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APPLICATION OF NUMERICAL GAS FLOWS MODELLING TO OPTIMISATION OF NITROGEN INJECTIONS IN THE GOAF

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ABSTRACT

In Lorraine Collieries (France), the risk of spontaneous combustion in the goaf of longwall coalfaces is relatively high. Nitrogen injections into the goaf are used to control this risk. However, this practice remains relatively empirical in terms of choice of injection locations and flowrates.

Carrying out experiments in the goaf is both difficult and expensive. Thus, the CFD modelling of gas flows (air, methane and nitrogen) is an investigation method well adapted to the situation.

For 5 years, a research project has been carried out at INERIS with financial funding from Charbonnages de France and European Coal and Steel Community. So a numerical model has been developed and calibrated using a large quantity of field data and then used for various simulations.

The results of these simulations indicate that numerical modelling using CFD codes, such as PHOENICS©, is a very efficient tool for improving our knowledge of flows in the goaf and for perfecting the various processes and techniques used to control firedamp and spontaneous combustion. For the particular conditions of the modelled faces, optimal nitrogen injection parameters values can now be determined, allowing increased production, diminution of costs and simultaneously safety improvement.

This research is still in progress, in order to make the model more realistic. But computer modelling has already become a powerful and practical tool enabling better understanding of the complex phenomena occurring in goaf of coalfaces , thus being a valuable aid for the mining engineer.

1. MODELLING OBJECTIVES

The spontaneous combustion of coal and fires in the goaf of coalfaces are very serious hazards in French collieries. Quite apart from the serious implications for workers, they can cause the shutdown - sometimes permanently - of the faces, leading to loss of production or equipment.

One of the most common ways of controlling these phenomena is to inject nitrogen into the goaf.

Although there is extensive experience of this technique, its practical application to a particular face configuration is still fairly empirical, in terms of choosing the most suitable and effective approach, i.e., the number and location of the nitrogen injection points, as well as the flowrates to be used.

To improve knowledge in this field, there is continuing research programme, involving physical and numerical modelling of gas flows in the goaf of Lorraine retreat faces (Pokryszka, 1995, Jones et al.,1997). One of the ways explored during this research work was the development of a CFD numerical model with the particular objectives of :

- finding the optimum values of the parameters governing the injection of nitrogen for preventing and/or controlling spontaneous combustions ;
- improving firedamp drainage bearing in mind the risk of spontaneous coal combustion in the goaf.

A number of results have already been obtained and are summarised here, as an aid to decision-making by mining engineers. This picture is not complete and will be added to and/or revised as the project proceeds.

2. OUTLINE OF THE MODELLING PRINCIPLES

The availability of CFD packages on the market has indeed made their use relatively common. CFD models have been used not only for ventilation simulation in headings (Oberholzer and Meyer, 1995) and around machines (Cook, 1995) but also for the concerned matter (Kershaw, 1993). Specific models have also been designed for the same purpose (Sulkowski and Dieu, 1994; Michaylov and Vlasseva, 1995). Other ways have been explored such as physical scale models (Jones et al., 1995) and specially adapted ventilation network softwares (Banik et al., 1995).

The INERIS numerical model is based on the use of a standard CFD package known as PHOENICS©, into which the appropriate equations representing the phenomena of interest have been incorporated. The modelling of a particular configuration requires a number of operations to be performed, obviously involving simplifications. Thus it is necessary :

- **to describe the geometry and intrinsic characteristics** of the working. This is done using a grid technique. An elementary calculation of transfers to and from the neighbouring meshes is performed for each mesh of the grid. These exchanges depend on the incoming and outgoing flows and on the intrinsic characteristics of the zones represented : for example porosity and permeability as concerns the goaf, and resistance for the roadways and the face.

The model is only two-dimensional, first in order to simplify the problem, but also because of the 3D spatial variation of these parameters, which is difficult enough to determine in actual conditions. Accordingly, for the data introduced and the results obtained, it is assumed that the variables at one point in the two-dimensional space are a resultant of the values along the missing direction (perpendicular to the plane of the seam) ;

- **to describe the boundary conditions**. This part of the task is simpler, covering the incoming flows of air, firedamp and nitrogen as appropriate, the outgoing flows (air return and firedamp drainage) and the atmospheric pressure at the system inlet. However there is still a problem in describing the methane flow distribution ;

- **to calibrate and validate the model** by adjusting the values of the parameters : porosity, permeability and methane emission, at each point in space. To validate the model in this way, the results of the calculations (concentrations of different gases, flow velocities and directions and hence the transit time between different points) are compared with the actual data available. These data include the values of gases concentrations at a certain number of points (air return, drainage, and so on). They also include information obtained by specific tests using tracer gases : leakage flows in the goaf, transit times, etc. (Tauziède et al., 1994, 1997, Pokryszka et al., 1995).

  The parameters are fitted by successive iterations (based upon intuition, knowledge of the model's sensitivity and mining engineering experience) until the differences found are regarded as acceptable.

The model can then be used for simulating particular cases or simply to investigate the sensitivity of a result to a change in a parameter whose real value is difficult to evaluate.

More details on the principles and methods used in this modelling procedure can be found in the final report of the ECSC Research Project 7220/03/277 entitled "Modelling of gas circulation in the waste of retreat coalfaces" (Pokryszka, 1995). The theoretical aspects of the modelling process have also been described in detail by Tauziède et al. (1993).

3. DETERMINING THE OPTIMAL NITROGEN INJECTION PARAMETERS

3.1 Simulations done

After calibration on a particular face configuration, the numerical model can be used for simulations. The calculations then involve varying the parameters whose influence is to be investigated (in this case, the location and flowrate of nitrogen injection).

We describe here nitrogen injections simulated for two faces : Dora 1 Sud and Frieda 5 Sud. These faces are representative of conditions in the Lorraine Collieries. For Dora 1

Sud the simulations were done for two separate positions of the face corresponding to distances from the start line of 210 m and 340 m respectively. The Frieda 5 Sud face was simulated for the situation corresponding to a distance from the start line of 230 m.

The calculations were done assuming drainage values corresponding to actual conditions at the faces analysed. The principal features of the configurations investigated are shown in the following table:

Table 1 : Characteristics of Studied Faces

Characteristic	Unit	DORA 1 SUD		FRIEDA 5 SUD
		June 1992 situation	September 1992 situation	December 1992 situation
Face length	m	240	240	190
Distance from the start line	m	210	340	230
Average dip	degrees	20	20	28
Total air flow	m^3/s	32	34	33
Rate of air leak through the waste	%	15	15	25
Total firedamp inflow	m^3/s	0.75	0.90	0.40
Firedamp drainage flowrate	m^3/s	0,3 (chamber 1)	2 x 0,2 (chambers 1 and 2)	0

The aim of these simulations was to investigate the influence of the injection flowrate and the injection point position on the effectiveness of goaf inerting. In the presented cases of simulations, the injection point was located at the bottom of the goaf (abandoned intake roadway).

The following values were used in the calculations :

- nitrogen flowrate : 0.3, 0.6, 1.2 and 1.8 m^3/s ;
- distance from the face to injection point : 15, 25, 50, 75 and 95 m.

From all the results obtained, we give here only those concerning the two problems most interesting from the practical point of view : the effectiveness of goaf inerting and the influence of nitrogen injections on the release of methane from the goaf to the atmosphere of the workings and to the drainage.

3.2 Effectiveness of goaf inerting

For characterising the effectiveness of goaf inerting, the parameter selected was the "width" of oxygen penetration into the waste zone. This parameter is (arbitrarily) expressed as the maximum distance between the face and the 1% oxygen contour in the goaf.

The set of results obtained for the Dora 1 Sud for two situations of face advance are given in figures 1 and 2 respectively, where the distance from the face to the 1% oxygen contour is plotted as a function of nitrogen flowrate and injection point location.

These results show that whatever the length of the goaf, the two main parameters - the distance between the face and the injection point, and the nitrogen injection rate - show **limiting values**. These limiting values turn out to be practically identical for the two positions of the face investigated and are about 25 m for the distance and more than 0.3 m^3/s for the flowrate.

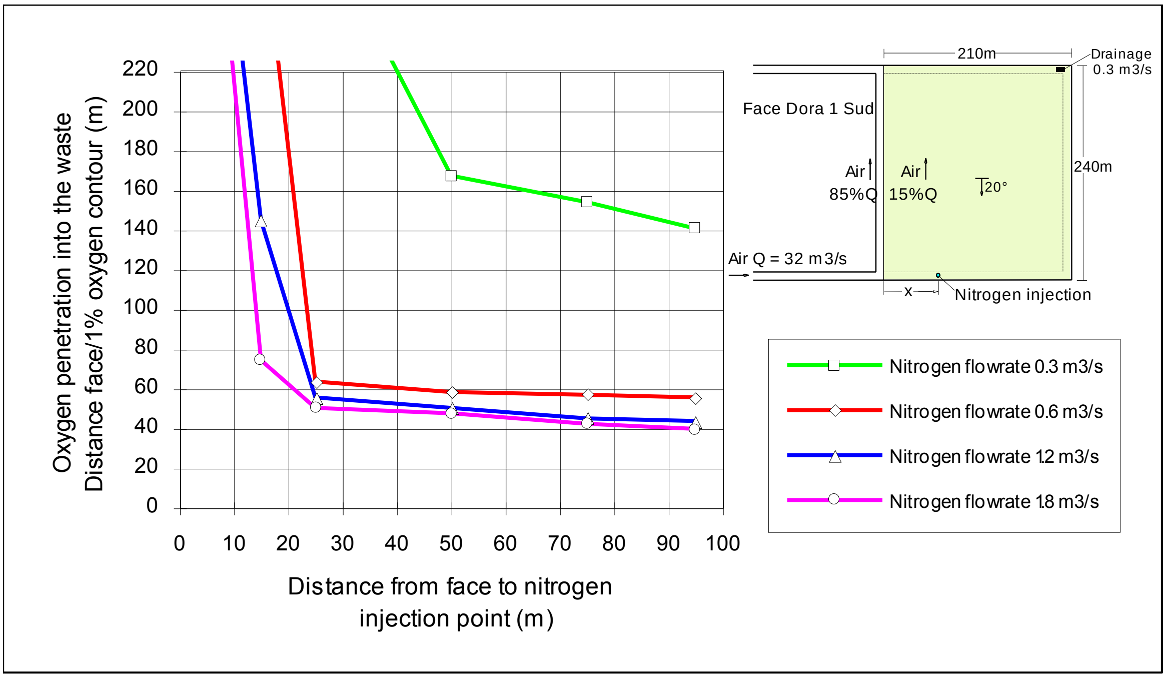

Figure 1. Influence of nitrogen injection parameters on effectiveness of goaf inerting. Simulation 1- coalface Dora 1 Sud (June 1992 position).

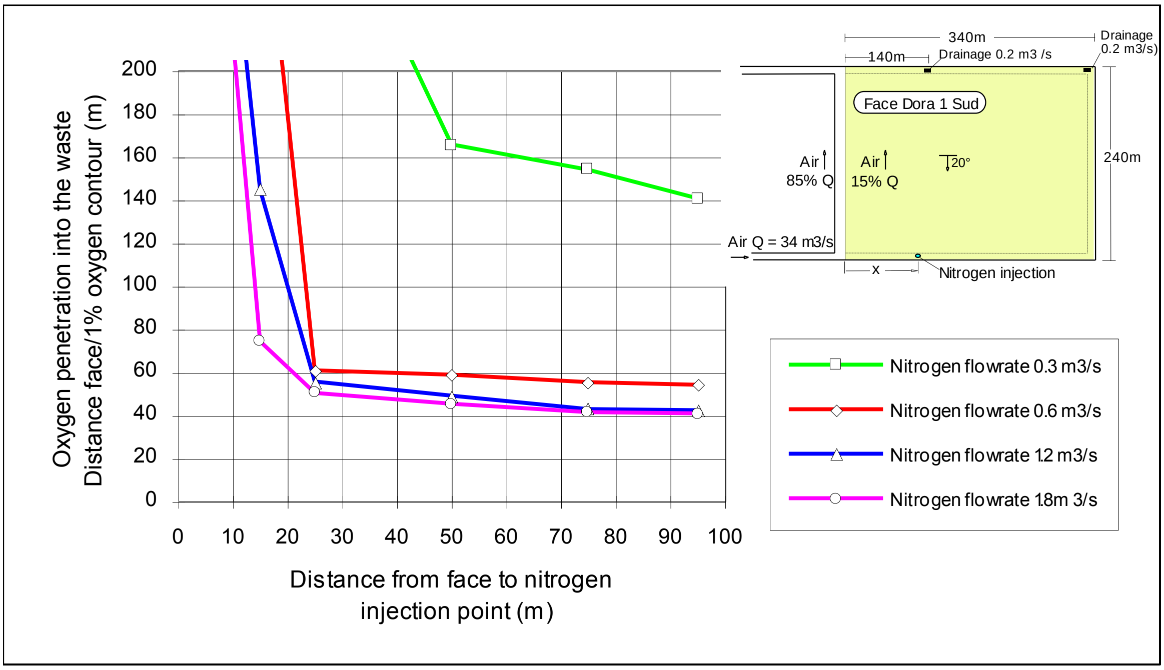

Figure 2. Influence of nitrogen injection parameters on effectiveness of goaf inerting.
Simulation 2 - coalface Dora 1 Sud (September 1992 position).

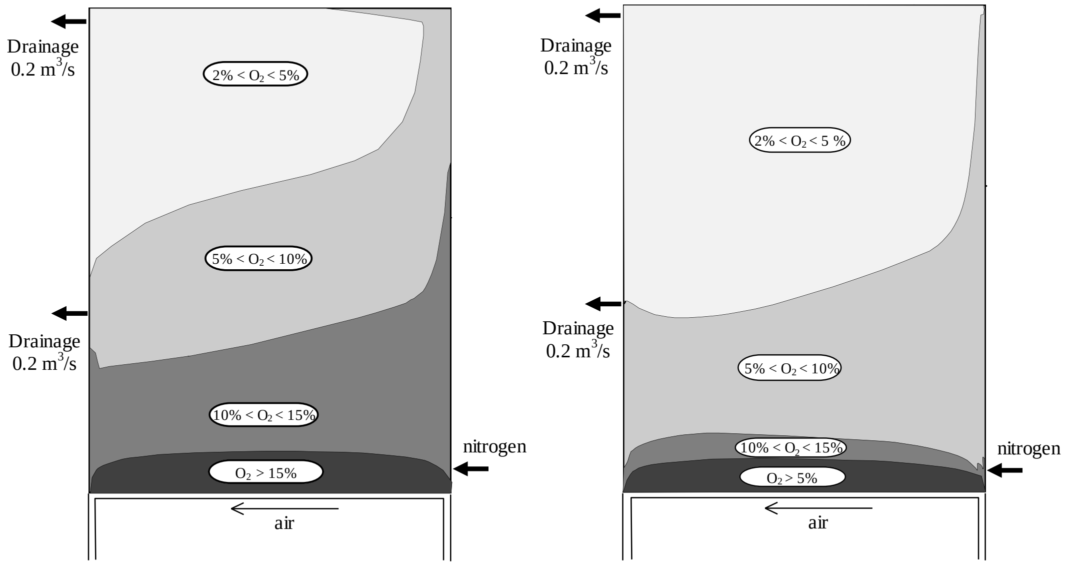

Figure 3a. Injection at 15 m, flowrate 0.3 m ^{3}/s

Figure 3b. Injection at 15 m, flowrate 0.6 m ^{3}/s

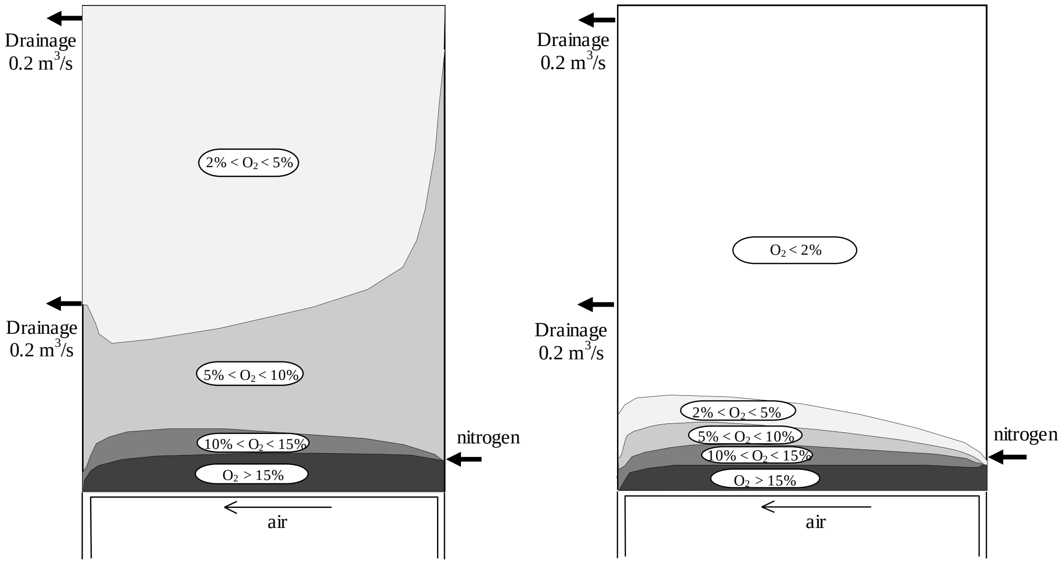

Figure 3c. Injection at 25 m, flowrate 0.3 m ^{3}/s

Figure 3d. Injection at 25 m, flowrate 0.6 m ^{3}/s

Figure 3. Example of goaf inerting for various nitrogen injection positions and flowrates

If effective inerting is to be possible, the parameters used must be greater than these limiting values. Otherwise it is impossible to completely inert the goaf, as the maps of oxygen concentration in the goaf in figure 3 show.

The calculations show that an injection flow of 0.3 m^3/s is insufficient to completely inert the goaf. In this case the 1% oxygen front penetrates the goaf to a minimum of 140 m.

However if the flowrate is 0.6 m^3/s or higher, the maximum penetration of the 1% oxygen front is limited to 50 to 60 m and the effect of inerting is practically unchanged by further increases in the nitrogen flowrate (in steady conditions).

As regards the influence of the injection position, the simulations show that for nitrogen flowrates above the critical value (i.e., exceeding 0.3 m^3/s), the inerting effect is virtually the same for injections made at distances in the goaf lying in the range 25 to 95 m.

The results obtained in this way have been combined in the form of a nomograph, showing the approximate position of the oxygen front penetrating the goaf as a function of two variable parameters : the nitrogen flowrate and the distance between the face and the injection point (figure 5a).

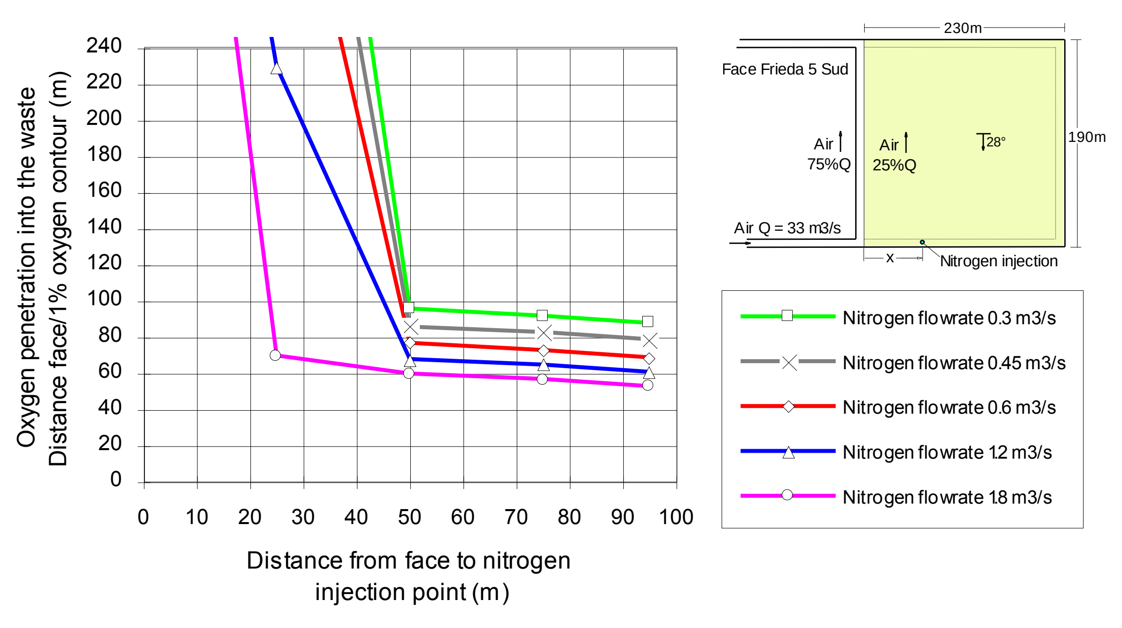

Figure 4. Influence of nitrogen injection parameters on effectiveness of goaf inerting. Simulation 3 - coalface Frieda 5 Sud (December 1992 position).

For the Frieda 5 Sud face, the results of the simulations carried out show similar trends to those observed for Dora 1 Sud (figures 4 and 5b). However there are some significant differences:

- first, it is practically impossible to inert the goaf in such a way as to reduce the width of the zone penetrated by oxygen behind the face to less than 60 m ;
- secondly, the limiting values of nitrogen flowrate and the distance from the injection point to the face are higher than those determined for Dora 1 Sud, even though there is no drainage in the goaf of Frieda 5 Sud.

The explanation of these results stems from the difference in air leakage into the goaf. Since this rate is higher in the case of Frieda 5 Sud, the relatively high air flow circulates further in the immediate goaf area, resulting in a greater optimal distance between the face and the injection point in order to avoid diluting the nitrogen "at source". At the same time, in order to replace a greater quantity of air flowing throughout the goaf, it is necessary to utilise a proportionately higher flowrate for the nitrogen.

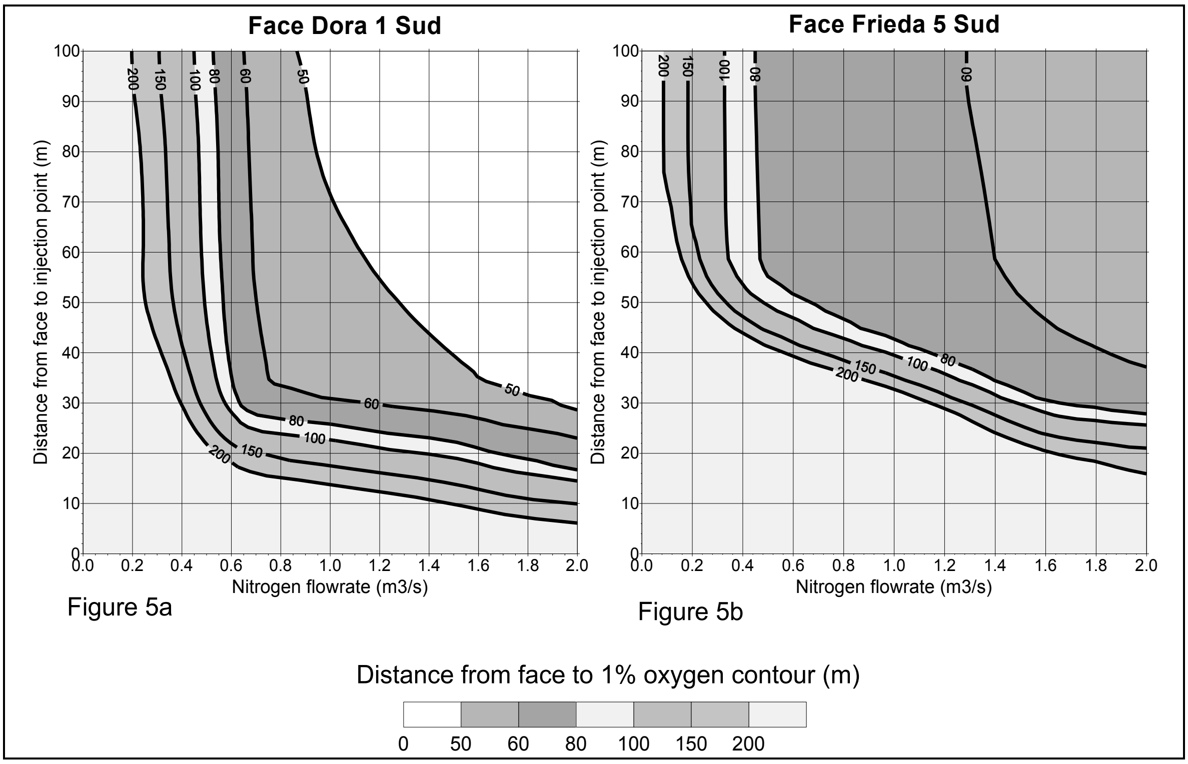

Figure 5a

Figure 5b

Figure 5. Oxygen into the goaf penetration as a function of nitrogen injection parameters .

3.3 Influence of nitrogen injections on methane emission

The effect on methane emissions of nitrogen injection is characterised by the changing methane concentration in the air return and in the drainage system.

As regards dependence of the methane concentration in the return air on nitrogen flow, the calculations show that this falls practically in proportion with the injected nitrogen flow, implies that the total flow of air and nitrogen is higher (dilution effect).

In the case of the coalface with firedamp drainage (Dora 1 Sud), a slight but nevertheless appreciable increase in methane concentrations is calculated when the injection point is displaced towards the goaf (figure 6a). The reason for this tendency is an increasingly large nitrogen circulation in the distant parts of the goaf and a gradual replacement of methane by nitrogen in the gaseous mixture collected by the drainage systems (see figure 6b). Consequently, the net methane flow collected tends to fall, which results in a larger amount of methane leaving the goaf to the ventilation system.

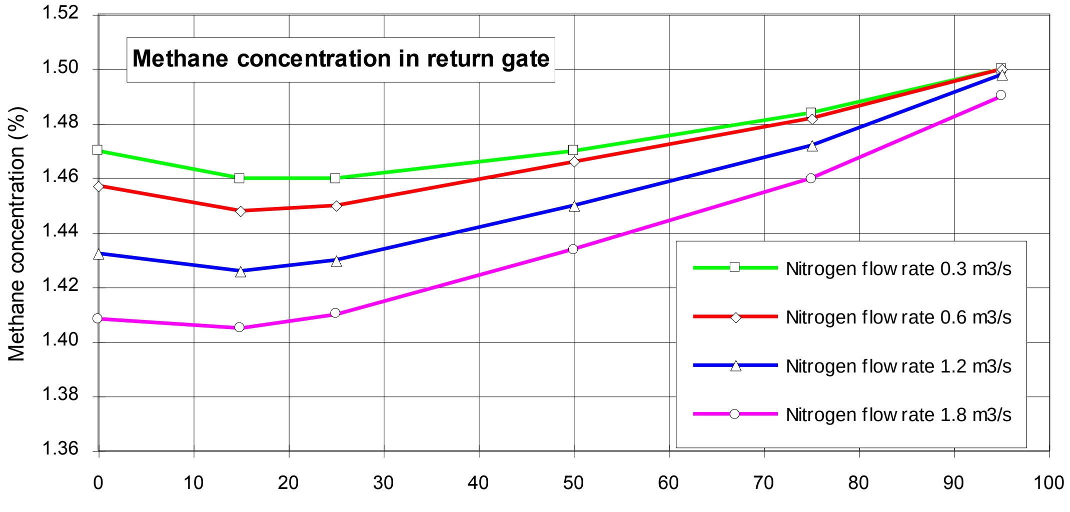

Figure 6a

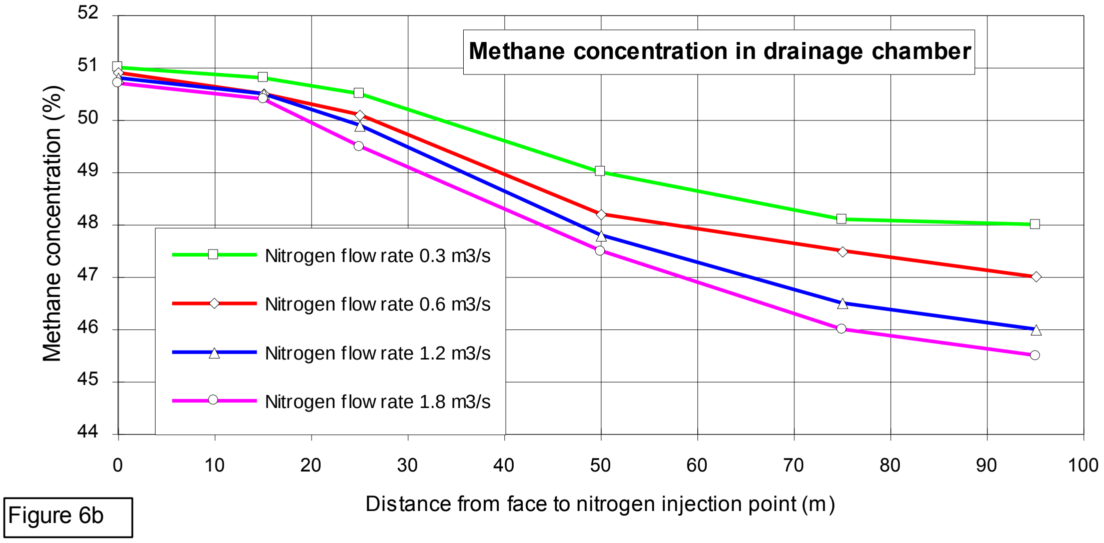

Figure 6b

Figure 6. Influence of nitrogen injection on methane concentration in return gate and drainage. Simulation 2 - coalface Dora 1 Sud (september 1992 position).

This shows that **when inerting a goaf which has substantial firedamp drainage, it is preferable to avoid injecting nitrogen too far into the goaf**.

4. SUMMARY

Using a CFD code, it is possible to identify the optimal parameters for inerting before starting a face. The first step - reasoning by analogy with old faces having similar conditions - is to determine the expected leakage rate of air into the goaf. To do this, an attempt will be made to compare the face with others at which this leakage flowrate has already been measured, mainly with regard to the way in which the goaf will be opened up and then recompacted. The estimated leakage rate will make it possible to determine the extent of nitrogen injection, if any needed for the new face.

Secondly, when the face has started, specific tests will be done using a tracer gas to measure the actual leakage rate and thus normalise the face in question to the cases already analysed. Repetition of these measurements at a later date may be useful to confirm the results.

The principles to be applied in order to minimise the extent of the oxygen penetration zone in the waste are as follows:

- nitrogen injection should be done from a point upstream in the ventilation of the zone to be inerted : e.g. for faces with up cast ventilation, the injection point should be located at the bottom of the goaf (in the abandoned intake roadway) ;

- injection should be done with a minimum flowrate and at a minimum distance from the face so that the nitrogen is not diluted "at source" by the air circulating in the nearby goaf. The order of magnitude of nitrogen flows to be used for faces with a total air flow of 30 to 35 m^3/s is as follows :

    - for a leakage rate of about 15% (the case of Dora 1 Sud), in order to ensure that the not-inerted or poorly inerted zone does not extend 60 m behind the face, a flowrate of 1.0 m^3/s must be injected at 30 m from the face or 0.7 m^3/s at 40 m from the face;

    - for a leakage rate of 25% (the case of Frieda 5 Sud), to obtain the same result, inject 1.8 m^3/s at 40 m from the face or 1.3 m^3/s at 100 m from the face. If a non-inerted zone 80 m wide is sufficient, an injection of 0.5 m^3/s at 60 m or 1.2 m^3/s at 40 m will suffice.

- for a given flowrate, injection should be done as near as possible to the optimal distance given above. With injection further back, the inerting would be practically as effective, but it would have the result of replacing the methane by the nitrogen and would therefore reduce the firedamp concentration in the drainage system, consequently increasing the firedamp concentration in the air return from the face.

As a general rule, the outline values given above should provide an initial approximate solution to the problem. For complex cases, the ideal approach would be to model the face numerically taking all relevant conditions into account (geometry, ventilation, effective drainage, and so on).

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