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MODELING OF GAS CIRCULATION IN THE GOAF OF RETREAT FACES

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ABSTRACT

This paper presents recent developments in the use of a CFD model for representing the flow of gases in the goaf of retreat faces.

In France, it is of highest importance to optimize firedamp drainage in very gassy mines and nitrogen injection in faces prone to spontaneous combustion.

Numerical modeling has been used to solve this problem. So the model developed has been first calibrated using a large quantity of field data and could then be used for various simulations. Though still in progress, this research has given promising results, many of them being already set into practice.

INTRODUCTION

French coal mines are deep, gassy and prone to spontaneous combustion. The main technique used for mining at Houillères du Bassin de Lorraine (HBL) consists in retreat faces, mainly as a consequence of strata pressure at a current depth of 1000-1200 m.

Even with high air flowrates (35-60 m^3/s), there are still difficulties at the junction of the face with the air return roadway to obtain a good dilution of firedamp flowing out from the goaf.

In order to lower this flow, drainage is thus performed using as many workings as possible : drainage chambers in the goaf of the mined seam itself, drainage boreholes in the overlaying or underlying strata, drilled from the seam itself or from any roadway in the vicinity, sometimes driven only for this specific purpose. Though very efficient (up to 50 % or more of methane drained), this procedure is still only experience-based.

The goaf, being a porous media, is not tight, especially close to the edges and to the face, before its settlement, and allows air leaking through it. This parasitic flow can be high enough to initiate spontaneous combustion ("sponcom") of coal remaining in the goaf. In the recent past, several incidents occurred and at certain occasions, the sponcom provoked the ignition of methane in the goaf, hopefully without any fatality. Nevertheless the districts concerned had to be rapidly sealed, one of them never being reopened to recover the equipment. So, this situation presents a high risk for personnel safety and an important impact on economic results of the mine. In order to fight against sponcom, nitrogen injections are used in a curative way, generally in very large quantities, and even in a preventive way. Once again this procedure is totally empirical.

So in order to improve knowledge of gas circulation in the goaf and to optimize drainage efficiency and goaf inerting, an important research program has been funded by HBL and European Coal and Steel Community as early as 1990.

This research is now in the stage where it gives valuable and practical results aimed at establishing guidelines to the mine operators for their design of methane drainage and nitrogen injection.

DESCRIPTION OF THE COMPUTER MODEL DEVELOPED

One of the ways explored during this research work was the development of a numerical model describing the flows of different gases in the face and the goaf. A preliminary description of this work was given earlier (Tauziède et al., 1993).

The availability of CFD packages on the market has indeed made their use relatively common. CFD models have been used particularly 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 ventilation network softwares specially adapted (Banik et al., 1995).

The different stages of the development of our model include :

i) Conception of the model

This task consists in taking into account the adequate equations governing gas flows in free roadways and in porous media (Tauziède et al., 1993) and representing special distribution of physical variables (porosity, permeability and methane flow from the surrounding strata towards the goaf). These distributions are parametrized. PHOENICS® package has been used for this task.

ii) Calibration of the model

This very important step consists in gradually adjusting the above mentioned parameters until calculated values of gas concentrations, flow speed, etc. match available field data and practical experience. Concerning on site measurements, instead of getting (acquiring) a lot of local values of the expected variables in the goaf, which would anyway remain too limited, even when spending large amounts of time and money, global characterizations of the goaf were preferred in addition with available data in the atmosphere obtained with tracer gas tests. A standard set of experiments based on the use of SF_6 was designed and repeated in all studied faces in order to determine specifically :

- global leak flow through the goaf and the average transit time corresponding;
- interchanges of gas between goaf and the atmosphere : profiles of outflows, separately for air and methane, in the upper part of the face and at its junction with the return gate;
- spatial distribution of flows in the goaf and an estimation of speeds its different parts.

The characteristics of the first face investigated are given in Table 1 and a map of it is presented at Figure 1. This face is representative of a situation in HBL where the total leak through the goaf is among the lowest (15 % of total flow of the district). Besides, it is a very gassy face, the specific emission being 56 m^3 of CH_4 per mined ton.

Table 1 : Characteristics of a Studied Face
U.E. REUMAUX - DORA 1 SUD

Characteristic	Unit	Value
Face length	m	240
Distance from the start line	m	210
Average dip	degree	20
Total air flow	m^3/s	32
Total methane inflow	m^3/s	0.75

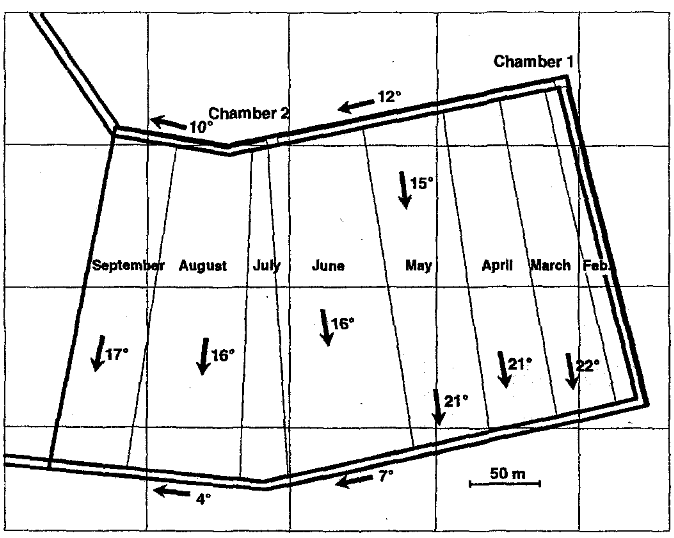


Figure 1. Map of Face Dora 1 Sud, Example of an Investigated Longwall.

These tests, an example of which is presented at Figure 2, gave valuable results allowing classification of longwalls according to their capacity of giving a higher percentage of parasite flow. In particular, it was determined that this characteristic was essentially the result of geology (nature of roof strata) and rock mechanics (governing settlement of blocks).

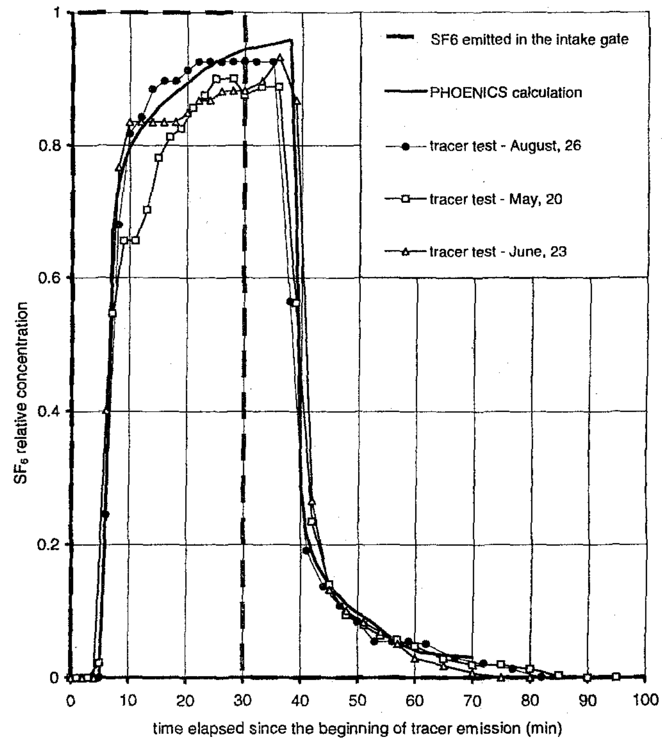


Figure 2. Example of Matching Between Model Result and Tracer Test Data for Face Dora 1 Sud (Ratio Between Tracer Concentration in the Return Gate and Tracer Concentration in the Intake Gate is Plotted Versus Time.

The orders of magnitude of flow speed were found to be 0.1-0.3 m/s in the zone of the goaf closest to the face, where the major part of air is leaking, 0.004-0.008 m/s between 50 and 100 m back of the face, and 0.001-0.002 m/s further. The things happen as if the different zones behind the face translate when the face advances. From one longwall to the other, the general patterns are similar but the importance and magnitude of values are different.

iii) <u>Utilization of the model for simulations</u>

After getting reasonable confidence from the model through its calibration for several representative longwall situations, a first series of simulations could be realized (Pokryszka, 1995). Those were aimed at finding out the best values of parameters governing methane drainage and nitrogen injections in order to optimize them. These simulations and their results are described in the following chapters. They must be considered only as preliminary results as they reflect particular conditions. Other simulations, for different conditions, are still in progress.

OPTIMIZATION OF FIREDAMP DRAINAGE

In order to determine the best way to drain with chambers in a given geometrical situation, the following simulations were carried out :

- drainage by means of a unique chamber located at the start line of the face (200 m from the face),
- drainage by means of a unique chamber located closer to the face (100 m from the face),
- drainage through both chambers above.

For all these situations, the drainage gross flowrate was varied and the result observed in terms of net flow rate and methane concentration in the air return.

The results of the simulations for the above first case investigated are presented at Figures 3 and 4.

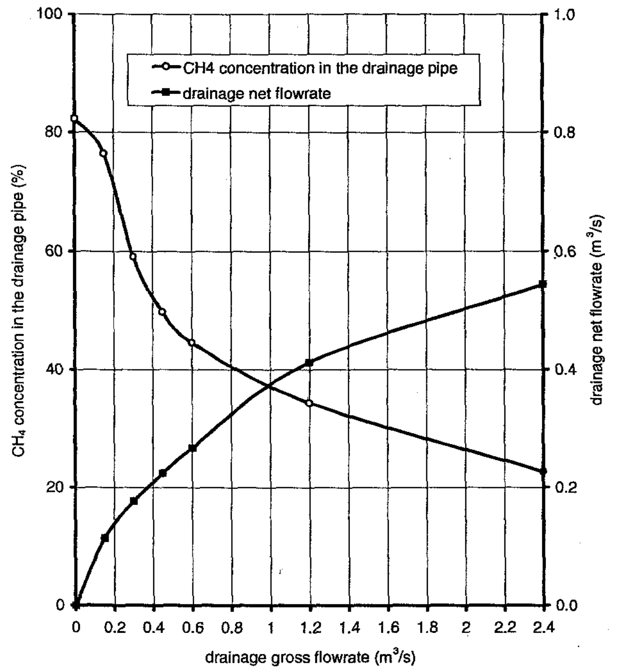


Figure 3. Example of the Results Obtained for Dora 1 Sud with a Drainage Chamber Located at the Start Line; Drainage Parameters.

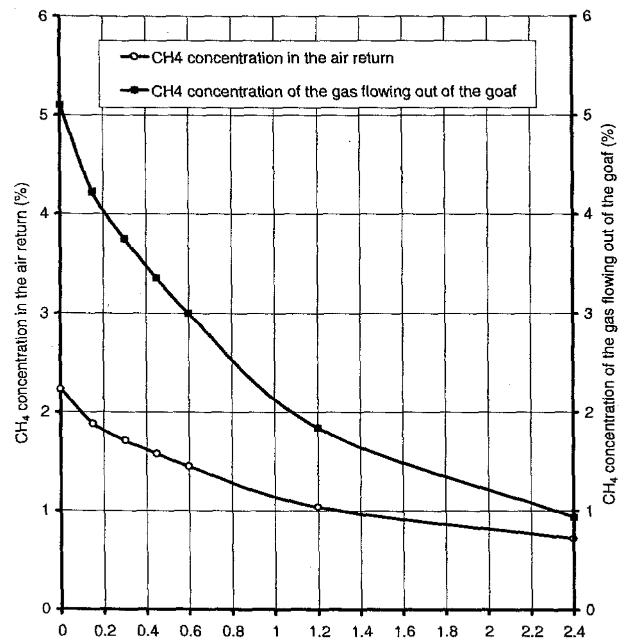


Figure 4. Example of the results obtained for Dora 1 Sud with a Drainage Chamber Located at the Start Line; Methane Concentration at the Face Tail (Concentration of the Air Return and the Gas Flowing out of the Ancient Tail Gate)

It can be observed that, for each situation, the higher the drainage gross flowrate, obviously the higher the efficiency of drainage in terms of net flowrate and consequently the lower the methane concentration in the air return. Nevertheless, to respect statutory rules (methane concentration threshold in the gas pipe), drainage flow has to be limited to a certain value, here about 2 m^3/s (7200 $m^3/hour$) which is in this context a very high value considering seam gassiness and never obtained in reality. Moreover, the effect of an increase in flow rate is limited, the response being not proportional.

From the point of view of efficiency, the best result is obtained with a unique chamber located as close to the face as possible.

These partial results have been found completely consistent with the observations and results of real drainage conditions at that face.

OPTIMIZATION OF NITROGEN INJECTIONS

The conditions for the simulations of goaf inerting consisted in injection of nitrogen from a unique point located in the abandoned intake gate at a certain distance behind the face and with a certain flowrate. Both these parameters where object of the study. Several flowrates and various locations were tested in order to determine which was (were) the most efficient. For each simulation, spatial distributions of different gases were obtained (oxygen of air, injected nitrogen, methane).

In order to compare all these results and find out the most pertinent ones, it was found useful to calculate for each of them penetration of oxygen in the goaf. As a result, distance to the face of the 1 % O_2 line is plotted against nitrogen flowrate and injection distance from the face on Figure 5 relative to the same face, Dora 1 Sud, as above.

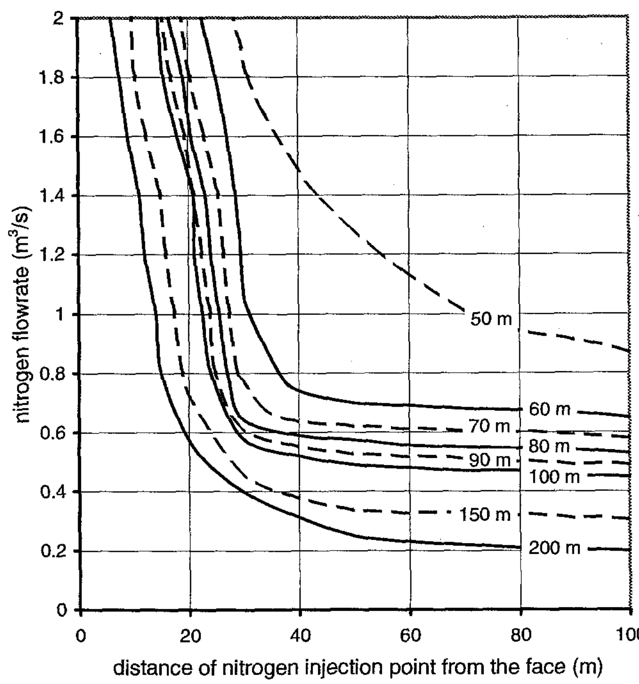
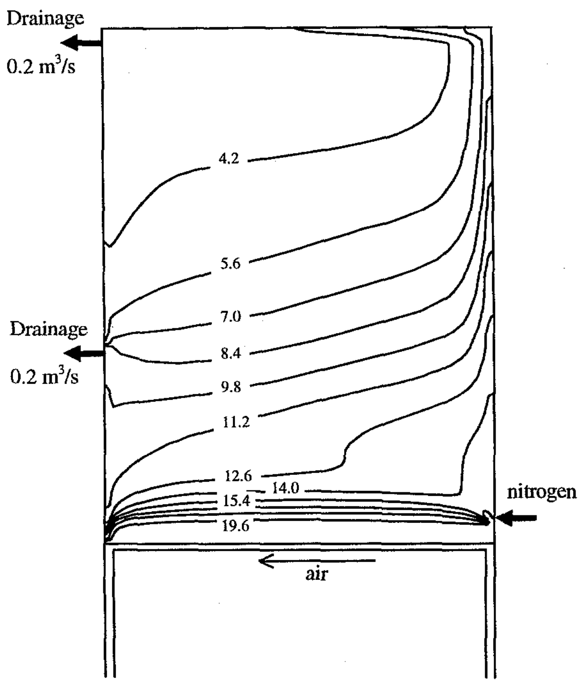
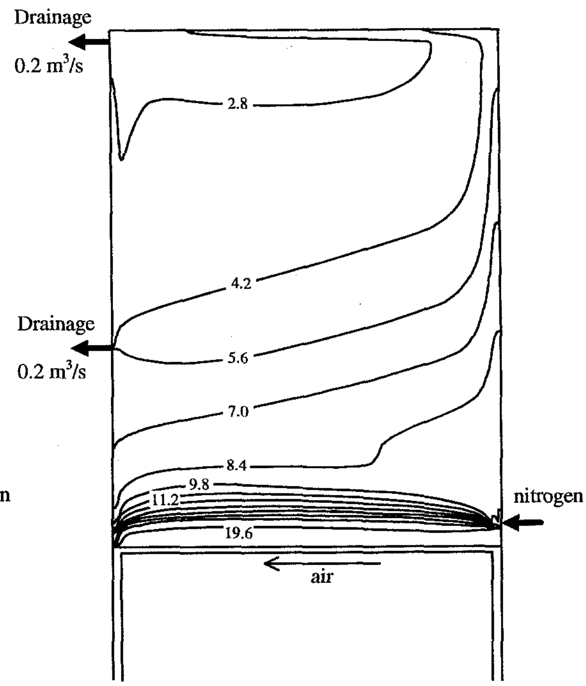


Figure 5. Optimization of Nitrogen Injection (Each Line Shows the Position of the 1 % O2 Fringe in the Goaf for Given Flowrates and Locations of Injection; Figures Indicate the Distance of this Fringe From the Face Line)

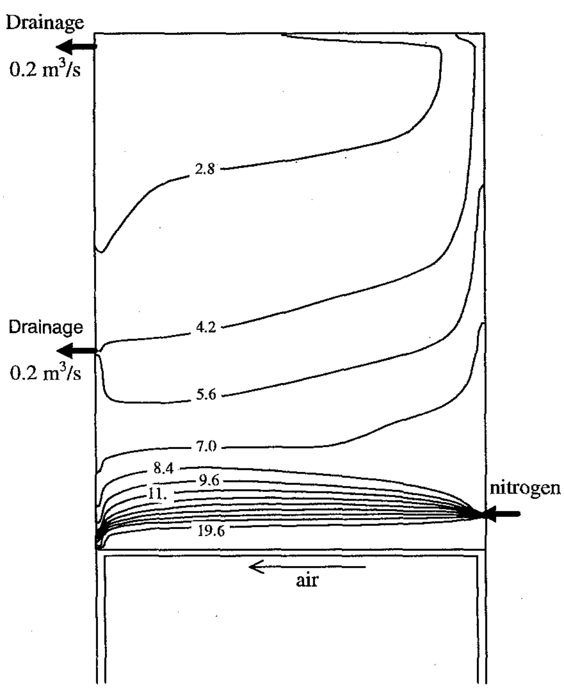
It can be seen that, over a given value of nitrogen flow, inerting has the same efficiency. Under this value, the best efficiency is obtained, for a given flowrate, with an injection performed the further from the face.



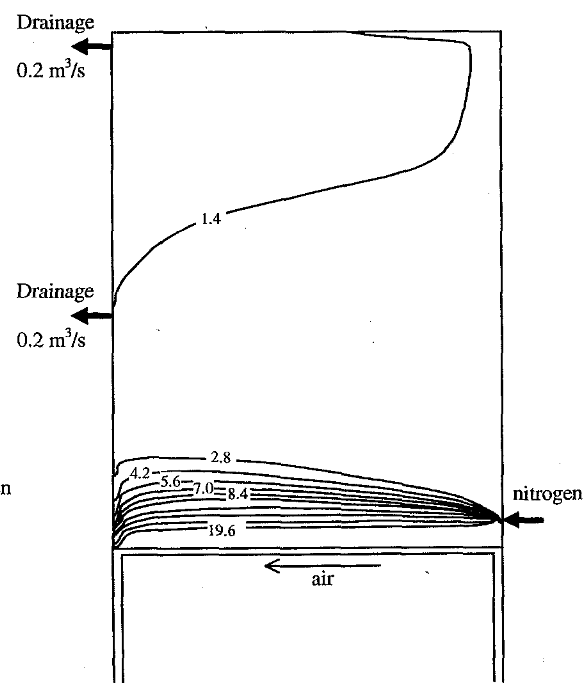
a. Injection at 15 m, flowrate 0.3 m³/s



b. Injection at 15 m, flowrate 0.6 m³/s



c. Injection at 25 m, flowrate 0.3 m³/s



d. Injection at 25 m, flowrate 0.6 m³/s

Figure 6. Example of Goaf Inerting for Various Nitrogen Flowrates and Positions of Injection

On an other hand, provided the flowrate is high enough, the efficiencies of various injections are similar if the injection is located far enough from the face.

This is particularly illustrated at Figure 6 where four combinations of nitrogen injection location and flowrate are presented. It can be clearly noted that if injection is realized too close to the face (cases a and b) or if flowrate is not high enough (cases a and c), then goaf inerting is not obtained. Only when flowrate and distance of the injection point to the face are high enough (case d), the main part of the goaf is well inerted.

One can conclude that, for this particular face, a good efficiency of goaf inerting can been obtained when nitrogen is injected at a minimum distance from the face (in this example at least 25 m) and with a minimum flowrate (in this example at least 0,6 m^3/s or 2 200 m^3/h).

From further simulations for other faces, we can set this result as a general rule : « inject nitrogen with a minimum flowrate at a minimum distance ». Unfortunately, numerical values of these two parameters vary from one face to another depending in particular of the ability of air to penetrate goaf, that one being characterized at least by the air leak rate.

OTHER CONSIDERATIONS AND CONCLUSIONS

Many other simulations have still to be carried out in order to study various face situations, in particular those with a very high air leak rate, up to 35 % or more as encountered in some cases, as well as to determine the interinfluence of methane drainage and nitrogen injections. It is relatively clear that if nitrogen injections are done with a too high flowrate or too deeply in the goaf it will lead to a replacement of methane by nitrogen and consequently to a reduction of drainage efficiency and to an increase of methane concentration in the return. This influence, finally negative from safety and productivity points of view, has still to be carefully studied.

Nevertheless, the use of a CFD model, illustrated on the example here above, has already given valuable information. Indeed, the first results obtained have permitted to establish a strategy for the mine operator aimed at optimizing drainage and inerting or a projected face. This strategy could have the following steps :

- determine the provisional global air leak rate. This can be done by comparing this face to previous faces situated in the same or similar geological and geotechnical contexts;
- choose the appropriate characteristics of drainage and injection locations and flowrates. This selection can be the result of previous simulations giving a « catalog of solutions » for various situations;
- check the real air leak conditions. This verification can definitely be made easily and at the best cost using tracer gas tests;
- if necessary adapt the previous parameters when the face is running.

Moreover the model, with all the experience now gained in its use during several years can be utilized for simulation of complex situations : particular geometry, faces totally or partially adjacent to a previous panel, etc.

Even still in progress, in order to make it more realistic, computer modeling is a powerful tool enabling better understanding of the complexity of gas flows in the goaf of retreat faces and a practical and valuable aid for mine operator.

ACKNOWLEDGMENTS

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