, and with that velocity they discharge 13,500 cubic feet of air per minute. Until, therefore, the proprietors of this colliery complete a proper air-way to the machine, the development of its powers can only be partial, and its results, as has been already shown, exhibit only a fraction of its capabilities.

Two more of these ventilators are now being used at a colliery near Swansea, each having only one cylinder of the same dimensions as one of those at the Eaglesbush Colliery. But as the upcast pit and the return air-way have an area of about 28 feet, there will be no difficulty in making the piston move at the rate of $3\frac{1}{2}$ feet per second, accomplishing a ventilation of 20,000 cubic feet per minute, at a velocity of about 12 feet per second, in the upcast

pit. The area of each set of inlet and outlet valves will be 42 square feet. The cost of this apparatus, worked by a wooden beam with an arched head, fixed complete to the pumping engine of the colliery, will be £100, and it will cost almost nothing to work.

It must take some time to develop any new system of ventilation, but the Author feels convinced, that the existing objections to mechanical ventilation will gradually vanish, as its use increases; and that it will be found a safe system, calculated to compete, without reference to the depth of the shafts, with the results produced by deep shafts and high temperatures.

Double airometers of the following dimensions, moving at the rate of about $3\frac{1}{2}$ feet per second, would effect the following ventilations per minute, viz. :—

Diameter in Feet.	Cubic Feet per Minute.
5	7,854
10	31,416
12	45,239
15	70,686
20	125,664
25	196,000
30	282,744

There is no difficulty in constructing airometers of these dimensions, but if the size be objectionable, it is easy to apply four instead of two; and the expense of erecting them, compared with the injury sustained in shafts from the use of furnaces, would be amply compensated.

Since writing this paper, two excellent practical Reports on the Ventilation of Mines have been published, one by Mr. John Phillips, and the other by Mr. J. Kenyon Blackwell; the two gentlemen appointed by Government to report on the Collieries of Great Britain. With reference to the injury which the furnace causes in the upcast shaft, Mr. Phillips states,—*

“The upcast shaft is either an entire clear open channel, wholly devoted to ventilation; or an entire working shaft, in which either the guide-frames are placed for the ascending and descending tubs, or the pumping apparatus is fixed; or a portion of a shaft bratticed off from the remainder and similarly employed. The sectional area of the upward air-passage thus afforded varies from about 30 feet to 200 feet. The currents nowhere exceed in velocity 30 feet in a second. The highest temperature in the shaft, where the furnace

* *Vide* Report on the Ventilation of Mines and Collieries, p. 20. By John Phillips. Folio. Plates and cuts. London, 1850.

drift enters, is not very well known, except by a few trials, which seem to indicate about 400° as a maximum.*

"The effect of this current of hot air, charged as it is with sulphurous acid gas, carbonic acid gas, ammoniacal vapour, steam, &c., is very wasteful, not to say pernicious, on the machinery for pumping water and drawing coal; and in shafts which are sheathed by iron-tubbing, the destruction of the iron work (sometimes converted to a sort of plumbago) is a further source of loss. These inconveniences are so great that it is doubtful whether the enormous cost of shafts, in the Newcastle district, ought in all instances to prevent even now the construction of new upcast shafts for air only, instead of those so generally in use for drawing coal."

Again, he states, "How very disadvantageous a bratticed shaft is and must be for ventilation purposes is obvious on the least reflection. The proximity of the air-channels, the difficulty of preventing intercommunication, the mutual exchange of temperature between them, the danger of much heat setting the woodwork on fire (water being sometimes applied to prevent this), the probability of the brattice being injured in ordinary working, and of being blown out in case of explosion, are sufficient objections. In the latter case the effects must be fearful, for thus the whole pit may indeed be 'laid dead,' with but a poor chance of escape for any of the men in it."

Under the head of special cases of departure from correct principles in Lancashire, and which in his opinion applies also to South Wales and to other districts, Mr. Blackwell states, † that—

"In some, the upcast shaft is greatly below the dimensions in its sectional area which it ought to have, to admit a sufficient circulation.

"In others, from the upcast column being returned to the surface by small wooden or other pipes fixed in the downcast shaft (and this even in deep mines), it is not only insufficient in its volume for the supply of a proper quantity of air for safety and health, but insecure against the slightest shock.

"The furnace is usually placed on the surface in mines under the last condition; and as only a small part of the upcast column can then be rarefied, another cause of weak ventilation is added.

"It some cases, especially, where two or more seams are worked,

* "Temperature at mouth of furnace drift at Willington, tried up to 360° by Mr. Johnson. Temperature of furnace drift, 4 yards from furnace at Castle Eden, 192° ; Mr. M. W. Robson."

† *Vide* Report on Ventilation of Mines, 25th March, 1850, page 8. By J. Kenyon Blackwell. Folio. Plates. London, 1850.

the downcast shaft is not accessible to all the men engaged, thus rendering escape more doubtful in the event of accident.

"Another defect is the small size of the air-ways to which the air is confined throughout the works. The ventilation is thus often very weak, and the air heavy and unwholesome, even where there is no fire-damp.

"Narrow, or strait work is driven too far without openings for ventilation or brattice.

"The openings are frequently made up with imperfect stoppings of dirt, allowing the intake air to leak into the returns.

"Pipes are sometimes used, instead of an intake or return drift, to convey the ventilation through long distances, from one section of the pit to another.

"Drifts, in which fire-damp can collect, are left without circulation.

"Heavy or foul return air-currents are allowed to pass to the upcast shaft by waggon roads, in which naked lights are used.

"The working of pillars is carried on in contact with goaves containing fire-damp, without using the Davy lamp; or, in cases in which the Davy lamp is used, it is not under proper regulations.

"The workmen are sometimes compelled to find lamps themselves where danger exists; and as the use of the lamp is not absolutely enforced in these cases, its employment, where necessary, is often neglected.

"The men are compelled, in numerous cases, to work in an explosive atmosphere, whilst driving narrow work in the whole coal, for want of brattice or pipes to carry the air up to the face. There are cases in which they have to work constantly with their lamps full of fire.

"Ventilation is sometimes neglected, and the Davy lamp used as a substitute for it.

"Dangerous shafts and tackle are used to descend and ascend.

"In some cases there is no proper system of rules enforced, particularly for the examination of the works in the morning, before the men commence to work."

On the subject of ventilation Mr. Blackwell proceeds to state:—

"The number of workmen to be employed is one of the most important elements in determining the quantities of air which ought to be introduced into a mine. The data which I have collected on this subject would induce me to assign an amount, varying from 250 cubic feet per minute, in coal seams which are not fiery, up to

500 cubic feet per minute in fiery seams, as requisite for each person employed.”*

Also that “the temperature in upcast shafts, which are used for winding, cannot be raised much above an average of 80° or perhaps 90° , without injury to the winding apparatus, and prejudicial effects on those who have to descend and ascend in them.”†

With reference to the velocities of the air-currents, he states :—
“The highest velocities which I have found in practice to be obtained in upcast shafts, which are also used for winding, are from 8 feet to 10 feet per second.”‡

In applying the formula already given, to average temperatures, in the upcast shafts of 90° , the temperatures in the downcast shafts being 60° , the column of water equivalent to the motive column of air will be as follows; of which one-half must be calculated for effective ventilation, viz.—

		Effective column for ventilation one-half.	
A pit	25 fathoms deep	= 0.13 inches	= 0.06 inches.
„	50 „	= 0.26 „	= 0.13 „
„	75 „	= 0.39 „	= 0.19 „
„	100 „	= 0.52 „	= 0.26 „
„	125 „	= 0.65 „	= 0.32 „
„	150 „	= 0.78 „	= 0.39 „
„	175 „	= 0.91 „	= 0.45 „
„	200 „	= 1.04 „	= 0.52 „

Such degrees of rarefaction as these, in upcast pits and air-ways, of small sectional area, can never produce the amount of circulation, which experience, in the best-ventilated mines of the North, has proved to be necessary. For instance in the Haswell colliery, where in order to gain a velocity of $27\frac{1}{2}$ feet per second in the upcast pit, it becomes necessary to obtain a motive column of air of 189 feet (equal to a column of water of $2\frac{7}{16}$ inches), and that the aggregate area of the air-tubes should be seven and a quarter times larger than the upcast pit; the average distance for the air to travel not exceeding $3\frac{1}{2}$ miles. And in the case of the Hetton colliery, in order to obtain a velocity of 18.3 feet per second in the upcast pit, it becomes necessary to have a motive column of air of 137 feet (equal to a column of water of 2 inches), and that the aggregate areas of the air-tubes should be five and three-quarter times larger than the upcast pit; the average distance for the air to travel not exceeding $2\frac{1}{2}$ miles. Whilst at Ynisdavid colliery it has been shown, that where the motive column was 385 feet, equivalent to

* *Vide* Report on Ventilation of Mines, 25th March, 1850, p. 15.

† *Vide* Ibid. p. 17.

‡ *Vide* Ibid. p. 17.

a column of water of $5\frac{2}{5}$ th inches, the velocity in the upcast was $24\frac{1}{8}$ feet per second, the ratio of the air-tube in the mine being only one and three-quarters larger than the upcast, the distance for the air to travel being 1 mile 7 furlongs.

All these are examples of extraordinary rarefaction, created by furnaces, which are inapplicable to most collieries, as they cannot be obtained in practice. They are respectively represented by an effective column of water of only $1\frac{1}{2}$ inch, 1 inch, and $1\frac{1}{8}$ inch; with velocities of $27\frac{1}{2}$ feet, $18\frac{1}{2}$ feet, and $24\frac{1}{8}$ feet per second.

In the use of the Author's Mine Ventilator, with a piston moving at $3\frac{1}{2}$ feet per second, a velocity of $27\frac{1}{2}$ feet per second may be obtained, in any upcast pit, by a piston of 8·3 feet for each superficial foot area of upcast pit, which is the rate at Haswell colliery. In order to obtain a velocity of 18·3 feet per second, it is necessary to have 5·5 feet of piston, for one foot of area in the upcast pit, as at the Hetton colliery. To obtain a velocity of $24\frac{1}{8}$ feet per second, it is necessary to have 7·3 feet of piston, for one foot of the upcast pit, which is the rate in the upcast shaft of Ynisdavid colliery. These velocities, therefore, which represent the highest standard of ventilation by furnaces, are easily and economically attainable by the Mine Ventilator.

DESCRIPTION OF THE PLATE.

- A**, The upcast pit.
- B**, A culvert 6 feet by 10 feet connecting the upcast pit with the ventilator.
- C, C**, Two cylinders of masonry 17 feet interior diameter, and 17 feet high.
- D, D**, Two interior cylinders of masonry, 10 feet interior diameter, and 7 feet 6 inches high. The space between the two cylinders **J** is filled with water, 7 feet deep, which prevents the air from escaping, or being admitted, except through the inlet, or outlet valves.
- E, E**, Two airometers 16 feet in diameter, and 7 feet high, made to balance each other, and to move vertically in the water by means of the guide-rods in the centre.
- F, F**, Rods working in guides, to give the pistons a steady motion, and to form a connection, by means of short chains, with the arch-heads of the beams.
- G, G**, Two cranks, placed at right angles to each other on a shaft, connected with an engine.
- H, H**, Two connecting-rods, conveying the motion from the cranks to the beams which work the airometers.
- I, I**, Two arch-headed beams.
- K, K, K, K**, Four air-ports 10 feet by 7 feet 6 inches, fitted with valves to admit air from the mine.
- L, L, L, L**, Four air-ports 10 feet by 7 feet 6 inches, fitted with valves for discharging the air into the atmosphere.
- M, M**, The framing which supports the working beams, and also the whole weight of the airometers.
- N, N**, The beams supporting the guides for the rods to work through.
- P, P**, The embankments formed from the cuttings of the foundations.
- R**, The framing of a pit for raising coal, showing the cover **S**, raised by the waggon, and the platform of the waggon supplying its place; also the other cover **S'**, at rest on the other compartment of the pit, with the rope, or chain working through it, in order that the raising of coal may not interfere with the continuous current of air from the mine to the ventilator; and in order to prevent leakage the tubes **T, T, T**, are attached to the top of the pit, and the platform, on which the waggon rests, enters one of these tubes before the cover **S**, is lifted.
- Z**, The engine-house with a 13 H.P. engine to work the machine.

LONGITUDINAL SECTION.

PLAN

TRANSVERSE SECTION.

SCALE OF FEET
5 0 5 10 15 20 25