The Development of Coal mine Ventilation in Great Britain up to the End of the Nineteenth Century

BY

Professor F. B. HINSLEY, D.Sc., C.Eng., F.I.Min.E., F.Inst.F.

(Read at the Science Museum, London, 12 *November* 1969)

INTRODUCTION

The Romans are said to have mined coal on a small scale at the outcrops in all the major coalfields of this country. With the decay of Rome the mines were abandoned and coal mining did not revive again on a significant scale until about the twelfth or thirteenth centuries. From these early days when underground coal mining was developing, the miner appears to have been troubled by the presence of noxious gases in the workings. Evidence of this is shown in a deed of 1316 in which Richard de Willoughby leased his mine of sea coal in Cossall, near Nottingham, to Adam, son of Nicholas and eight other men of Cossal, at a rent of 12d. per week for each "pickaxe" employed, so long as they worked the mine.[1] Provision was made for the remission of the rent when the mine could not be worked either from flooding or by air called "le dampe"—this is how it is spelt in the document. The reference to le dampe is undoubtedly to chokedamp, otherwise known as black-damp or styth. This gas is now known to be a mixture of carbon dioxide and nitrogen and is a product of the oxidation of carbonaceous matter; it is usually denser than normal air and settles on the floor of the workings. The miner could remove the chokedamp by the ancient method of swinging his jacket or a cloth to and fro, thereby causing it to mix with the slow moving, naturally generated, ventilating current.

In these early days, coal mining was taking place near the outcrops in most of the major coalfields and the workings were shallow. During the fifteenth, sixteenth, and seventeenth centuries the demand for coal increased and deeper coal seams had to be exploited, with the result that shafts became more expensive to sink and a greater area of coal had to be extracted from the region surrounding each shaft bottom in order to make the operations profitable. When the workings reached depths of about 50 to 80 yd., the miner met another hazard in the form of firedamp, an inflammable gas composed largely of methane. The removal of this dangerous gas from the mines gave the need for greatly increased ventilation. The previous requirements of air for the breathing of men and animals and the removal of chokedamp were small when compared with those required at a later date for the dilution and removal of inflammable gas.

Coal seams in the undisturbed state are usually charged with methane which is not able to migrate when the cover of relatively impermeable rocks exceeds about 50 or 60 yd. In some cases the superincumbent rocks may be permeable, especially at shallow depths, and the methane may have escaped during geological times. In general the firedamp or methane content of coal seams appears to increase with depth. It can usually only be released during the working of the coal as it is broken

[1] Smith, R. S., "Early mining in the Nottingham Area," *Univ. Nottingham, Mining Society Magazine* (1955/56), 125–131.

by the miner and by roof pressure. The miners followed the seams from the outcrop to the dip, and during the seventeenth and eighteenth centuries had to work more of the coal seams which still retained firedamp. The small outputs from the mines at this time did not demand extensive operations and the normal emissions of gas were generally within the capacity of the ventilating systems then available. The position with regard to the ventilation of coal mines towards the end of the eighteenth century appears to be that two openings from the surface to the mine workings were found to be advantageous in the creation of natural flows through the mine. These openings could consist of shafts or drifts, or, alternatively, one shaft and a drainage level were often employed. Where shaft sinking proved to be difficult and expensive, sometimes only one shaft was sunk, and this was then divided into two compartments by the construction of a wooden partition or brattice down the full length of the shaft. One side now functioned as the intake or downcast and the other side acted as the upcast. At the bottom of the shaft the air was directed into the workings, from whence it returned and was discharged into the atmosphere via the upcast compartment of the shaft. To increase the natural flow, the use of fire baskets or braziers of burning coals hung in the upcast shaft was often practised.[1] Another method of augmenting the flow of air was to build a furnace at the surface of the mine surmounted by a tall chimney to provide the draught. The intake to the furnace was connected by a culvert to the upcast shaft. The depth in the shaft at which the fire basket was hung influenced its effectiveness as a ventilator and towards the end of the eighteenth century furnaces began to be installed at the bottom of the upcast shaft.

The main advances in the technique of ventilating collieries took place during the nineteenth century. The annual output of coal had increased from 2·15 million tons in 1660 to 4·77 million tons in 1750 and in the year 1800 it was just over 10 million tons. During the next hundred years, the annual output of coal increased at a very rapid rate, reaching the figure of 228·77 million tons in 1900. In the more advanced coal fields of Durham and Northumberland, some of the mines at the beginning of the nineteenth century were working coal at depths of well over 1,000 ft. Copious steady emissions of firedamp were being encountered, and this situation was further aggravated by frequent heavy discharges of gas known as blowers, outbursts which often were of such magnitude that the normal ventilating flow was overpowered. The occurence of dangerous mixtures of firedamp and air in the working areas, which were often ignited by the flames of the miners' candles, caused many explosions which resulted in great loss of life.

The Circulation of Air in Mine Workings

The surface atmospheric air entering the mine workings had to be distributed so as to dilute and render harmless all the noxious and inflammable gases released during mining operations. The air current is also the vehicle by which these gases are removed from the mine. The workings of a coal mine represent a complicated network of tunnels and the air current had to be guided in the route it was required to take, by damming off those tunnels not included in the circuit, by the use of permanent stoppings, or if the tunnel was required for other purposes such as haulage of the coals or for communication purposes, by means of doors. The purpose of the doors was to prevent short circuiting of the air back to the upcast shaft.[1]

Before about 1760 the prevailing system was to have one main current of air which was passed successively to the various sections where men were working. This system was known as "face airing" and the predominant method of working the coal was by the "bord and pillar" system. The coal was extracted by driving bords or headings in the coal which were laid out in a definite geometrical pattern. This pattern of headings cut the coal seam into pillars which supported the super-

[1] Wood, Nicholas, "On . . . the working and ventilation of coal mines in the Newcastle-upon-Tyne district etc." *Proc. Inst. Mech. Engrs.* (1858), 177–233.

incumbent strata, thereby ensuring that the headings remained open. It was intended that the pillars should be of such dimensions as would be just sufficient to support the roof and the size of pillars was varied according to the depth of the seam. No attempt at this time was made to ventilate the old disused pillar workings or wastes. With the advance of workings into deeper coal this emission of firedamp increased and roof pressure tended to crack the edges of the pillars. This process persisted in worked out areas after they were abandoned, with the result that firedamp continued to be emitted. This firedamp collected in the wastes, and under conditions of falling atmospheric pressure would often invade the active working areas creating hazardous conditions for the men.

In 1760, James Spedding of Whitehaven initiated an improved method of ventilating the workings, known as "coursing the air." He altered the route taken by the air current and passed it through both the working areas and the wastes. His method was designed to ensure that all parts of the mine workings were swept free of polluting gases. Spedding's method greatly increased the length of the path taken by the air and whilst successful in small mines, it was later found difficult to apply in the large collieries in the North of England. In extensive workings, the air current was required to travel many miles and thus experienced great resistance or "drag" and the flow became very slow and inefficient.

In order to overcome these difficulties in the deep and extensive collieries in the North of England, John Buddle Jnr. (1773–1843) developed the method of ventilating known as "splitting the air current".[1] Buddle, an eminent North Country "Viewer" or mining engineer, arranged the workings into a number of circuits working in parallel. In this way each circuit could be made comparatively short and could be fed by a separate current of fresh air. In 1818, he also introduced the "panel" system of laying out the workings of a coal seam which consisted of working the coal by a number of districts, separated from each other by pillars or barriers of coal. This innovation had other advantages, which will not be dealt with here, besides those which contributed to better ventilating arrangements. The panel system of working was an important addition to split ventilation because it simplified the choice of parallel air circuits. Under this improved system each panel could now have its own separate supply of fresh air which had not been contaminated by passage through other workings. A typical panel system is shown in Fig. 1, where the route of the ventilating flow is shown by arrows. John Buddle also developed other useful ventilation arrangements such as air bridges or overcasts and dumb drifts. The latter allowed return air charged with firedamp to enter the upcast shaft without passing over the furnace. Buddle's contributions to the practice of coal mine ventilation were important and lasting, his method of split or parallel flows is still used at the present time.

At the beginning of the nineteenth century the lights used in coal mines consisted of candles, oil lamps and, in gassy mines, steel mills. The latter device was invented by Carlyle Spedding of Whitehaven, the father of James Spedding mentioned above. It consisted of a steel wheel which was hand driven by a crank handle through a speed increasing gear. The sharp edge of a piece of flint was held to the steel wheel which on rotation produced a shower of sparks, these gave a feeble light by which the man was able to work. The use of the steel mill required two people to do the work of one and for economic reasons it was not extensively used in working coal. It was used mostly in exploring the waste and old workings and to ascertain where firedamp had collected. The steel mill was considered to be a safe light in explosive atmospheres, but there were instances of accidents occuring due to its use. Nicholas Wood (1795–1865) another famous North Country mining engineer, mentions the possibility of igniting gas if the mill was turned rapidly. He says "this was well known by the men, and the mill was never worked fast in such circumstances." In

[1] Buddle, John, Letter to Sir Ralph Milbanke on the various modes employed in the ventilation of collieries (1st Report of the Sunderland Society), Newcastle, Edward Walker (1814), 28 p.

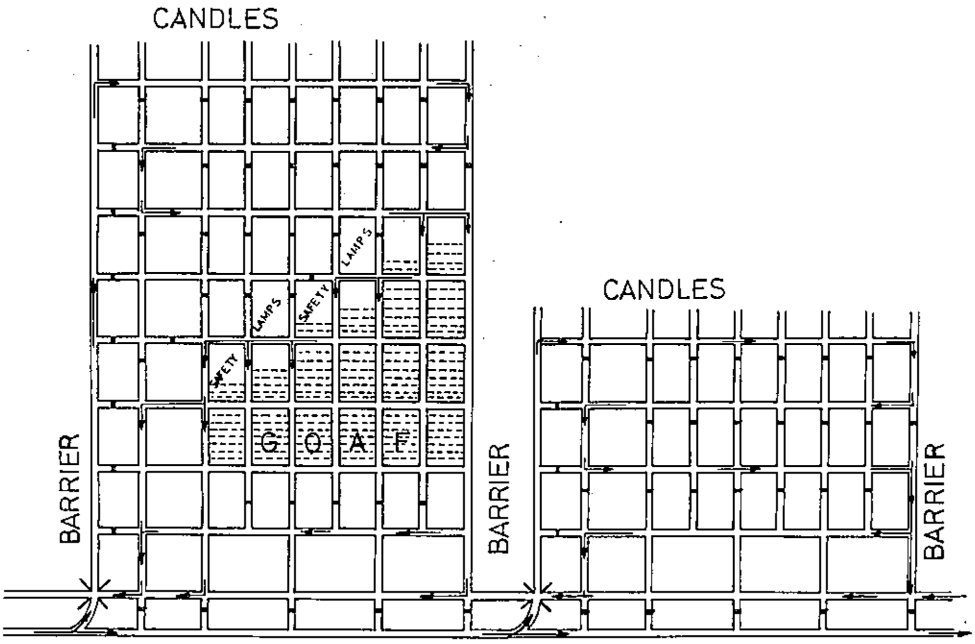


Fig. 1. Typical panel system in a coal mine (1818).

low concentrations of firedamp he says "the sparks from the mill were reduced to a dull red light; but when the gas was strong to a blood red colour."

The robbing or partial removal of pillars after the heading work had been completed, which had been practised to some extent from about 1700 onwards, produced more dangerous conditions owing to the increased breakage of the coal and release of firedamp. The dangerous conditions produced when pillar extraction was attempted led to the abandonment of large areas of coal pillars which could not be worked at a profit when the lighting was by steel mills. The extraction of pillars removed the solid boundaries of coal forming the airways and the cross-sectional area available for flow was much enlarged, which greatly reduced the speed of the ventilating current. The near stagnant air enabled the firedamp to accumulate in the roof instead of mixing with the air stream and moving away. This made atmospheric conditions extremely dangerous for open lights, hence the tendency to abandon areas of pillar working.

The invention of the wire gauze flame safety lamp by Sir Humphry Davy in 1815 produced important results; it prevented ignitions and explosions of firedamp by preventing the passage of flame from inside the lamp into the inflammable atmosphere. It also allowed the recovery of millions of tons of coal which otherwise could not have been worked. Pillar extraction had been found to be extremely hazardous with naked lights, but with safety lamps they began to be removed completely. Collieries which had been partially worked and abandoned for years because of firedamp were then re-opened. According to Nicholas Wood some of these mines still contained more than one-third of the coal in the form of pillars. T. J. Taylor (1810–61) said that at Haswell Colliery "more than five-sixths of the entire coal remains after the first working, all of which will have, now or hereafter, to be removed with safety lamps."[1] He went on to say that "in deep and fiery mines not more than

[1] Taylor, T. J., "Subsistence of the firedamp of coal mines in a state of high tension," *Trans. N.E. Inst. Min. Engrs.* (1825–53), **1**, 276–299.

a fifth or a smaller proportion of the aggregate produce is worked with naked lights." Candles were generally used in the driving of headings in the coal and safety lamps during the working of pillars. Wood says the miners were instructed to remove the lamp out of the inflammable atmosphere when the gauze became red hot, "experiments having shown that it will not ignite the gas until the wire becomes of a white heat."

After the introduction of the Davy safety lamp in 1815, the number of firedamp explosions increased with a still greater number of fatalities, and there was a tendency in some quarters to place the blame on the use of the Davy lamp. Richard Fynes[1] writing in 1873 stated that experience proved that the safety lamps "were the most deadly instruments ever devised in mining operations, and were the cause of more sacrifice of human life than ever had occurred before." He went on to say that "the men, having confidence in the lamp, . . . did not take the same precautions as they would have done had they not had any lamp at all, and to the reliance on the efficiency of the invention is to be traced the cause of many of the accidents that occurred." This view was not supported by mining engineers, as T. J. Taylor[2] pointed out "so far from our pit explosions having occurred from the use of the Davy, they have really happened where naked lights were employed; in other words, they have occurred because the safety lamp was not used." "On examining a list of the heavy explosions which have occurred in our district during the last 25 years" he found that "in 16 cases out of 18, these explosions have happened... in the districts where pillar mining had not commenced." In driving narrow headings, "erroneously considered the safest, naked lights had been, as a rule, made use of, while in the pillar workings, where ventilation is necessarily less effective, safety lamps are employed. The result is that no explosion whatever can be proved... to have taken place in the pillar districts, when safety lamps were used in those districts." The Davy safety lamp was a great safety invention but it needed informed supervision, because in some circumstances involving high concentrations of firedamp the gauze could become so hot as to transmit flame to the outside atmosphere. Similar effects could be produced where the lamp was subjected to high air speeds in high concentrations of firedamp. The main need appeared to be the production of more vigorous ventilation to sweep away the firedamp. However, as was to be shown later in the century, the main culprit responsible for the great explosions had not yet been identified. It was later to be shown that an explosion could be started by the firedamp, but it was the coal dust which played the principal role in all the great explosions.

The generation of air currents in mines has been accomplished first by natural means and later by means of furnaces and other artificial appliances. Some of the more important of these methods of inducing air flow in mines will now be discussed.

Natural Ventilation

The flow of air in mines which occurs without artificial aid is known as natural ventilation. The major factor in its production is the difference of temperature between the incoming and outgoing air columns. In vertical or inclined shafts or drifts, the colder column of air sinks, whilst the warmer column rises. As already stated, in hilly country one vertical shaft and a drainage level to the surface from the deposit, when connected underground, usually induced an air current through the system. This latter arrangement was found to be strongly influenced by seasonal temperature changes, with the flow going in one direction in the winter and in the opposite direction in the summer.

Gabriel Jars[3] in 1764 wrote "I have remarked for a very long time and have heard it said by all

[1] Fynes, Richard, *The Miners of Northumberland and Durham*, Thos. Summerbell, Sunderland Pub. 1873, second reprint 1963.
[2] T. J. Taylor, *op. cit.*
[3] Jars, Gabriel, "Observations on the circulation of air in mines, etc.," *Academy of Sciences Paris* 1768, 218–220. Reproduced in Appendix G of the *Report of South Shields Committee* 1843.

miners, that the air circulates with difficulty in the mines at the budding and at the fall of the leaf, that is to say at spring and autumn; it even happens that some works are suspended at that time for want of air." These remarks obviously refer to the periods when the natural ventilation was almost stagnant and when reversal was about to take place. He went on to say that in order to create a flow it is necessary "to have the air more dilated in one place than in another." Later, as mines became deeper and two or more shafts were sunk from the same surface level, the surface atmospheric temperature changes could not so readily cause reversal of the air current; their effects, however, were reflected in the seasonal variation of the volumes of air circulating. Because of its variability natural ventilation was not to be depended on and needed augmenting during the warm season.

Furnace Ventilation

To augment natural air flows, braziers of burning coals were hung in the upcast shaft; in other cases a permanent furnace was fixed at the top of the upcast shaft surmounted by a tall chimney. By this means the chimney draught was utilised in exhausting the air from the mine. During the latter part of the eighteenth century furnaces were constructed near the bottom of the upcast shaft. In this way the heated column of air was extended in length much beyond the height of the surface chimney, thereby producing a greatly increased ventilating effect. At the beginning of the nineteenth century the amounts of air circulated in the coal mines of the North of England, according to John Buddle, were in the region of from 5,000 to 7,000 cu. ft. per min. These amounts, he said, were adequate for the collieries under his care which were "abounding in inflammable gas."[1]

During the eighteenth and early nineteenth centuries the technique of ventilating mines by furnaces was further developed and sometimes two or three furnaces would serve the same upcast shaft. Steam haulage engines together with their boilers were also being installed underground and the waste heat from these installations was passed into the upcast shaft to boost the ventilating current The adoption of split ventilation with parallel circuits underground had the effect of greatly reducing the total drag or resistance of the workings; by the middle of the nineteenth century extremely large quantities of air were being circulated in the large mines of the North of England. However, explosions still occurred and several Government Select Committees studied the situation. The Select Committee which reported in 1852 said they were of the opinion "that any system of ventilation depending on complicated machinery is inadvisable, since under any disarrangement or fracture of its parts the ventilation is stopped or becomes less efficient." They also stated "that the two systems which alone can be considered as rival powers are the furnace and the steam jet."[2]

Experiments carried out by mining engineers in the North of England were soon to prove that steam jets were neither so economical, nor so capable of producing large volumes of air as a furnace and their use was abandoned except in cases of emergency. It was during the investigation to test these rival powers that Nicholas Wood[3] indicated the vast quantities of air which were being circulated in some mines. A test at Hetton Colliery on 13 November 1852 with three furnaces working at a depth of 900 ft. from the surface, showed that they circulated 225,000 cu. ft. per. min. and produced a ventilating pressure across the underground workings of 1·95 in. of water. This colliery was considered to have one of the best ventilating arrangements in the country at that time.

The furnace, however, was an extremely dangerous method of producing ventilation, and it had other important defects. Its limits became more obvious as the mine workings extended and resistance to flow increased. By forcing the furnace action, ventilating pressures of 3 or perhaps 4 in.

[1] Buddle, J., *op.cit.*
[2] Report of Select Committee of House of Commons 1852.
[3] Wood, Nicholas, "Furnace and the steamjet in the ventilation of coal mines," *Trans. N.E. Inst. Min. Engrs.* (1852–53), 1, 71–163.

of water were possible, but even these ventilating pressures were to prove too small for the requirements of some of the coal mines. The furnace made inefficient use of the coal it consumed in producing air flow; this was pointed out by J. J. Atkinson (1820–70) in papers written in 1854 and 1858.[1,2] He showed the economy of the ventilating machine over the furnace by examining a number of published cases of mines having depths varying from 558 up to 1,800 ft. The results showed that "the coals consumed per horse power exerted by the furnace, exclusive of the power of natural ventilation, ranged from 27·2 to 162·4 lb. per horse power per hour, compared with 20 lb. per horse power per hour by a ventilating engine consuming 12 lb. per horse power and utilising 60 per cent. of the power expended." The second half of the nineteenth century was to witness the almost complete replacement of furnaces by ventilators driven by mechanical means.

Mechanical Ventilation

Early attempts to ventilate coal mines by mechanical means are said to have been made by John Smeaton (1724–92). An exhausting reciprocating pump made of wood was installed by John Buddle at Hebburn Colliery in 1807.[3] The wooden piston of this pump was 5 ft. square and the length of stroke was 8 ft. The pump was worked by a steam engine at 20 strokes per min. and was capable of exhausting about 6,000 cu. ft. of air per min. from the mines.

By the middle of the nineteenth century the volumes of air circulated in the majority of coal mines were in the range of 30,000 to 50,000 cu. ft. per min. Increased ventilation was considered to be the answer to the problem of reducing the explosion hazard, which at this time was considered to be due entirely to firedamp. The efficiency of furnaces to generate air flow was found to increase with depth and they were less effective in shallow mines. The coal mines in South Wales at this period were relatively shallow and mechanical ventilation was first developed there to a much greater extent than in the other coalfields of Great Britain. Around the middle of the nineteenth century a large number of air moving devices were invented and tried out on the mines. These included several types of reciprocating air pumps, rotary pumps or displacers and many types of fans.

Reciprocating Air Pumps

One of the most successful air pumps was the Struve ventilator developed by William Price Struve of Swansea.[3] This machine employed a circular iron pistons shaped like gas holders or bells which were moved up and down by a steam engine. The lower edge or skirt of the bell dipped into a circular water trough which prevented leakage past the piston. Each piston functioned as a double-acting pump and generally two pistons were employed. The air from the mine entered the space above and below the piston by way of a large number of inlet flap valves. Reversal of the piston closed the inlet valves and opened exhaust valves through which the mine air was discharged into the atmosphere. In some cases ventilating pressures of 5 in. of water were produced. The first Struve ventilator was installed at Eaglebush Colliery, South Wales and began to work in February 1849; the upcast shaft was 60 yd. deep and the quantity of air circulated was 56,000 cu. ft. per min. at an average water gauge of 3/5 in. About a dozen of these machines were said to have been installed. Plate I(*a*) shows a sectional elevation of a Struve ventilator.

The method of estimating the effectiveness of ventilating machines employed at this time was to

[1] Atkinson, J. J., "On the theory of the ventilation of mines," *Trans. N.E. Inst. Min. Engrs.* (1854–55), **3**, 73–222.

[2] Atkinson, J. J., "On the comparative consumption of fuel by ventilating furnances and ventilating machines ect," *Trans. N.E. Inst. Min. Engrs.* 1(57–8), **6**, 135–150.

[3] Struve, W. P., "The ventilation of collieries, theoretically and practically considered," *Proc. Inst. Civil Engrs.* (1850–51), **10**, 22–44.

assess what was known as the percentage useful effect. The ventilator and its driving engine were treated as a complete machine and the useful effect was calculated from the relationship

$$\text{Useful Effect} = \frac{\text{horse power transmitted to the air}}{\text{indicated horse power of engine}}$$

In the case of the Struve ventilator, various values of the useful effect appear in the literature and occur in the range from 40 to 58 per cent. Upkeep of these machines proved to be rather excessive, the flap valves requiring much maintenance with consequent stoppages of the machine.[1]

Another type of large reciprocating pump was developed by Nixon in 1859.[2] The first of these was installed at Deep Duffryn Navigation, Collieries, Mountain Ash, South Wales. This was a horizontal machine having two rectangular-shaped wooden pistons, each 30 ft. wide by 22 ft. high. The stroke of the pistons was 6 ft. and when the machine ran at 6½ strokes per min. it delivered air at the rate of 93,000 cu. ft. per min. The return air from the upcast shaft was sucked into the cylinders through a large number of flap valves and was discharged into the atmosphere through a similar number of outlet valves. In Nixon's machine it was not possible to have water seals on the pistons and leakage was a difficulty. The pistons were actuated by a steam engine. A second machine was later installed in South Wales at Merthyr Vale Colliery. They are said to have given a useful effect of about 46 per cent. when in good condition. Plate I (*b*) shows a sectional elevation of the Nixon Ventilator and illustrates the path taken by the air in passing through the machine.

Rotary Air Pumps

Rotary air pumps were invented to overcome the objections to the reciprocating air pumps of slow piston speed and much valve maintenance. They consisted of vertical drums revolving eccentrically within a cylindrical chamber. The rotation of the drum formed spaces which caused the air from the upcast shaft to enter the cylindrical chamber and in turn be discharged into the atmosphere. The Lemielle ventilator, which was extensively used in the ventilation of Belgian collieries from 1853 onwards, was one of the most successful of this type of machine.[3] Several of these machines were installed in this country, the one erected at Page Bank Colliery, Durham,[4] around the year 1860, had a casing 22½ ft. diameter and the hexagonal drum was 15 ft. diameter and 32 ft. high When the drum revolved at the rate of 10 times per min. the useful effect was 33·8 per cent. Plate II(*a*) shows the plan of one of these machines.

Fans

One of the earlier mine ventilating fans was said to have been installed at a colliery near Paisley, Scotland, in 1827.[5] Little detail is available of this fan, which is said to have had windmill-type vanes rotating in a horizontal plane. The fan was installed on the top of the upcast shaft.

Fans on the Archimedian screw principle were also tried both in this country and on the Continent, with little success because they failed to produce sufficient ventilating pressure to cause the required quantities of air to flow through the mines.

The type of fan which proved to be the most successful in meeting the requirements of mine ventilation was the centrifugal fan. Early efforts to use these fans as mine ventilators were not very

[1] Brown, G., *Trans. S.W. Inst. Engrs.* (1866–67), **5**, 275–281.

[2] Report of Committee on Mechanical Ventilators, *Trans. N.E. Min. Engrs.* (1880–81), **30**, 273–287.

[3] Lloyd, S., "Description of Lemielle's ventilating machine for mines," *Proc. Inst. Mech. Engrs.* (1868–69, **18**, 63–70.

[4] Steavenson, A. L., "Lemielle ventilator at Page Bank Colliery," *Trans. N.E. Inst. Min. Engrs.* (1868–69), **18**, 63–70.

[5] Moss, K. N., "Ventilation of coal mines, Chap. 9 of *Historical Review of Coal Mining*," *circa* 1925, Min. Assoc. of G.B. London, Fleetway Press.

successful, owing to their small size and the small engine power employed. The early work on the development of mechanical ventilation for mines had been done mainly by Belgian and French engineers. They had experimented with all kinds of air pumps and with many types of fans. The Continental engineers developed the fundamental theory of fans and pioneered their practical application to mines. At the same time experiments were being tried in this country and several successful centrifugal fans were developed which are linked with the names of Brunton, Nasmyth, Waddle, Schiele and Capell.

Brunton's Fan

In 1849 William Brunton (1777–1851) designed and erected a centrifugal fan at Gelly Gaer Colliery, South Wales.[1] His fan was of the open running radial-bladed centrifugal type with its plane of rotation horizontal. It was installed over a culvert which connected with the upcast shaft and was directly driven by a steam engine. The dimensions of another Brunton fan which was installed at Cwmsaerbran Colliery were as follows: outside diameter of fan wheel 20 ft., diameter of inlet 8 ft. The fan wheel had 24 radial vanes which were arranged to have equal cross sectional area from inlet to outlet. This was arranged by narrowing the distance between the two iron discs forming the runner from 2 ft. 10 in. at the inlet to 1 ft. 2 in. at the periphery. Huxham,[1] who made tests on this fan, gave useful effects varying from 14 to 34 per cent.; the variation depended on the resistance of the mine system used in the tests. The higher resistances gave lower useful effects. The layout of Brunton's machine is shown in Plate IV(*a*).

Nasmyth's Fan

In 1851, James Nasmyth (1808–90) described before the British Association at Ipswich a double-inlet open running centrifugal fan, which he had designed for mine ventilation purposes. This fan had four radial blades fixed to a shaft which was directly driven by a steam engine. The first fan of Nasmyth's design was installed at Abercarn Colliery in South Wales in 1854.[2] This colliery had one shaft which was bratticed so as to function as both downcast and upcast. The fan was fixed at the surface so as to exhaust the air from the upcast division of the shaft. A sectional view of this fan is shown in Plate II(*b*). The fan was $13\frac{1}{2}$ ft. in diameter and had 8 radial sheet iron vanes each 3 ft. 6 in. wide and 3 ft. long. The fan worked within a casing of thin wrought iron plate which was entirely open all round the circumference. The air inlets on each side of the fan were 6 ft. diameter. The steam driving engine had a 12 in. diameter cylinder with a 12 in. stroke and was actuated by steam at a pressure of about 13 lb. per sq. in. The fan was worked at a speed of 60 revs. per min. and extracted 45,000 cu. ft. per min. with a water gauge of 0·5 in. According to Mr. E. Rogers the fan performed satisfactorily and a second larger fan by Nasmyth was installed at Skiar Spring Colliery, near Elsecar, which was also said to have worked satisfactorily. No test data appears to have been published on either of these fans.

Schiele Fan

The type of fan developed and patented by Christian Schiele of Manchester for use in mine ventilation in 1863 appears to have been an enlarged version of the blast fan used for blowing cupolas. This fan had a strongly built iron runner of comparatively small diameter which could be revolved at high speed when compared with other mine fans then available. The runner consists of a central disc of wrought iron to which the blades tapering towards the periphery were fixed The blades

[1] Huxham, H., "Memoranda on Brunton's Ventilating Fan," *Trans. S.W. Inst. Engrs.* (1857–59), **1**, 163–178.
[2] Rogers, E., "Description of the ventilating fan at the Abercarn Collieries," *Proc. Inst. Mech. Engrs.* (1856), 251–59.

were inclined backwards from the direction of rotation and revolved in a wrought iron volute casing which fitted closely to the sides of the blades. This was the first British mine fan to be enclosed in a volute casing, which collected the air discharged from the fan wheel and guided it into the atmosphere. The arrangement of the fan is illustrated in Plate III(*a*). The Schiele fan became very popular on account of its low capital cost and small size, requiring little space and light foundations. A typical Schiele fan was that installed at Car House Colliery. The fan runner has a diameter of 9 ft. 6 in. and circulated 106,500 cu. ft. per min. with a fan pressure of 2·38 in. of water. Its useful effect is given as 49 per cent.

Waddle Fan

The first Waddle fan was introduced by Mr. J. R. Waddle of Llanelly, South Wales, about 1864 and was installed at Bonville's Court Colliery, South Wales.[1] This colliery was 540 ft. deep and the fan was 16 ft. in diameter and circulated 30,000 cu. ft. per min. with a ventilating pressure of $1\frac{3}{4}$ in. of water. The runner of this fan is composed of two circular iron discs which shroud the blades which are bent backwards from the direction of rotation. One of the discs is convex on the outside and the inlet opening is made in the middle of this disc. The Waddle fan was not cased and the air was expelled all round the periphery of the runner directly into the atmosphere. Fans of this type were built in diameters varying from 20 to 50 ft.[2] A sectional elevation of the fan is shown in Plate IV(*b*).

Guibal Fan

One of the most successful centrifugal fans developed during the middle of the nineteenth century was that invented by Theophile Guibal (1814–88) of Mons, Belgium. Guibal was born at Toulouse and educated in Paris, and became Professor of Exploitation of Mines at the University of Mons. Several of the earlier fan inventors had considered that an exhausting or suction fan drawing air from a mine did not require a casing round the rotating impeller. They considered that the discharged air should have a free and unrestricted escape into the atmosphere. It was Guibal who first showed that a casing was necessary to allow a suction fan to develop its full useful effect. He also introduced the expanding chimney or evasee in which the discharged air slows down and converts kinetic energy into pressure, thereby increasing the total pressure generated by the fan. Guibal's casing was not of the volute type with a progressive expansion of the area round the rotating impeller. but was close fitting until the discharge orifice was reached. Guibal's patent for this fan with casing and regulating shutter was taken out in this country in 1862. His first fan was installed on the Continent at the Jean Bart Colliery in 1859. The impeller of the Guibal fan consisted of 8 or 10 rectangular vanes which were inclined backwards from the direction of rotation. Each vane was composed of oak planks $1\frac{1}{2}$ in. thick, secured by bolts to a pair of bars and angle irons, which were bolted to two cast iron bosses keyed on the main shaft. The simplicity, freedom from repairs and high useful effect of this fan caused it to be greatly favoured and more fans of this type were erected than of any other. By 1870 nearly 150 of these fans were at work on the Continent and in this country, of diameters varying from 16 to 50 ft. and capable of passing volumes of air from 30,000 to over 200,000 cu. ft. per min. with fan pressures up to 6 or more inches of water.[3] A sectional elevation of the 10-bladed Guibal fan installed at Thrislington Colliery, which was 36 ft. diameter, is shown in Plate III(*b*). The useful effect of this fan in most applications was in the region of 50 to 65 per cent.

[1] Brough, L., *Trans. S.W. Inst. Engrs.* (1866–67), **5**, 202.
[2] Morison, D. P., *Trans. N.E. Inst. Min. Engrs.* (1868–69), **18**, 99–100.
[3] Cochrane, W., "Description of Guibal's ventilator at Elswick Colliery," *Trans. N.E. Inst. Min. Engrs.* (1864–65), **14**, 73–81.

Capell Fan

The Capell fan was a small diameter centrifugal fan designed to run at a relatively high rotational speed. The inventor of this fan was the Rev. George Marie Capell, a graduate of Oxford University. He became interested in fans for agricultural purposes and first applied his fan for the purpose of drying stacks of farm produce. In 1883 he turned his attention to mine ventilation, having noted that on the Continent slow moving fans of large diameter were being replaced by smaller, quick running fans. The distinguishing feature of the Capell fan was in the construction of the impeller, which is divided into two concentric compartments by what the inventor calls a "cylinder." There are two separate series of vanes, one in each concentric chamber, the two series forming portions of one structure. The air enters the impeller through a central inlet and by the action of the inner set of vanes is driven through port holes in the cylinder into the outer compartment, whence it is expelled at the periphery. His first fans were open running, but later he added a casing which gave improved performance.[1] The first Capell fan was installed at Waleswood Colliery near Sheffield and is illustrated in Plate I(c). The outside diameter of the fan impeller was 10 ft. and its width 8 ft. The fan was tested by Mr. W. Fairley and Mr. Jonah Davies and according to Capell their results gave the high useful effect of 88·79 per cent. This high result appears to have been faulty, also the fan had a rope drive which would reduce the useful effect. Later values of the useful effect of this fan given by Arnold Lupton ranged from 59·5 per cent to 72 per cent. A test made on a Capell fan (diameter 2½ m., width 1·8 m) erected at the Friedrich Joachin shaft of the Koenigin Elizabeth Colliery, Essen, gave mechanical efficiencies ranging from 56 per cent. to 76 per cent. depending on the resistance of the air flow system.[2] Many fans of this type were installed in this country and abroad during the latter part of the nineteenth and early twentieth centuries.

Walker Fan

Another strongly built fan which was developed during the last quarter of the nineteenth century was the Walker fan, by Walker Bros. of Wigan. The impeller had ten iron blades curved backwards, with an increased backward curvature of the tips. The casing of the fan was of the volute type and the outlet is fitted with an expanding chimney. The Walker fan was widely employed in mine and tunnel ventilation, both in this country and abroad.

Conclusion

In the early days of coal mining only shallow seams were worked, as these were easily reached and could be worked with the minimum of difficulty. The chief gaseous pollutant in these early days was chokedamp, but methods of producing vigorous ventilation to ensure its removal had not been developed. In the course of time the coal seams were followed to greater depths and firedamp began to be encountered, making more energetic ventilation a necessity.

The use of fire to produce air currents was found to be effective, but in some circumstances highly dangerous, and this method held the field up to the second half of the nineteenth century. From 1860 onwards the centrifugal fan began to displace the furnace on the score of safety, economy and efficiency. The main types of fans installed were the large diameter Guibals and Waddles, with some smaller fans of the Schiele type.

In the latter quarter of the nineteenth century, the large slow running fans began to be replaced by the smaller, quicker running fans of the Schiele, Cappell, improved Waddle and Walker types.

[1] Capell, G. M., "Mechanical ventilation of collieries, with a description of a new form of enclosed mine ventilator," *Trans. Ches. & Mc. Inst. of Engrs.* (1888–89), **17**, 174.

[2] Wabner, R., *Ventilation in mines* (translated by C. Salter 1903), Scott, Greenwood & Co., London, p. 188.

The centrifugal fan could now be designed to handle the largest flows required for the efficient ventilation of the deepest and most extensive mines. At the end of the century, air flows of 300,000 cu. ft. per min. and more were circulated in some of the deep, gassy collieries. Increased depth brought with it the problem of increased strata temperature, and the necessity to transport heat from the mine in order to maintain suitable environmental conditions in which men could work. Thus, increased air flow was needed to produce the necessary cooling power. However, the major ventilating problem of circulating large air flows through mines with safe mechanical means had been solved before the close of the nineteenth century.

DISCUSSION

Mr. REX WAILES said that he had been fortunate enough to see two Waddle fans and asked the Author if others were still extant. There was one until quite recently at the Abergorki Pit at Mountain Ash. This was installed with a steam engine to drive it when this North Pit of Nixon's Navigation Company was sunk in 1870. The fan is by the Waddle Patent Fan and Engineering Company of Llanelly. It is of steel, about 36 ft. diameter by 2 ft. wide with the vanes enclosed by deep shrouds and extracting from the centre. The fan is in the open, in a narrow gap between the engine house and the enclosed head of the ventilating shaft. This fan was *in situ* in June 1967; the pit was closed in August of that year. There are two steam engines, dated 1870, on the same bed driving the same crank; when one engine was under repair the other could keep the ventilation system working. They are single-cylinder simple engines with piston valves, 22 in. bore × 4 ft. stroke with a common disc crank. The normal speed was 50 r.p.m. measured with a revolution counter by John Hardy of Derby. There is another Waddle fan at Ryhope Colliery County, Durham., This Colliery was almost completely re-equipped in 1957 but was closed in 1967. The fan appears to be of the same type as the one at Abergorki but is not as accessible. It was originally driven by a steam engine, latterly by electric motors, and could still be used if necessary. Mr. Wailes hoped that Mr. Frank Atkinson would manage to acquire it for Beamish Hall Museum.

Professor HINSLEY replied that he did not know of any more of these fans; but he believed there were one or two still remaining in the East Midland region, the mines had been reorganised since 1947 and the fans were replaced in nearly every case. It would be unfortunate if all the Waddle fans were broken up because they were quite a step forward in their day; he was glad to hear that Mr. Atkinson was hoping to keep one in the North of England. Perhaps Mr. Thomas could say what had happened to the one at Abergorki.

Mr. THOMAS, of the National Museum of Wales, Cardiff, said that the fan at Abergorki was still in existence and was being scheduled as an Ancient Monument. The Coal Board are quite willing for it to be preserved. Some enthusiastic members of a local industrial archaeology society had been working on it during the school vacation. They had restored a considerable part of the engines and carried out preservation work. Mr. Thomas hoped that it would eventually be taken into guardianship.

Mr. C. MCCOMBE said that as a Northumbrian and a Tynesider, he rather thought George Stephenson had invented the safety lamp and was disappointed to hear after all these years that Sir Humphry Davy is still credited with the invention. He had seen miners in the North Antrim coalfield working the debris left by the "old men" by the light of candles. Also acetylene lamps were used at Radstock Colliery in the Mendips. Was it some quirk of geology that these mines were presumably gas free?

Professor HINSLEY replied that he supposed that the pits in the Mendips were fairly shallow. Shallow seams were usually less gassy than deep ones so that candles could be used at shallow depths except for the risk of the occasional presence of fire-damp. The Mines Inspectors prefer safety lamps to be used on all occasions because of this risk. Regarding the Stephenson lamp, they would see in the Paper that he (Professor Hinsley), had spoken of the wire gauze safety lamp. This was invented by Davy. He knew that Stephenson was working on his safety lamp at the same time, but this lamp did not have a wire gauze at first; Stephenson adopted the wire gauze later after seeing the Davy lamp, but insisted on retaining his other distinctive features.

Mr. T. R. HARRIS, from Cornwall, asked if Professor Hinsley could elaborate on the effects of the steam jet in the coal mines. He understood that Goldsworthy Gurney proposed the use of the steam jet before a Royal Commission in 1835 and that it came into use in 1843. It wasn't taken very seriously by people in the North; apparently they were rather adverse to anything new; but the Report of the Commission before the House of Lords in 1849 was very favourable. It had been used at Seaton Delaval and the speaker thought that the working miners there gave it a very good testimony. It was preferred to the furnace in 1852; but Nicholas Wood did some further experiments and persuaded the Committee of 1854 that the furnace was superior to the steam jet. The speaker thought that the Committee had said that the steam jet was useful in certain collieries but not in all and had thanked Gurney for stimulating research which had improved ventilation by suggesting a rival method. It was interesting to note that both the steam jet and the furnace went out of use with the introduction of more reliable mechanical fans. As a fellow Cornishman Mr. Harris wanted to speak up for Davy—he had been reading recently that explosions associated with Davy lamps were sometimes caused when the colliers didn't keep them clean; they might get foreign matter on the outside of the gauze which could ignite and set off an explosion.

Professor HINSLEY said that all his information about the steam jet was from Nicholas Wood's Papers in which tests were recorded. Mr. Harris referred to the correspondence for and against the steam jet for mine ventilation in *The Mining Journal* in the years from 1851 to 1853. Professor Hinsley said that he did not think that there had been any test in which the same amount of heat was used in both furnace and steam jet ventilation, but Nicholas Wood could get 225,000 cu. ft. of air per min. through Hetton Colliery's furnaces which was much more than was possible with the steam jet installation in the same mine. Although the fuel consumption of the two systems are now unknown, the results of this and other tests were the reason why steam jet ventilation was abandoned.

Mr. HARRIS said that he was rather interested in Gurney and would like to have a description of his apparatus. Professor Hinsley said that it was described in the *Transactions of the North of England Institute of Mining Engineers*, Vol. 1 which contains several Papers on steam-jet ventilation.

Mr. R. J. LAW said that he was a little puzzled that the Guibal fans had no proper volute chamber because the lack of one would restrict the flow of air. The air could only flow out from between the blades which were passing the short exit port. In Agricola's *De Re Metallica* (1556), there is a drawing of a wooden centrifugal fan for mine ventilation, but Agricola didn't know what was inside the box, so he drew the outside with a little hole for the air to come out; he also drew the bits. It is apparent from his plates that the fan had no chamber outside the vanes and the air could only flow out from the two vanes that happened to be in line with the hole. Mr. Law had recently seen drawings of a Guibal fan installed in 1888 to ventilate the Severn Tunnel; as he remembered these showed a volute chamber. Could Professor Hinsley say whether Guibal fans were improved by the addition of a volute chamber?

Professor HINSLEY said that he didn't think that Guibal ever changed to the volute chamber because he claimed that his experiments showed that his original form was best, but few of his contemporaries agreed with him. Contributors to discussions in the *Proceedings of the Institution* *of Mechanical Engineers* all said that he should add a volute casing of the type used on forcing fans at that time. They said that the volute chamber was invented by a man called Ericsson about 1850.

Mr. SEAGER (of Sheffield) wanted to know if the steam jet units were intended to work on the Venturi principle or merely as a safer way of heating the air to induce natural convection. Professor Hinsley said that Gurney had suggested it as an ejector which would take the air with it; he neglected the heating effect of the steam. Mr. Seager then asked how the draught was re-started after a ventilation furnace had been stopped for repairs.

Professor HINSLEY said that this was a difficult job in a gassy mine, because once ventilation stopped, there would be a tremendous accumulation of fire-damp. He gathered that the furnace was built up with wood and that they lowered a light down the shaft to start it off. Usually the heat remaining in the shaft itself was enough to maintain a good flow or air during repairs but they didn't put the furnace out if it could be avoided; they always kept it going a little. If there was a complete shutdown of the furnace, ventilation was re-started either by use of a waterfall in the downcast shaft or by a steam jet. The furnace was re-lit after the fire damp had been removed by these means.

Mr. ANDRE KENNY said that some members that evening seemed to be pre-occupied with the place they came from; perhaps he should state his claim to Bermondsey and West Suffolk. Mr. Kenny said that the Romans used up-cast and down-cast shafts for mine ventilation and this practice is known to go back to the Athenian silver mines of the fourth and fifth centuries B.C.—if not earlier. There is also evidence of the use at that period of a single shaft divided by a brattice. At the silver mines of Laureion, near Athens, there are traces of furnaces, or fires at any rate, having been used to stimulate ventilation in shafts both with and without brattices. The Romans even ascribed a divinity to the ventilation of mines; possibly because of the capricious and un-governable nature of the air currents, this deity was female, the goddess Scaptensula, mentioned by Lucretius. Further, Struve's pump with a skirted piston like a gas-holder is strongly reminiscent of an air pump for raising water described by Philo of Byzantium. Unfortunately the original Greek text of its description is lost but there is an Arabic version which was edited and translated by Baron Carra de Vaux (1903). A drawing of that pump by our Past President, Mr. R. H. Clark, appeared in a Paper on Greek Physics which the speaker had presented to the Society in 1964 (*Trans.*, XXXVII, Plate VI).

Turning to more modern matters Mr. Kenny asked Professor Hinsley if there was any connection between the rotary air pump of Lemielle (which consisted of a rotating cylinder on an eccentric shaft) and the principle of the Roots blower; also, had the latter device ever been used for such large jobs as extracting air from mines? Finally Mr. Kenny asked if Professor Hinsley had any special reason for mentioning that the Walker's fan would not be used for tunnel ventilation much longer, was it unsatisfactory or too expensive?

Professor HINSLEY replied that fans were now available which could handle air flows through a wide range of resistance with greater efficiency; these were superseding the Walker type. He realised that a very long paper would be needed to deal with the ventilation of all types of mining at all periods. The Laureion mines and others long ago had reached a high state of technology in their time but it had been largely forgotten. Hundreds of years later British coal miners started from the beginning and went through inventing it all again. The only new thing in modern times appears to be electricity, all the other ideas appear over and over again in the old literautre. He had limited his Paper to coal mine ventilation in Great Britain because of the vast amount of development which had gone on before and elsewhere. There had been odd cases in the Nineteenth Century where Root's blowers were used for Colliery ventilation. A Root's Blower was installed at Chilton Colliery in County Durham in 1877 which appears to have worked satisfactorily. This is described in a paper by E. Hamer Carbutt in the *Proceedings of the Institution of Mechanical Engineers*, 1877 p. 92.

Mr. W. K. V. GALE said that the last furnace ventilation for a mine of any size (but he was open to correction on this) was at Walsall Wood Colliery, Staffordshire, in the 1920's. The whole mine was furnace ventilated, it was a fair sized colliery employing several hundred men. It has been closed and dismantled since it came into Coal Board ownership and there is little trace of it left. He further asked if the Guibal fan at the Severn Tunnel was still there.

Mr. R. J. LAW said that the Guibal fan of 1888 was removed in 1927 (he thought) when the present Walker fan was put in. The old Guibal fan had been built by Walkers and was driven by a Walker engine, it was forty odd feet in diameter. Part of its volute chamber could still be seen at Sudbrook shaft. Mr. Gale commented that the present fan is a forcing fan and not a drawing fan like the earlier one. You can stand by the air intake, which is fortunately protected by a grid, or you too would be forced into the Severn Tunnel. It was driven, until recently, by one steam engine. When the drive was electrified they put in two electric motors, one as an installed spare.

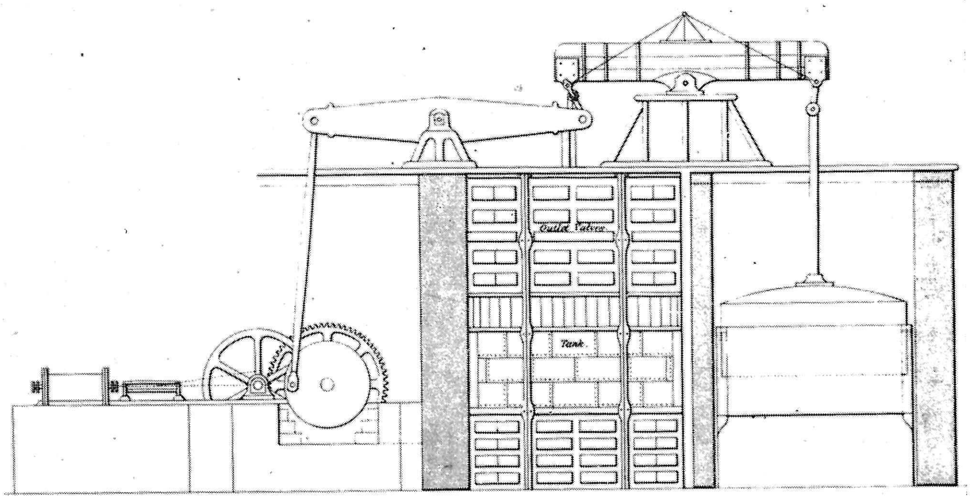
Mr. J. W. C. BUTLER asked if any of the steel mills used for illumination still survived. They seemed an exciting sort of thing and a possible safer substitute for fireworks. He also asked what kind of apparatus had superseded the equipment described in the Paper in modern times.

Mr. R. J. LAW said that there was a steel mill in the Science Museum, South Kensington and another in the Blackgate Museum, Newcastle-upon-Tyne.

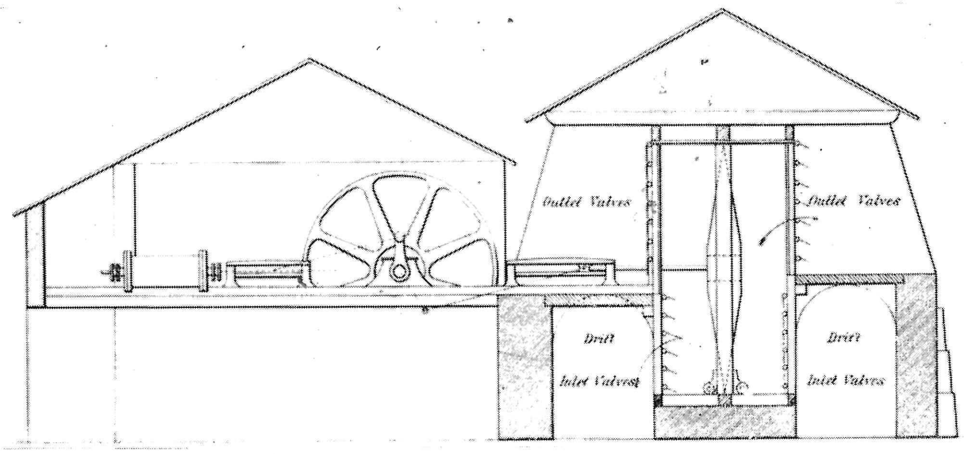
Professor HINSLEY said that he had one at Nottingham which he thought had come from Whitehaven where the device originated. There are two types of fan installed at the present time; one is the centrifugal fan with aerofoil blades and a top efficiency in the region of 90 per cent. It can also be fitted with variable inlet guide vanes which can be adjusted to suit a particular mine. The old fans were driven by steam engines which allowed the speed of the fan to be varied to control the output; other means must often be used with the electric drive if the motor is of constant speed type. The other type of fan is the axial-flow and the output can be varied either by changing the angle of the blades or by providing additional stages. These fans also are capable of high efficiencies. A modern colliery may have five working coal faces; the Coal Board are talking of producing 1,000 tons a day from one face so that only three faces are needed to win 3,000 tons per day. That would need three ventilation circuits in parallel. Cutting coal at such a tremendous rate releases vast amounts of firedamp and the fans must deliver large quantities of air at high pressure to remove it.

Mr. R. H. CLARK said that there was an interval of only three days between the lamp made by Sir Humphry Davy and that by George Stephenson, so that it appears that the two lamps were at work and in use at the same time. Mr. Clark believed that Stephenson showed great physical courage in testing his lamp by himself down a mine; Davy did not test his own lamp. Mr. Clark went on to ask if Professor Hinsley could confirm that the cylinder of the engine that drove the Nasmyth fan at Abercorn Colliery was 12 in. bore × 12 in. stroke; this was unexpectedly early to find a "square" engine. (Professor Hinsley confirmed this after the meeting).

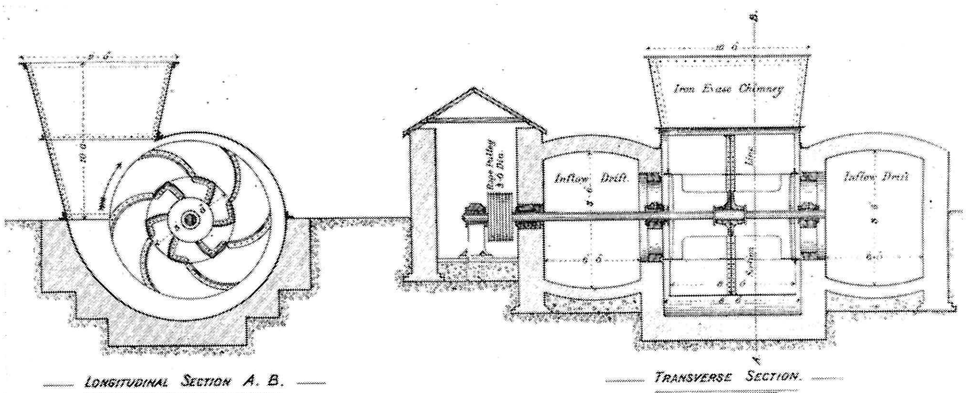
Mr. R. J. Law proposed the vote of thanks.



(*a*) Struve Ventilator (1849).

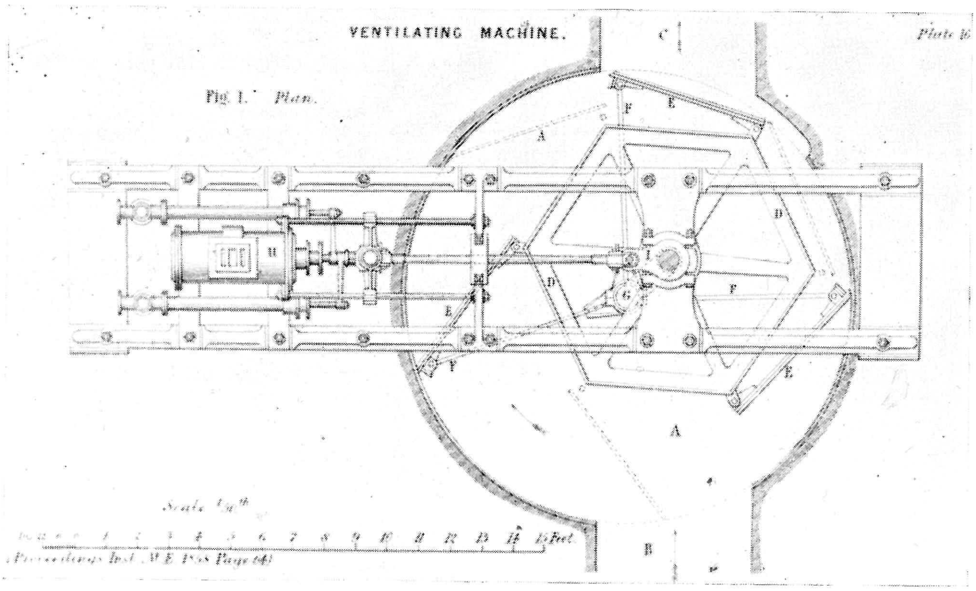


(*b*) Nixon Ventilator (1859).

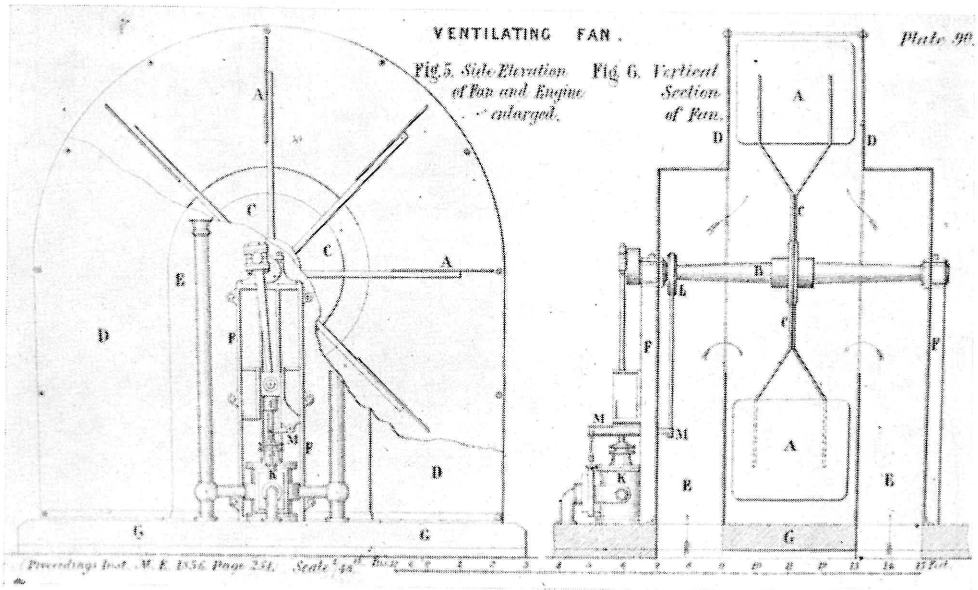


(*c*) Capell Fan (1883).

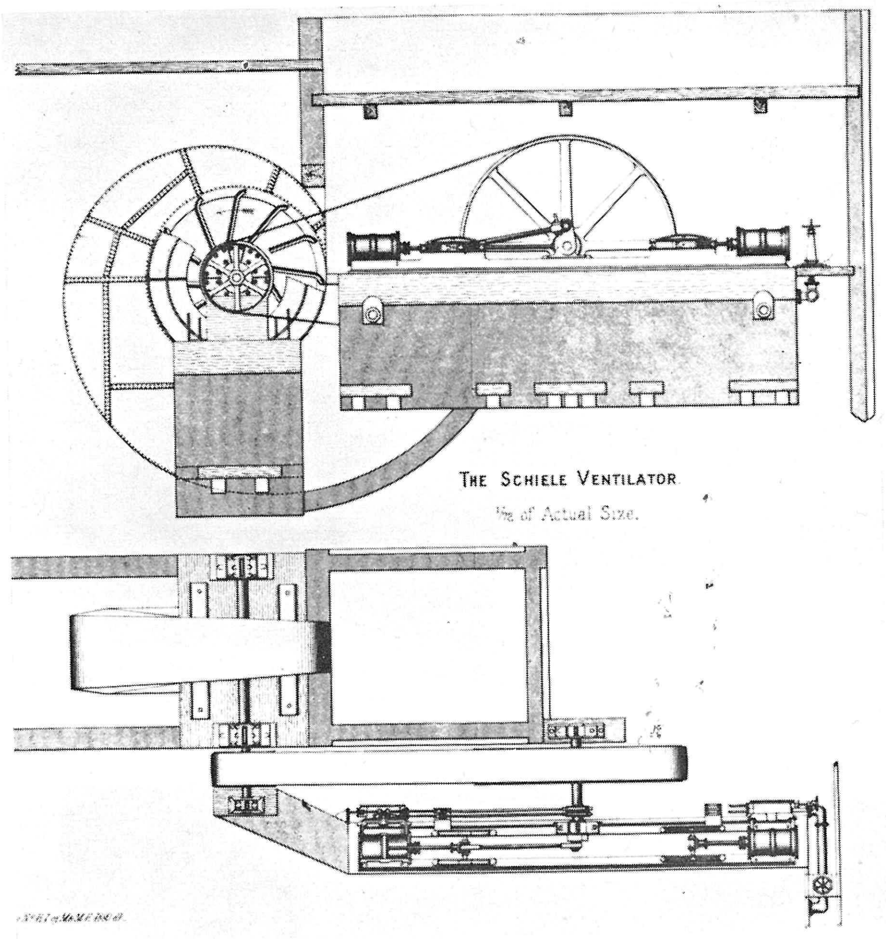
PLATE II



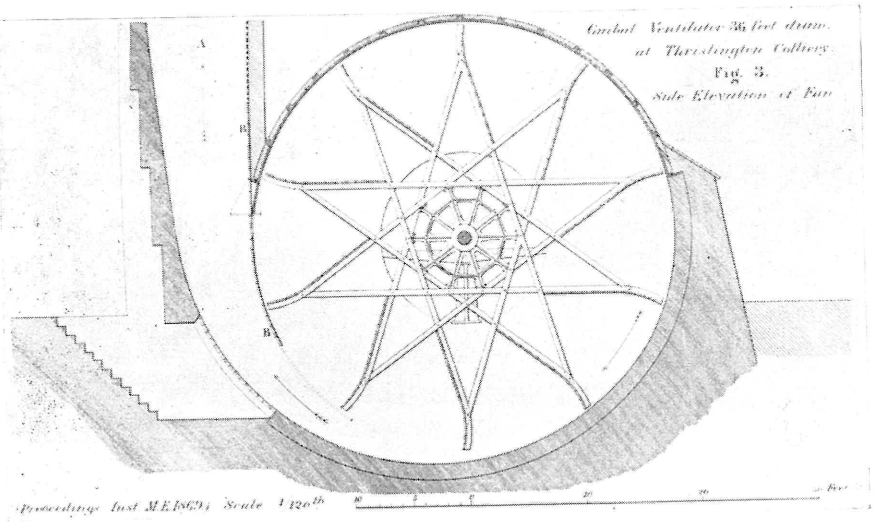
(*a*) The Lemielle rotary air pump (1853).



(*b*) Nasmyth's Fan (1854).

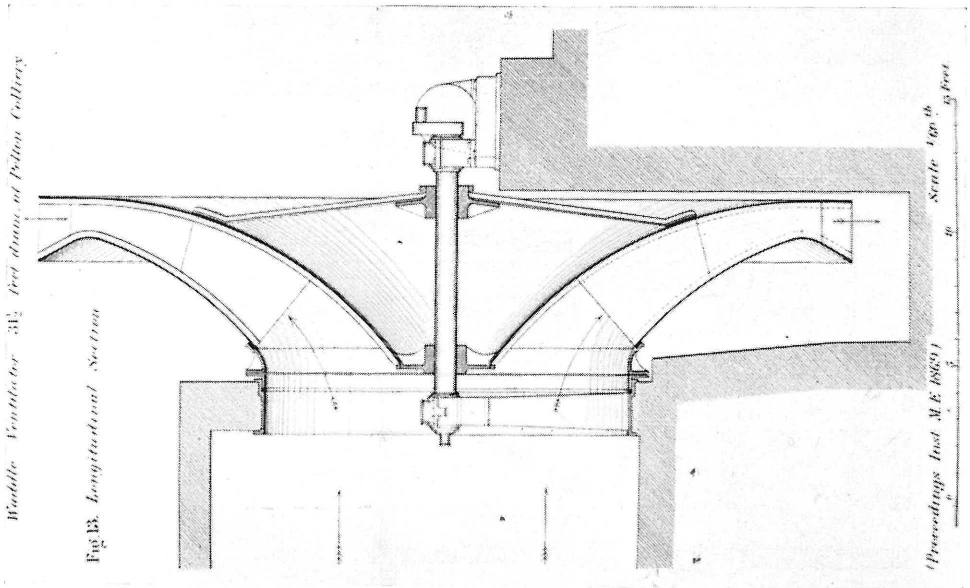


(*a*) The Schiele Ventilator (1863).

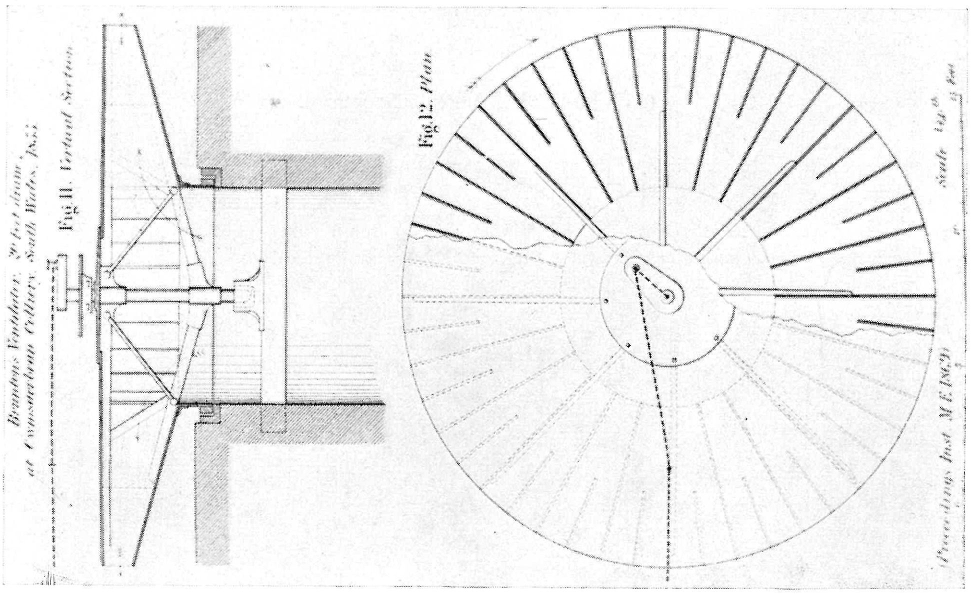


(*b*) The Guibal Ventilator (1859).

PLATE IV



(b) Waddle Ventilator (1864).



(a) Brunton Ventilator (1855).

THE

NEWCOMEN SOCIETY

for the study of the history of

ENGINEERING and TECHNOLOGY

TRANSACTIONS
Volume XLII
1969–70

LONDON
Printed for the Society by
W. Heffer & Sons Ltd., Cambridge
1972