Coal Mining Research in the United Kingdom: A Historical Review

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ABSTRACT: This paper reviews the history of coal mining research in the United Kingdom, referring to the development of the industry from its early days a few centuries ago, the subsurface environmental conditions which led to many explosions and loss of lives, and the development of mining research as a consequence. The decline of UK coal mining industry and the changes this brought about are discussed. Using methane prediction technology as an example, brief details of industrial and academic research carried out at the end of the 20th Century is presented.

INTRODUCTION

Coal has fuelled the industrial revolution and, over the years, had major economic, social and political impacts on communities worldwide. Throughout the history of coal production, the industry has continuously evolved and the focal points of production have moved around the globe. Development of new technologies and the geographical shifts in coal production worldwide meant that the science of coal has been re-invented many times over. The world currently is in a new economical and technological era where it is suggested that the internet and e-commerce is a revolution as great as the industrial revolution. As surprising as it may seem, coal still has its place in this revolution. As Mark P. Mills (1999) once wrote, “the internet begins with coal”. In recent years, the internet has been responsible for a significant part of the growth in electricity demand and, although over-estimated by nearly an order of magnitude, Mills (1999) had argued that a kilogram of coal is being burned for every 4 megabytes of information moved over the internet. Until the 1960’s, coal was the single most important source of the world’s primary energy. In the late 1960’s it was overtaken by oil; but it is forecast that coal will remain an extremely important part of the world’s energy mix for many years to come. Currently, coal provides 26.5% of global primary energy needs and generates 41.5% of the world's electricity. Estimates of proven coal reserves worldwide are considered to be around 850 billion tonnes with total global hard coal and brown coal production in 2008 estimated at ~5.9Gt and ~0.95Gt respectively.

Presented in two parts, this paper reviews the historical development of coal mining research in the United Kingdom and, by using methane prediction technology as an example, demonstrates how complementary (and sometimes competing) strands of industrial and academic research has helped further our knowledge in this field.

PART I - THE DEVELOPMENT OF COAL MINING RESEARCH IN THE UK

Pre-1994 Industrial Research in the UK

Within a historical review of coal mining research it is useful to appraise the industrial and social developments which shaped the research direction and research resource which was made available at that time. As reported by Unwin (2007), one of the earliest deaths attributed to an explosion of firedamp occurred in 1621. With the increase in the demand for coal and, as a result, the depth and size of mines, the number and severity of these incidents rose subsequently. The urgent requirement for better control over the mining environment, and in particular the dire need to prevent or at least reduce the subsequent violence of methane (firedamp) and coal dust explosions led to the earliest mining research per se.

The explosion on 25 May 1812 at Felling Colliery near Gateshead-on-Tyne claimed the lives of ninety-two men and boys and led to the establishment of the “Sunderland Society” on 1 October 1813, under the patronage of the Duke of Northumberland. The explosion, indirectly, resulted in the invention by Sir Humphrey Davy of the flame safety lamp, an important milestone. The wire gauze safety lamp was tested underground at Hebburn Colliery on 9 January 1816 (Saxton 1986). Following the death of fifty-two men and boys in an explosion in June 1839 at St Hilda Colliery, County Durham the ‘South Shields Committee’ was formed to study the prevention of accidents in coal
The problems of the UK coal industry in the interwar years were related to a dependence on the exported coal trade together with delays in mechanisation compared with nearby European competitors. Exports fell sharply during this period, whilst UK domestic consumption remained static. This resulted in major unemployment problems in the coastal coalfields. The industry was traditional in its structure and included many small companies. It was also heavily dependent on manual labour, with labour costs accounting for between two thirds and three quarters of the cost of the coal mined. This situation was compounded in that the introduction of mechanisation was very slow. In 1913 less than ten percent of coal was cut by machine. Between 1913 and 1939, output per man shift rose by 81 percent in the Ruhr in Germany, and by 73 percent in Poland, but by only 10 percent in the UK. The decline in the UK's position as an international coal producer can therefore be traced back to fragmented ownership within the UK, coupled with increasing international competition compounded by delays in introducing mechanisation. The latter can be effectively considered to be a delay in exploiting the fruits of mining equipment development.

Arguably, the major thrust in mining research and development in the UK occurred after the nationalisation of the coal industry. However, it would be unfair to leave an impression that little or no Government-sponsored research was conducted prior to 1947. By way of example, in 1911 the UK Government agreed to fund an experimental station at Eskmeals in Cumberland for the investigation of explosions in coal mines. In 1924 the Harpur Hill, Buxton site was acquired for large scale mining safety work, following on from the establishment of the Safety in Mines Research Board in 1921. The UK government took control of the coal mining industry during and after World War I (1917-1921) and during World War II. On 1st January 1947 the coal industry became wholly nationalised under the body of the National Coal Board (NCB). The large reserves of coal, coupled with an anticipated increasing requirement for coal led to many modernisation projects associated with large capital investment. However, the increasing availability and low cost of production of Middle-East oil, partly coupled with an emerging nuclear power industry led to a rapid run-down in the coal mining industry. In 1961, more than 600,000 were employed at 698 collieries. By 1971, those figures were down to 300,000 and 292 respectively. In 1965, coinciding with the discovery of substantial reserves of North Sea oil and gas, the UK Government published its National Plan for Coal which endorsed an intensification of the industry contraction programme. A turning point was reached in 1973, when the UK's economy was affected significantly by oil price rises arising when the members of the Organization of Arab Petroleum Exporting Countries initiated an oil embargo in response to the US decision to re-supply the Israeli military during the Yom Kippur war. This lasted until March 1974 and resulted in a fundamental reappraisal of national energy policies. Consistent with a view that coal should maintain a significant part in the primary energy mix considerable attention was given to coal related research on both sides of the Atlantic.
At the time of nationalisation in 1947 National Coal board established the Operational Research Executive (ORE), which played a major part in developing the longwall system of mining coal. Within the UK, coal related research was broadly split into two avenues; (1) initiatives to advance the efficiency of combustion and scope of coal utilisation, conducted at the Coal Research Establishment (CRE) located at Stoke Orchard, and (2) wide-ranging mining research focussing on all aspects of exploration, coal production and workplace environmental controls. The NCB's first research establishment at Stoke Orchard in Gloucesteshire was founded in 1950 with Jacob Bronowski as Director of Research. The establishment at Stoke Orchard was cited, in the words of the UK Government's Parliamentary Office of Science and Technology, as a “world centre of excellence”. The work undertaken there, particularly the work on clean coal technology and the coal Topping cycle, if applied to major power stations, was recognised as potentially increasing the thermal efficiency of generation from about 36 to 47 per cent. Global expenditure on coal combustion research has been generally maintained at a high level compared with mining related research.

In 1952 the structure and organisation were changed and the Mining Research Establishment (MRE) set up, which became the principal focus for mining research in the UK until 1994. MRE was located at Isleworth, near London. This was the former site of Isleworth Studios, where The African Queen was shot (with a few other noteworthy films). Desired improvements in the productivity of the British mining industry required reliable machinery. As a result, and to assist in its development, in 1955 the NCB set up the Central Engineering Establishment (CEE). This was sited at Stanhope-Brethby, near Burton on Trent, closer to the coalfields. In 1969 MRE and CEE were merged to form the Mining Research and Development Establishment (MRDE) at Stanhope-Brethby. It is noted that explosion and electrical safety research was undertaken at the Safety in Mines Research Establishment (SMRE) located jointly at Buxton and Sheffield and established in 1947 as part of the Ministry of Fuel and Power. A further notable mining industry related research development in the UK was the formation of the Institute of Occupational Medicine medical research centre in Edinburgh. The Institute of Occupational Medicine (IOM) was founded in 1969 by the National Coal Board (NCB) as an independent charity, but with staff employed by the NCB. Its research was overseen by a Council of Management with representatives of the NCB, the mining trade unions and independent scientists. The early history of the IOM's research is inextricably linked to the NCB's Pneumoconiosis Field Research (PFR). The PFR started in the early 1950s with the objective of determining how much and what types of coal caused pneumoconiosis and what dust levels should be attained in order to prevent miners from becoming disabled by the air they breathed. These objectives were ahead of their time, implying a requirement to measure both exposure and outcome in a large cohort of miners over a prolonged period, and to use these quantitative data to set protective health standards in the industry. Thus started the largest occupational epidemiological study ever carried out. Early in the history of IOM, the NCB recognised the importance of ergonomic research to the coal industry, in terms of protecting men from adverse environments and in the design of mining equipment. This became an important additional area of medical research in addition to that of the mechanisms of respirable dust exposure and risks of pneumoconiosis.

The period 1973 until 1988 represents a period of significant research intensity in the UK. The fact that most of the energy industry (apart from petroleum) belonged to the public sector in the United Kingdom during this period resulted in extensive research and development related to energy being undertaken, with a fair balance between short-term and long-term objectives. Emphasis was given to improving the reliability and efficiency of existing machines and systems for the short term. For the longer term, the principal developments related to the effects of the depths at which mining was carried out in the UK. This included research into the feasibility of extending systems for remote operations and control, with overriding aims of reducing the hazards of mining and increasing productive capacity. One significant development, well in advance of its time, was early experiments to enhance the performance of the main power-loading equipment with ROLF (Remotely Operated Longwall Face). This demonstrated the possibility of remote control of coal face equipment, but also exposed the limitations of electro-hydraulic controls of roof supports and the crudeness of the prototype power-loader steering. Subsequently significant research resources were assigned to develop effective semi-automatic face and face-end operations, eventually accruing in the development of an 'integrated coal face' system. This required basic research on nucleonic sensing devices to steer the machine within the seam approach. Much of this research has found its way into current automated face support and cutting systems. Indeed, it is with some pride that UK and international mining engineers can look back at the significant range of developments which emerged from this period. The list of candidates for mention would be lengthy, but of note is the work on the science and application of in-seam and surface seismic exploration techniques, fundamental work to control dust and noise exposure, together with world-class research on understanding the mechanisms of methane emissions and their control. Allied with much of this
science there were significant initiatives to develop and advance remote controlling and monitoring techniques for the production and transport machinery, as well as environmental monitoring systems. The electrochemical gas sensor was a notable development, together with a wide range of intrinsically safe certified fixed and hand-held instruments for mine environmental monitoring. Associated development of computer based monitoring and control systems, the forerunners of current SCADA (supervisory control and data acquisition) systems, were also a major hallmark of UK mining research.

National Coal Board implemented the systems engineering concept in the mid 1970s to design MINOS (Mine Operating System), a highly centralised, hierarchically organised system of remote control and monitoring in mines. Control engineering and computerised information systems were the main technical factors on which MINOS was based upon. Amongst its few other aims, the main objectives of the MINOS system were reduction of repair and maintenance costs; improvement in output quality; improvement in monitoring and information; elimination of human error; and increase in safety levels and improvement of working conditions (Burns et al. 1985; HQT&D 1983; HQT&D 1986). MINOS consisted of a number of subsystems each of which can be treated as a system in its own right. For example, the coal face system consists of the shearer and armoured face conveyor, roof supports, power supplies, gate end activity, the coal seam, face workers, information about production, delays and machine status. Upon its development, the Barnsley West Side Complex was the first mine complex which was targeted for the full implementation of the MINOS system and the Selby complex was designed to use MINOS system from the start (Burns et al. 1985). The full mechanisation of coal production through the combined use of a power loader, armoured face conveyor and powered roof supports increased the technical complexity of coal extraction and led to the development of the IMPACT (In-built Machine Performance and Condition Testing) subsystem within MINOS. A further development of note, but which originated in the United States, was the adaptation of rock bolting systems to the deep and variable strata conditions present within the UK. This development, arguably more than any others, introduced a step change in the performance and related cost base of the UK coal mining industry’s development phase activities.

Progressive decline in the UK coal industry and the need to respond to the industry’s numerous testing, analysis and investigation requirements lead to an increasing diversification of the research and technical support activities undertaken within the National Coal Board and its successor, the British Coal Corporation, which replaced NCB in 1987. The MRDE function witnessed a number of changes to its strategic research and development activities, with operational 'rebranding' to reflect this; firstly Headquarters Technical Department (HQT&D) in 1989, then Technical Services and Research Executive (TSRE) in 1990. Operating in conjunction with these functions was an extensive Scientific Control function which provided the principal laboratory services arm and undertook selective research activities including the development and introduction of the tube bundle analysis approach, and the development and evaluation of escape respiratory protective devices. The mechanical and rotary testing, material testing, rope and support testing and rock mechanics laboratory functions at Bretby also had an ongoing and critical role in the research an introduction of several key technologies within the industry. These included measures to improve corrosion resistance, enhancements to lubricants and fire-resistant fluids and materials, design improvements to gearboxes and hydraulic power units, together with the introduction of ferrographic analysis and early condition monitoring techniques. All of these initiatives achieved substantial and sustainable gains in the general robustness, performance and fitness for purpose of the heavy duty mining systems which are now commonplace in the underground mining industry. The close relationship and synergies with the large mining equipment manufacturing sector in the UK should also not be underestimated. This was an essential component of the process of technology development and technology transfer within the industry. Whilst many initial concepts and prototype designs were evaluated internally within NCB/British Coal, it was generally the mining equipment suppliers who were charged with completing the final development and refinement. As noted below, virtually all active equipment and machine development from the 1990s became the province of the equipment manufacturers - a situation which prevails today. British Coal closed TSRE in April 1994.

At this point, forgiveness is sought from the reader for the unashamedly UK-centric nature of this paper. It is therefore very necessary to point out the excellent work that was also being undertaken at a national level elsewhere. Within the United States, the US Bureau of Mines (USBM) and its successor within the CDC's National Institute for Occupational Safety and Health (NIOSH) are of particular note, particularly in regard to their open, collaborative research approach and initiatives to disseminate their research findings. In mainland Europe, the work of Bergbau-Forschung and other establishments in Germany, Poland, Spain, France and Belgium are noted. In Australia, the work of CSIRO and others is noted. In the Republic of South Africa, the Chamber of Mines and subsequently
Mining Technology CSIR and Safety in Mines Research (SIMRAC) have provided a continuum of mine safety related research. Whilst these national initiatives are well-known, there were equally significant programmes conducted in the USSR (principally Russia and Ukraine), Japan, India and China. Indeed, it is anticipated that the focus of mining research and development must shift to look east towards the massive industries of China and India. As a further point of note, it would equally be an omission to understate the extensive research, development and demonstration undertaken within the hard rock mining industries. Here the general freedom from hazardous area electrical system approvals has permitted a range of advanced automation technologies to be evaluated and implemented in advance of the coal industry. Research within Canada, Sweden and Austria is mentioned, but the hard-rock industry deservedly warrants a separate paper on its own specific technological developments.

Post-1994 Industrial Research in the UK

The strategic provision of mining research was materially affected when the British Coal Corporation ceased its research programme on privatisation of the UK coal industry. Whilst it is not intended that the respective merits of public and private ownership models be discussed here, it was evident in the privatisation proceedings that the new owners would not, at least initially, support significant research activities. However, it was recognised that technological stagnation and eventual obsolescence were equally undesirable in the longer term. The strategic response to this was an attempt to relocate the research within academia and possibly within the mining consultancy and specialist mining technical service companies. This was enacted in part with the transfer of much of British Coal's coal preparation (beneficiation) and rock testing and characterisation equipment and laboratory apparatus to the University of Nottingham. Health and safety related research was taken up in part by International Mining Consultants Ltd. (IMCL). With the restructuring and acquisition of parts of IMCL, there was a further need to maintain a stable but viable level of support for mining research. This was achieved to a significant extent by the transfer of activities to Mines Rescue Service Ltd., described below.

Provision for a rescue service with rescue workers that wear breathing apparatus to rescue/recover mineworkers underground where irrespirable atmospheres exist due to fires and/or explosions can be traced back to the beginning of the last century. Over the years, legislation has ensured that an adequate service and facilities are provided and maintained. The first rescue station was established at Tankersley in the UK in 1902. The UK Mines Rescue Service was maintained as part of the National Coal Board and subsequently the British Coal Corporation. With the privatisation of the UK coal industry, the UK Mines Rescue Service continued as a non-profit limited company known as Mines Rescue Service Limited (MRSL). MRSL provided continuous rescue cover for coal mines under the Statutory Mines Rescue Scheme, where deep mine coal operators pay a levy per tonne of coal mined towards the maintenance of rescue cover and rescue training. The business of the company is managed by a Board of Directors and the day to day running of the company is managed by the Chief Operating Officer. In response to the contraction of the UK mining industry, MRSL has implemented a strategy to maintain its services to the mining industry at an acceptable cost by diversifying into other areas of work whilst maintaining its non-profit status. As mentioned above, MRSL made a strategic decision to support mining research within the UK. In 2001, the Chief Operating Officer, backed by MRSL’s Board of Directors and with agreement from the European Commission, acquired two research projects from IMCL which was undergoing a rationalisation process. The two projects entitled ‘Fire Fighting Systems’ and ‘Alarm and Evacuation’ were funded under the European Coal and Steel Community (ECSC) Research Programme and were deemed to be within the capabilities of MRSL. Engineers with a research background were employed to lead these projects and the MRSL Research and Consultancy Unit was formed.

From 2001 to-date, the Unit has successfully acquired funding for 16 mining projects. Of these projects, 13 were funded under the ECSC Programme or its successor Research Fund for Coal and Steel (RFCS) Programme. The project research areas have included mine fire fighting involving the development of water mist fire suppression systems, escape and rescue support in mines, resilient wireless network and data transmission systems, radio imaging of coal seams, speech intelligibility improvement in noisy environments, virtual and augmented reality systems, improvements to mine transport systems, mine shaft stability and mine water impacts after closure. The specialist research team, though modest in numbers, has significant prior experience in mining research and disciplines such as general physical sciences and specific disciplines such as computational fluid dynamics, ergonomics, intrinsic safety and communications technology. Two projects were funded by the UK Health and Safety Executive (HSE) for research into thermal physiological impacts of attempting escape whilst wearing escape respiratory protective devices (self-rescuers) in hot and humid conditions, together with the development of suitable wearer expectations training. A further project funded under the EU 5th Framework Research Programme examined
the issues and options for supporting personnel evacuating within road, rail and metro tunnels in conditions of smoke. The MRSL Research and Consultancy Unit continues to expand its activities and has arguably offered a small-scale but effective strategic response to the general decline in mining research in the UK.

Mining Research in UK Academic Institutions

Over the past one hundred years there has been a requirement for mining research in terms of seeking improvements in mining systems and productivity. There has also been a requirement for suitable academic institutions and departments to train the engineers, scientists, managers and craftsmen required by the mining industry. In the pre-WW2 years, the output from approximately 1,600 collieries was ~230Mt (Statham 1958). During the period 2008-2009, 18Mt was produced with 10Mt from 10 opencast operations and 8Mt from 6 large deep mines and 6 small collieries. The underground mines have continued to reduce during 2009. In terms of academic establishments which have served the coal mining industry, these were centred in many of the coal mining areas. At the time of nationalisation of the British coal mining industry (1947), eight regional Divisions were formed, each with a number of Areas which in turn had a number of collieries assigned. As the mining industry reduced in size the operational areas merged. Along with this reduction in Areas, there came a reduction in the requirement for mining departments at colleges and universities. During the early 1980’s the remaining academic establishments with mining departments included the Royal School of Mines, University of Newcastle, University of Nottingham, University of Leeds, University of Cardiff, University of Strathclyde, North Staffordshire Polytechnic, Nottingham Trent Polytechnic, with Camborne School of Mines serving the hard rock mining industry. Rationalisation of UK’s mining engineering departments in 1988-89 resulted in the closure of the mining departments in Cardiff and Strathclyde and the merger between the two departments in Leeds and Newcastle at Leeds University.

Many of these academic institutions developed well-deserved academic reputations in specific mining fields. The University of Newcastle which served the North East of England area focused its mining research on mine mechanisation, rock mechanics and mine waters. Although the University of Newcastle's mining department no longer exists, their research on mine waters continues to thrive under an environmental engineering departmental banner. North Staffordshire Polytechnic served the Western Area which comprised of the Lancashire, Staffordshire and North Wales coalfields. Its research was focused mainly on pump packing and the use of mine wastes for packing in longwall advancing faces which was the major production method up to the mid 1980’s. Towards the late 1980’s, when retreat mining became prominent, and the Western Area reduced the number of working collieries, North Staffordshire Polytechnic's mining department closed and mining research ceased. At Nottingham University mining research included mine ventilation and methane control, mineral processing, and rock mechanics. Towards the end of the 1990’s, the mining department in Nottingham University was incorporated into a merged School which consisted of chemical, environmental and minerals engineering. Today, the University of Nottingham continues mining-related research in the areas of rock mechanics and mineral processing in two different departments, namely the Civil Engineering and the Chemical and Environmental Engineering. Coal mine subsurface environmental engineering research at the Royal School of Mines has evolved over the years and today mainly deals with clean coal and energy technologies, carrying out research into coalbed methane, enhanced coalbed methane and CO₂ storage in coalbeds, as well as research into CO₂ storage in saline aquifers and depleted natural gas reservoirs.

PART II – THE DEVELOPMENT OF METHANE PREDICTION METHODS IN THE UK

British Coal Firedamp Prediction Model

Starting as early as the 1950’s, the European coal mining industry developed a number of methane prediction methods suited to the geological conditions of the coalfields in each country (Curl 1978). These empirical approaches to methane emission prediction were all based on the “degree of gas emission” principle, where the percentage of the gas contained in the coal seam at a specific level above or below the workings which flows into the workings is referred to as the degree of gas emission. The gas left in coal seams after mining is considered to be the difference between the in situ gas-in-place and the total amount of gas emitted over the entire mining period.

Research carried out by MRDE in the UK during the 1970’s and 80’s developed a methane prediction method which was unique in Europe that time dependent behaviour of gas emission was introduced to the predictions (MRDE 1980). The method is based on Airey’s theory of gas emission from broken coal, which was later extended to include fractured or fragmented coal seams around a working longwall face (Airey 1968,1971). The rate of gas release from the coal blocks was assumed be determined entirely by the emission characteristics of the broken coal, represented by a variable time constant τ, defined as a function of distance from the face (Airey 1971) as,
\[ t_1 = t_o \exp \left( \frac{x}{x_o} \right) \quad x \geq 0 \]  

where \( x \) represents the distance ahead of the position of the maximum stress (front abutment), \( x_o \) is a distance constant and \( t_o \) is the minimum time constant in hours, which occurs at and behind the front abutment position. Therefore, smaller the value of \( t_1 \), larger the gas emission rate from a relatively smaller blocks of coal nearer to the working coal face. From a subsequent theoretical work in rock mechanics Airey used the ratio of principal stresses \( \sigma_1/\sigma_3 \) as a criterion for coal failure around a longwall face and assumed that surfaces of equal \( \sigma_1/\sigma_3 \) would be coincident with the surfaces of equal \( t_1 \) (MRDE 1980), thus providing the theoretical basis to his degree of gas emission surfaces (Figure 1a). Using analytical solutions for the stresses around a coal face given by Berry and Sales (1967), Airey then computed the distribution of time constants around a coal face (Figure 1b), and hence the degree of gas emission from sources seams in the roof and floor, as a function of distance from the face line (Figure 2). As well as accounting for the emission from the roof and floor source seams, Airey proposed gas emission curves for the seam being mined, based on the weekly advance rate, and the coal being transported out of the district on the conveyor in order to calculate the total gas volume entering the longwall district.

![Figure 1](image1.png)

**Figure 1.** (a) Distribution of principal stresses ratio \( \sigma_1/\sigma_3 \) (vertical section parallel to and half way between the gate roads, (b) Distribution of time constants \( t_1 \) around a 900 m deep working (after MRDE 1980)

Airey’s theory and the accuracy of his degree of gas emission curves were validated through field measurements of gas quantities and residual gas contents of coal seams at a large number of UK collieries. As Creedy (1981) once wrote, the results of residual gas content measurements carried out in the floor of a mined out area indicated that methane emissions using Airey’s prediction method were overestimating the gas quantities released. Based on these validation studies carried out over a period several years the gas emission curves were modified to eliminate the observed over- and underestimates and produced the British Coal Firedamp prediction method as it is know today. In order to be comparable with the other European methane prediction methods, Airey’s degree of gas emission curves have later been transformed in to a more conventional form where the degree of gas emission is plotted against vertical distance from the working face horizon, with separate lines for different district ages. Figure 3 presents the degree of emission curves for a longwall face at 900 metres depth, and a chart from which corrections could be calculated for other depths (MRDE 1980). As it can be seen from Figures 2 and 3, the final gas emission curves reached represent a significant departure from the original, theoretically based, emission curves Airey proposed. In fact, it can be argued that this final semi-empirical model mimics the unique strata behaviour observed in the UK coalfields more closely than the original model developed by Airey.
Figure 2. Airey’s degree of gas emission (%) curves for the roof and floor of a longwall district at 1,200 m depth (after MRDE 1980)

Figure 3. The British Coal methane prediction method - degree of gas emission curves for a 900 m deep longwall coal face and the chart to calculate the correction factors for workings at different depths (after MRDE 1980)

The development of the methane prediction method was followed by field efforts towards determining the in situ gas contents of all the coal seams in the UK coalfields and a supplementary research programme towards computerising the prediction method for its widespread use by the industry. Research funded by the ECSC Programme at MRDE resulted in the development of FPPROG, the Personal Computer based firedamp prediction model (HOTD 1987). Used mainly as an in-house facility within British Coal, FPPROG came with a borehole/coal seam database and was very easy to use (Figure 4). Selecting the relevant coal seam sequence, and entering longwall face design parameters such as the worked seam thickness, face length and weekly advance rate the user could predict methane emission rates from the roof, floor and worked seams for desired periods (district age) in the life of a longwall district and calculate drainage and air quantity requirements based on a chosen methane drainage capture rate (Figure 5).
Figure 4. FPPROG user interface illustrating (a) the borehole section showing seam depths and thicknesses, (b) the longwall face design parameters for a case example

Figure 5. FPPROG output screen illustrating the methane emission rates and air quantity requirements for different drainage capture rates (0 to 100%) at a weekly advance rate of 5 to 18 metres per week in a 70 week old longwall district

The transformation of Airey’s methane prediction model from its purely theoretical format (built upon the theory of gas emission/diffusion in coal and strata mechanics principles) into a semi-empirical format in order to accommodate the unique coalfield characteristics prominent in the UK has confirmed the view that such empirical models cannot be transported and applied at a new coalfield with relatively different geology than that found in the UK.

Academic Research into Methane Prediction and Models Developed

Methane prediction research at UK universities during 1970s and 80’s was conducted in parallel with the research of National Coal Board, the emphasis being more on petrophysical properties of coal seams and the application of rock and reservoir engineering principles to modelling the flow of methane around working longwall faces. At the University of Nottingham, Mordecai and Morris (1971), Gawuga (1979) and Durucan (1981) investigated the impact of stress on permeability of coal measure rocks and coal seams as a function of depth and stress abutments around working faces. Durucan (1981) extended his research to study the distribution of principal stresses and the propagation of fractures around longwall faces using finite element analysis and correlated these with his early work on stress-permeability relationship for coal seams to define the position of different stress zones and the maximum permeability areas around working longwall faces (Figure 6). Parallel research carried out by O’Shaughnessy (1980) used finite element analysis to predict methane pressure and flow rates around longwall coal faces and developed a methodology to predict the methane flux in to mine roadways with or without methane drainage (Figure 7).
Figure 6. Maximum and minimum principal stress, mean stress and permeability profiles around a 500m deep working longwall face (after Durucan 1981).
Research at Imperial College in the 90’s extended Durucan’s early work and implemented dynamic finite element analysis to study the time dependent behaviour of stresses, the fracture zone and permeabilities around longwall faces and predicted methane emission in to longwall districts (Durucan et al. 1993). A coupled geomechanical reservoir model was developed, which was first used for predicting methane emission and production at operating and abandoned coal mines respectively (Durucan et al. 2004; Martinez-Rubio 2007). In an attempt to demonstrate the advantages of using reservoir models for the prediction of methane emissions in coal mines, rather than the empirical models developed by the European mining industry, Martinez-Rubio (2007) used field data from the UK and the US, each representing a specific coalfield rock and seam characteristics. Figure 8 demonstrates that, when the same UK coalfield reservoir characteristics (mechanical/elastic properties and permeability) are used, both British Coal and the Imperial College models produce the same degree of gas emission curves for a given longwall district. When compared with Figure 8, Figure 9 illustrates the difference between the obtained degree of gas emission curves for cases where the roof is predominantly made of strong, low permeability coal measure rocks (non UK) and those with weaker and thus more easily fractured roof rocks (UK). The coupled geomechanical reservoir model (METSIM) was later extended, first for the assessment of wellbore and far field permeability and flow behaviour of Coalbed Methane (CBM) reservoirs and later (METSIM2) for Enhanced Coalbed Methane (ECBM) and CO₂ storage (Shi and Durucan 2005; Durucan and Shi 2009).

Figure 8. Degree of gas emission curves for coal seams around a longwall panel obtained using the Imperial College reservoir model and the UK coalfield reservoir characteristics (after Martinez-Rubio 2007).
CONCLUSIONS

The coal mining industry and coal production in the UK have shrunk significantly during the post-1994 era since privatisation. This also had a significant impact on the funding available for both the industrial and academic research on mining. Current coal mining research in the UK is mainly carried out at universities and by the MRSL.

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