Min-218 Reading Material

A BRIEF HISTORY OF MINE VENTILATION

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Observations of the movements of air in underground passages have a long and fascinating history. Between 4000 and 1200 BC, European miners dug tunnels into chalk deposits searching for flint. Archaeological investigations at Grimes Graves in the south of England have shown that these early flint miners built brushwood fires at the working faces—presumably to weaken the rock. However, those Neolithic miners could hardly have failed to observe the currents of air induced by the fire. Indeed, the ability of fire to promote airflow was rediscovered by the Greeks, the Romans, in medieval Europe and during the Industrial Revolution in Britain.

The Laurium silver mines of Greece, operating in 600 BC, have layouts which reveal that the Greek miners were conscious of the need for a connected ventilating circuit. At least two airways served each major section of the mine and there is evidence that divided shafts were used to provide separate air intake and return connections to the surface. Underground mines of the Roman Empire often had twin shafts, and Pliny (AD 23-79) describes how slaves used palm fronds to waft air along tunnels.

Although metal mines were worked in Europe during the first 1500 years *anno Domini*, there remain few documented descriptions of their operations. The first great textbook on mining was written in Latin by Georgius Agricola, a physician in a thriving iron ore mining and smelting community of Bohemia in Central Europe. Agricola's De Re Metallica, produced in 1556, is profusely illustrated. A number of the prints show ventilating methods that include diverting surface winds into the mouths of shafts, wooden centrifugal fans powered by men and horses, bellows for auxiliary ventilation and air doors. An example of one of Agricola's prints is reproduced in Fig. 1.1.

Agricola was also well aware of the dangers of 'blackdamp', air that has suffered from a reduction in oxygen content—'miners are sometimes killed by the pestilential air that they breathe'—and of the explosive power of 'firedamp', a mixture of methane and air—'likened to the fiery blast of a dragon's breath' . De Re Metallica was translated into English in 1912 by Herbert C. Hoover and his wife, Lou. Hoover was a young American mining engineer who graduated from Stanford University and subsequently served as President of the United States during the term 1929-1933.

From the seventeenth century onwards, papers began to be presented to the Royal Society of the United Kingdom on the explosive and poisonous nature of mine atmospheres. The Industrial Revolution brought a rapid increase in the demand for coal. Conditions in many coal mines were quite horrific for the men, women, and children who were employed in them during the eighteenth and nineteenth centuries. Ventilation was induced either by purely natural effects, stagnating when air temperatures on the surface and underground were near equal, or by fire. The first ventilating furnaces of that era were built on surface but it was soon realized that burning coals suspended in a wire basket within the upcast shaft gave improved ventilation. Furthermore, the lower the basket, the better the effect. This quickly led to the construction of shaft bottom furnaces.

The only form of illumination until the early nineteenth century was the candle.

Figure 1.1 A print from Agricola's De Re Metallica. (This figure is similar to Figure 1.1 in the Hartman text.)

With historical hindsight we can see the conjunction of circumstances that caused the ensuing carnage: a seemingly insatiable demand for coal to fuel the steam engines of the Industrial

Revolution, the working of seams rich in methane gas, inadequate ventilation, furnaces located in methane-laden return air and the open flames of candles. There are many graphic descriptions of methane and coal dust explosions, the suffering of mining communities, the heroism of rescue attempts and the strenuous efforts of mining engineers and scientists to find means of improving ventilation and providing illumination without the accompanying danger of igniting methane gas. Seemingly oblivious to the extent of the danger, miners would sometimes ignite pockets of methane intentionally, for amusement and to watch the blue flames flickering above their heads. Even the renowned engineer George Stephenson admitted to this practice during the inquiries of a government select committee on mine explosions in 1835. A common method of removing methane was to send a 'fireman' in before each shift, covered in sackcloths dowsed in water and carrying a candle on the end of a long rod. It was his task to burn out the methane before the miners went into the working faces.

John Buddle (1773-1843), an eminent mining engineer in the north of England, produced two significant improvements. First, he introduced 'dumb drifts' which bled sufficient fresh air from the base of a downcast shaft to feed the furnace. The return air, laden with methane, bypassed the furnace. The products of combustion entering the upcast shaft from the furnace were too cool to ignite the methane but still gave a good chimney effect in the shaft, thus inducing airflow around the mine. Buddle's second innovation was 'panel (or split) ventilation'. Until that time, air flowed sequentially through work areas, one after the other, continually increasing in methane concentration. Buddle originally divided the mine layout into discrete panels, with intervening barrier pillars, to counteract excessive floor heave. However, he found that by providing an intake and return separately to each panel the ventilating quantities improved markedly and methane concentrations decreased. He had discovered, almost by accident, the advantages of parallel layouts over series circuits. The mathematical proof of this did not come until Atkinson's theoretical analyses several decades later.

The quest for a safe form of illumination went on through the eighteenth century. Some of the earlier suggestions made by scientists of the time, such as using very thin candles, appear quite ludicrous to us today. One of the more serious attempts was the steel flint mill invented in 1733 by Carlisle Spedding, a well known mining engineer, again, in the north of England (Fig. 1.2). This device relied on a piece of flint being held against a rapidly revolving steel wheel. The latter was driven through a gear mechanism by a manually rotated handle. The complete device was strapped to the chest of a boy whose job was to produce a continuous shower of sparks in order to provide some illumination for the work place of a miner. The instrument was deemed safer than a candle but the light it produced was poor, intermittent, and still capable of igniting methane.

Figure 1.2 Spedding's Flint Mill. (Reproduced by permission of Virtue and Co., Ltd.)

A crisis point was reached in 1812 when a horrific explosion at Felling, Gateshead, killed 92 miners. With the help of local clergymen, a society was formed to look into ways of preventing such disasters. Contact was made with Sir Humphrey Davy, President of the Royal Society, for assistance in developing a safe lamp. Davy visited John Buddle to learn more of conditions in the mines. As this was well before the days of electricity, he was limited to some form of flame lamp. Within a short period of experimentation he found that the flame of burning methane would not readily pass through a closely woven wire mesh. The Davy lamp had arrived (Fig. 1.3). Buddle's reaction is best expressed in a letter he wrote to Davy.

> *I first tried it in a explosive mixture on the surface, and then took it into the mine.. .it is impossible for me to express my feelings at the time when I first suspended the lamp in the mine and saw it red hot...I said to those around me, 'We have at last subdued this monster.'*

The lamp glowed 'red hot' because of the methane burning vigorously within it, yet the flames could not pass through the wire mesh to ignite the surrounding; firedamp.

Davy lamps were introduced into British mines, then spread to other countries Nevertheless, in the absence of effective legislation, candles remained in widespread use through the nineteenth century because of the better light that they produced.

Figure 1.3 The original appearance of the Davy safety lamp. (Reproduced by permission of Virtue and Co., Ltd.)

Perhaps the greatest classical paper on mine ventilation was one entitled 'On the theory of the ventilation of mines', presented by John Job Atkinson to the North of England Institute of Mining Engineers in December, 1854. Atkinson was a mining agent—an intermediary between management and the mine owners. He later became one of the first Inspectors of Mines. Atkinson appears to have been well educated in mathematics and languages, and was clearly influenced by the earlier work of French hydraulic engineers (Chapter 5). He seems to have had some difficulty in having his paper accepted. Officers of the Institute decided, perhaps understandably, that the 154 page paper was too long to be presented at a meeting. It was, however, published and a meeting of the Institute arranged to discuss it. Despite publicity referring to the importance of the subject, attendance at the meeting was poor and there was little discussion. In this paper, Atkinson proposed and expanded upon the principles on which most modem mine ventilation planning is still based. However, the analytical reasoning and mathematical analyses that he developed in great detail were simply too much for engineers of the day. The paper was consigned to the archives and it was some 60 years after Atkinson's death that his work was 're-discovered' and put into practice.

During Atkinson's productive years the first power-driven ventilators began to appear. These varied from enormous steam-driven piston and cylinder devices to elementary centrifugal fans.

The years around the turn of the century saw working conditions in mines coming under legislative control. Persons responsible for underground mining operations were required to obtain minimum statutory qualifications. Mine manager's examination papers concentrated heavily on ventilation matters until well into the twentieth century.

The 1920s saw further accelerated research in several countries. Improved instrumentation allowed organized ventilation surveys to be carried out to measure airflow and pressure drops for the purposes of ventilation planning, although there was no practical means of predicting airflow in other than simple circuits at that time. Atkinson's theory was confirmed in practice. The first successful axial fans were introduced in about 1930.

In 1943, Professor F. B. Hinsley produced another classical paper advancing understanding of the behaviour of airflow by using thermodynamic analyses. Hinsley also supervised the work at Nottingham University that led to the &t practical use of analogue computers in 1952 to facilitate ventilation planning. This technique was employed widely and successfully for over a decade. The development of ventilation network analysis programs for digital computers in the early 1960s rendered the analogue devices obsolete. Initially, the network programs were written for, and required the power of, mainframe computers. These were employed throughout the 1970s. However, the 1980s saw a shift to desk-top computers and corresponding programs were developed. This is now the dominant method used for ventilation planning (Chapter 7).

The discipline of mine ventilation is an addictive subject for researchers of industrial history, full of lost discoveries and rediscoveries, excitement and despair, achievement and tragedy. It has been the subject of many papers and books. An excellent place to commence further reading is the text by Saxton serialized in Volume 146 of the *Mining Engineer*.

THE RELATIONSHIPS BETWEEN VENTILATION AND OTHER SUBSURFACE SYSTEMS

1.3.1 The objectives of subsurface ventilation

The basic objective of an underground ventilation system is clear and simple. It is to provide airflow in sufficient quantity and quality to dilute contaminants to safe concentrations in all parts of the facility where personnel are required to work or travel. This basic requirement is incorporated into mining law in those countries that have such legislation. The manner in which "quantity and quality" are defined varies from country to country depending on their mining history, the pollutants of greatest concern, the perceived dangers associated with those hazards and the political and social structure of the country. The overall requirement is that all persons must be able to work and travel within an environment that is safe and which provides reasonable comfort. An interpretation of the latter phase depends greatly on the geographical location of the mine and the background and expectations of the workforce. Personnel in a permafrost mine work in conditions that would be unacceptable to miners from an equatorial region, and vice versa – and neither set of conditions would be tolerated by factory or office workers. This perception of "reasonable comfort" sometimes causes misunderstandings between subsurface ventilation engineers and those associated with the heating and ventilating industry for buildings.

While maintaining the essential objectives related to safety and health, subsurface environmental engineering has, increasingly, developed a wider purpose. In some circumstances, atmospheric pressure and temperature may be allowed to exceed the ranges that are acceptable for human tolerance. For example, in an underground repository for high level nuclear waste, a containment drift will be sealed against human access after emplacement of the waste canisters has been completed. However, the environment within the drift must still be maintained such that rock wall temperatures are controlled. This is necessary to enable the drift to be re-opened relatively quickly for retrieval of the nuclear waste at any subsequent time during the active life of the repository. Other forms of underground storage often require environmental control of pressure, temperature and humidity for the preservation of the stored material. Yet another trend is towards automated (manless) working faces and the possible use of underground space for in situ mineral processing. In such zones of future mines, environmental control will be required for the efficient operation of machines and processes, but not necessarily with an atmosphere acceptable to the unprotected human physiology.

1.3.2 Factors that affect the underground environment

During the development and operation of a mine or other underground facility, potential hazards arise from dust, gas emissions, heat and humidity, fires, explosions and radiation. Table 1.1 shows the factors that may contribute towards those hazards.

Ventilation and other subsurface systems

These divide into features that are imposed by nature and those that are generated by design decisions on how to open up and operate the facility.

The major method of controlling atmospheric conditions in the subsurface is by airflow. This is produced, primarily, by main fans that are usually, but not necessarily, located on surface. National or state mining law may insist that main fans are sited on surface for gassy mines. While the main fan, or combination of main fans, handles all of the air that circulates through the underground network of airways, under- ground booster fans serve specific districts only. Auxiliary fans are used to pass air through ducts to ventilate blind headings. The distribution of airflow may further be controlled by ventilation doors, stoppings, air crossings and regulators.

Table 1.1 Factors that feature m the creation and control of hazards in the subsurface environment.

Factors that contribute to hazards			Methods of control	
Natural factors →	Design factors →	Hazard	← Ancillary control	← Airflow control
Mining depth	Mining method	Dust	Dust suppression	Main fans
Surface climate	Mine layout	Gas emissions	Gas drainage	Booster fans Auxiliary ventilation Natural ventilation
Geology		Heat and humidity	Refrigeration systems	
	Rate of rock fragmentation			
Physical and chemical properties of rocks	Seam thickness	Fires and explosions	Monitoring systems	Airlocks, stoppings, overcasts, regulators
		Radiation		
Gas content of strata	Type, size, and siting of equipment			Number, size, lining, and layout of airways
Groundwater and other underground liquids	Vehicular traffic			
Age of airways	Stored materials			

It is often the case that it becomes impracticable or impossible to contend with all environmental hazards by ventilation alone. For example, increases in air temperature caused by compression of the air in the downcast shafts of deep mines may result in that air being too hot for personnel even before it enters the workings. No practical amount of increased airflow will solve that problem. Table 1.1 includes the ancillary control measures that may be advisable or necessary to supplement the ventilation system in order to maintain acceptable conditions underground.

1.3.3 The integration of ventilation planning into overall system design

The design of a major underground ventilation and environmental control system is a complex process with many interacting features. The principles of systems analyses should be applied to ensure that the consequences of such interaction are not overlooked. However, ventilation and the underground environment must not be treated in isolation during planning exercises. They are, themselves, an integral part of the overall design of the mine or subsurface facility.

It has often been the case that the types, numbers and sizes of machines, the required rate of mineral production and questions of ground stability have dictated the layout of a mine without, initially, taking the demands of ventilation into account. This will result in a ventilation system that may lack effectiveness and, at best, will be more expensive in both operating and capital costs than would otherwise have been the case. A common error has been to size shafts that are appropriate for the hoisting duties but inadequate for the long-term ventilation requirement of the mine. Another frequent related problem is a ventilation infrastructure that was adequate for an initial layout but lacks the flexibility to handle fluctuating market demands for the mineral. Again, this can be very expensive to correct. The results of inadequate ventilation planning and system design are premature cessation of production, high costs of reconstruction, poor environmental conditions and, still too often, tragic consequences to the health and safety of the workforce. It is, therefore, most important that ventilation engineers should be incorporated as an integral part of a design team from the initial stages of planning a new mine or other underground facility.