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# INVESTIGATION OF SPONTANEOUS HEATING ZONES AND PROACTIVE INERTISATION OF LONGWALL GOAF IN FENGHUANGSHAN MINE

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*ABSTRACT:* To understand the spatial distribution of spontaneous combustion zones under a Y ventilation scheme, field tests and numerical modelling studies were carried out on a longwall face in Fenghuangshan mine. Computational fluid dynamics models were developed and base model results validated using tube bundle gas monitoring data. A three dimensional high oxygen concentration zone where spontaneous combustion was most likely to occur was predicted behind the longwall face. Parametric studies were conducted to develop proactive goaf inertisation strategies to minimise the spontaneous combustion zones. Results indicated that effective goaf inertisation can be achieved by injecting inert gas on the belt road side at least 100 m behind the face, and, if underground access becomes prohibitive, injection can be carried out via surface wells/boreholes. Injection behind the retaining wall is only effective for localised heating(s) around the injection point(s), as much of the injected inert gas will be dispersed by air leakage along the unconsolidated goaf boundary.

## INTRODUCTION

Spontaneous heating of coal has always been an issue of mine safety concern for mines operating seams liable to heating. There has been persistent effort for engineers and researchers to understand the mechanism of self-heating of coal and the prevention of its further development into spontaneous combustion or open fire. Experimental studies were carried out by Beamish (2005) and Beamish *et al.* (2005a; 2005b) to investigate the relationship between $R_{70}$ and coal rank (together with the ash content and moisture) aiming at better evaluating the risk of spontaneous combustion. Yuan and Smith (2007; 2008; 2009) conducted numerical studies on the self-heating of coal in longwall gobs where the impact of bleeder and bleederless ventilation system was investigated. Rapid inertisation strategies were developed by Ren *et al.* *(*2005) and Ren and Balusu, (2009) by inert gas injection in longwall goafs assisted by extensive Computational Fluid Dynamics (CFD) modelling, and field application demonstrated the success in converting goaf into an inert environment; Whilst in China, the three-phase foam (composed of mud, nitrogen, and water), slurry-grouting, gel and inert gas are typical strategies carried out in field for goaf inertisation and fire control (Zhou, *et al.*, 2006; Liang and Luo, 2008).

Like many other coal production countries, a large number of Chinese coal mines are also under the threat of spontaneous combustion (Liang and Luo, 2008). Fenghuangshan is a Chinese coal mine famous for its good quality coal (Anthracite/hard coal). Although the coal is identified as spontaneous combustion prone, Y type ventilation was adopted for 154307 longwall face to minimise the number of coal pillars and increase the coal extraction rate simultaneously. This paper presents the development of 3D CFD models as a tool to investigate oxygen ingress distribution patterns particularly potential spontaneous oxidation zones behind the face and the optimisation of inertisation strategies under the mining condition of Fenghuangshan mine.

## OXYGEN INGRESS INTO LONGWALL GOAF

It is acknowledged that Y type ventilation can lead to higher levels of oxygen penetration into the goaf than the U type ventilation (Smith, *et al.*, 1994). For the effective control of a possible goaf fire development in a spontaneous combustion prone coal seam, the air ingress patterns must be well understood and the gas compositions in the goaf carefully monitored to understand the changes of goaf atmosphere as the longwall retreats from its start-up line.

Figure 1 shows the layout and ventilation system of the 154307 longwall face, in which both belt road and rail transport road are used to bring fresh air to the face. As the face retreats from the start-up line,

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caved goaf is formed immediately behind face, and the rail (track) roadway behind the face (which would collapse normally) is maintained by building a retaining wall close to the longwall goaf, and used as a bleeder road for air return in this case, thus forming the Y type ventilation. A tube bundle system was employed on site along the retaining wall at intervals of 30 to 50 m (refer to the red points in Figure 1) to monitor changes of goaf gas composition (distribution) inside the retaining wall along the goaf edges, especially the levels of carbon monoxide (CO) which has been widely used as an indicator gas for spontaneous heating. Gas samples were collected every two days and analysed by dedicated gas chromatograph (GC) on the surface. Figure 2 provides a snapshot of oxygen distribution in the goaf along the retaining wall when the longwall face had retreated some 850 m from the start-up line. Gas monitoring data showed that there was significant ingression of fresh air on the goaf rib side, with high oxygen levels at more than 18% even 700 m behind the face. This high level oxygen leakage could lead to the development of self heating of residual coal in the goaf, particularly around the edge of unconsolidated goaf inside the retaining wall.

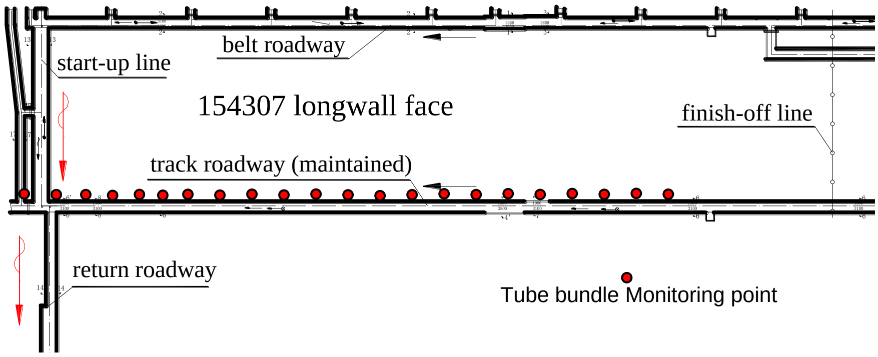


**Figure 1 - Longwall face layout and ventilation system**

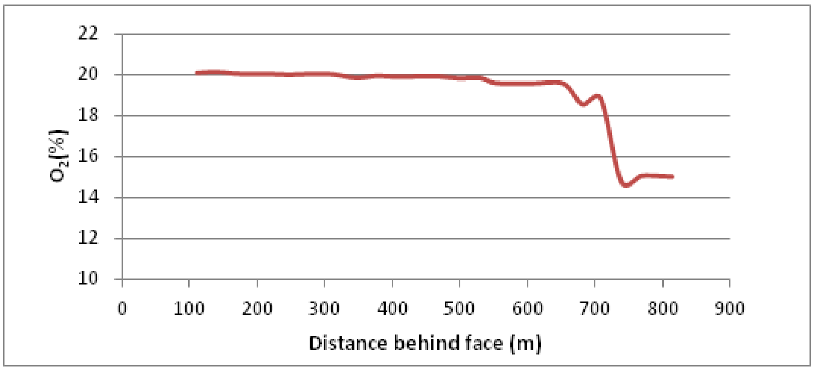


**Figure 2 - Oxygen concentration changes along the goaf**

## BASE CFD MODEL RESULTS AND VALIDATION

A three dimensional CFD model was developed to represent the longwall face which was 780 m in length, 176.4 m in width and 80 m in height to cover the caved and fractured zones in the goaf. Figure 3 shows the geometry of the CFD model, boundary conditions and computational grid.

As an integrated part of the CFD numerical modelling, validation of base model results was carried out using the field gas monitoring data. Figure 4 shows a comparison of the predicted oxygen concentration levels and field monitoring data inside the retaining wall along the goaf. CFD modelling results show that the oxygen ingress inside the retaining wall remains as high as 20% even up to 700 m behind the longwall, indicating that significant air leakage between the retaining wall and boundary of consolidated goaf. A good agreement can be observed between the base CFD modelling result and field gas monitoring data. The base model was then used to investigate the spatial distribution of spontaneous heating zones and proactive goaf inertisation strategies.

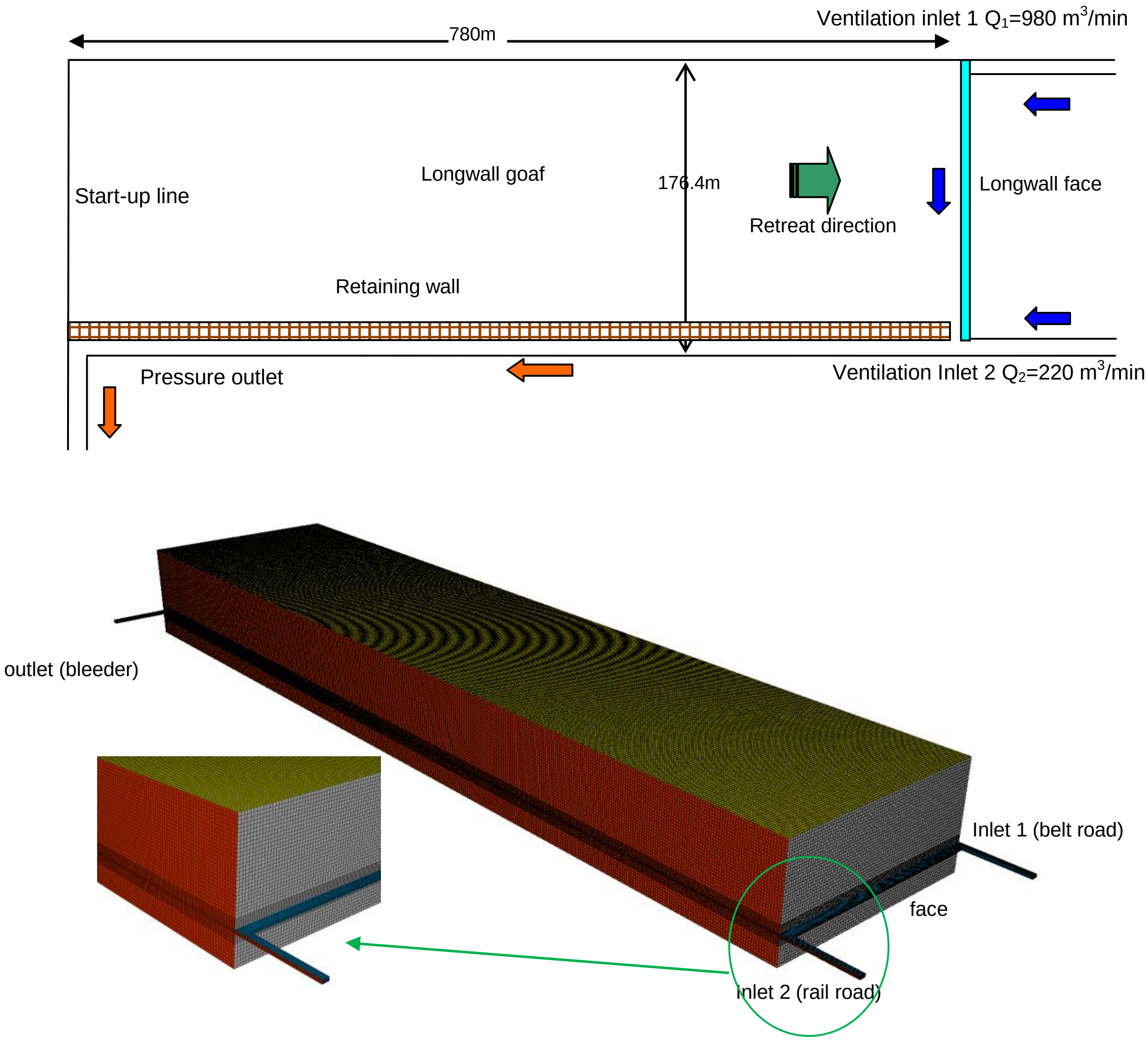
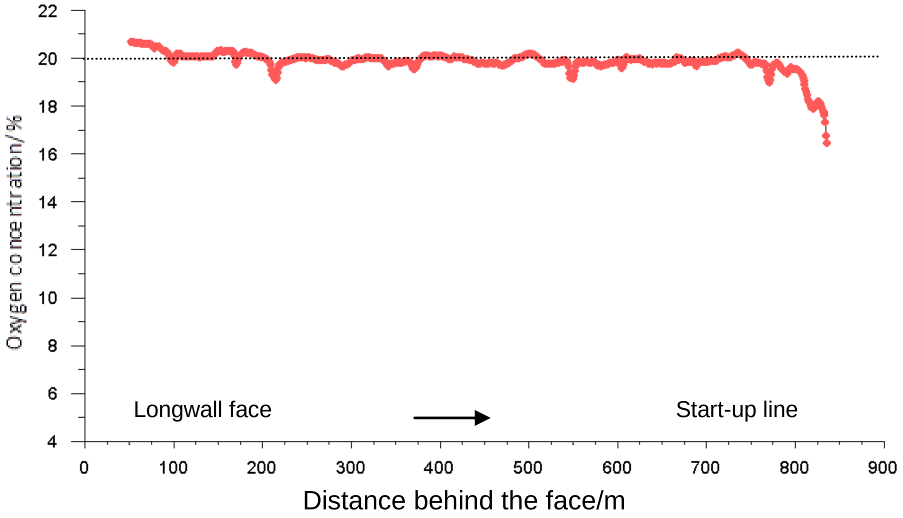
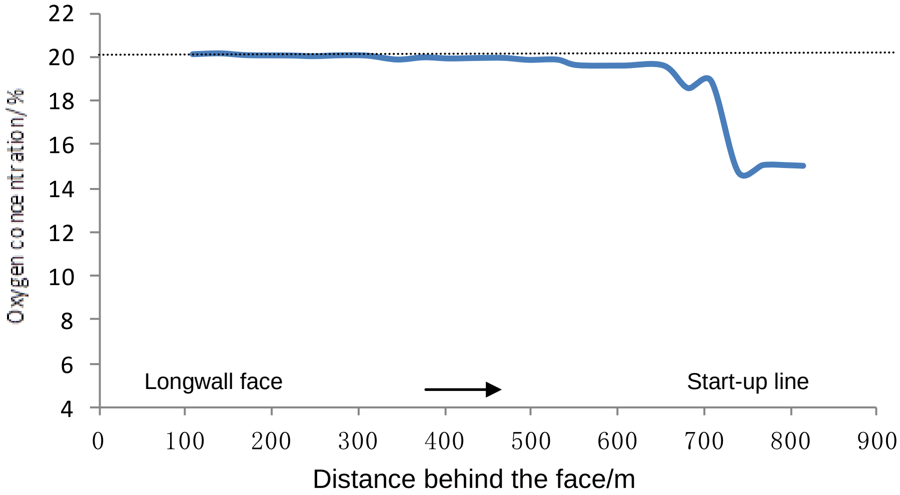


**Figure 3 - Longwall CFD model geometry and computational grid**



**(a) CFD base model results - oxygen levels along the goaf edge inside the retaining wall**

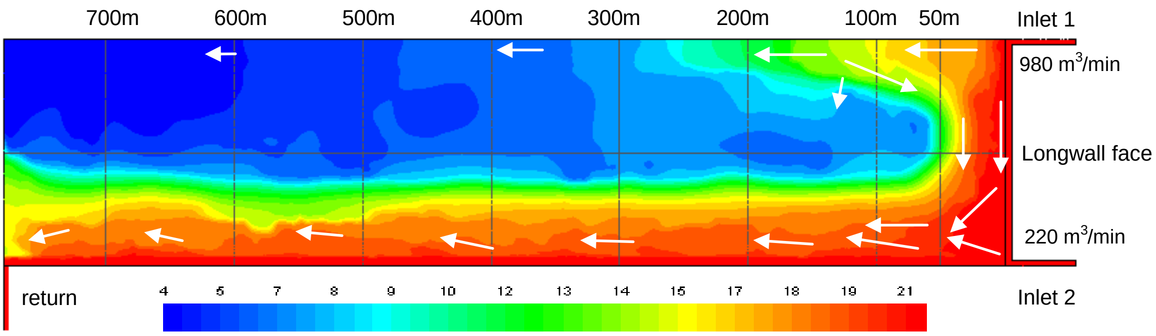


**(b) Field gas monitoring data - oxygen levels along the goaf edge inside the retaining wall**

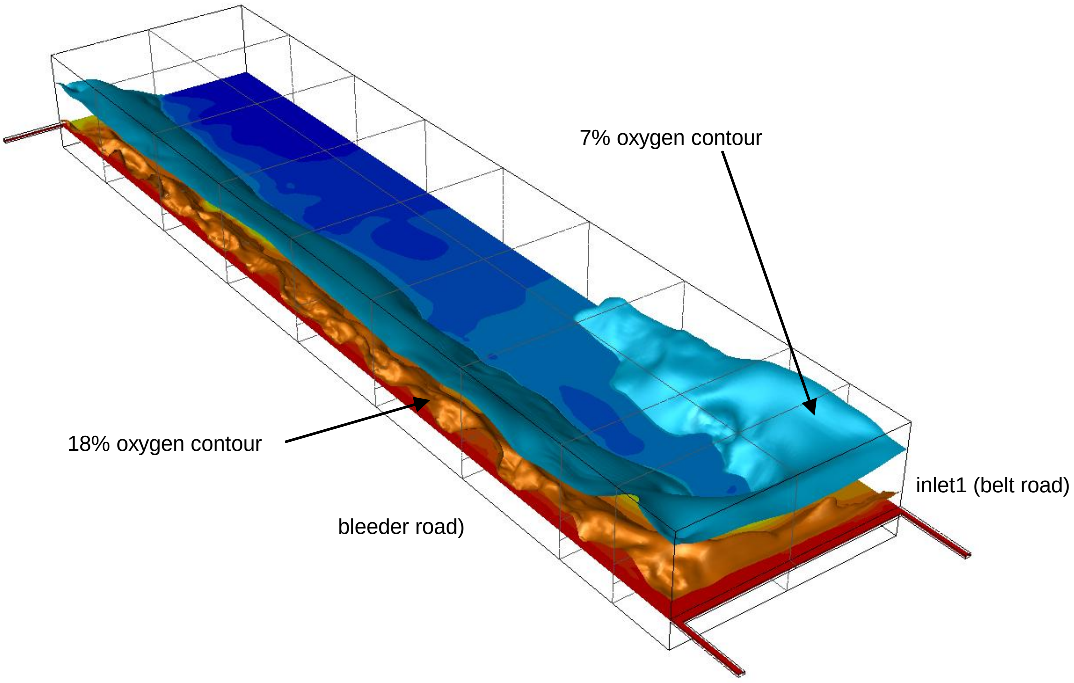
**Figure 4 - Base CFD model validation - model results vs. field monitoring data**

Figure 5 shows the CFD predicted oxygen distribution and the spatial distribution of spontaneous combustion zones in the goaf. CFD results indicate that fresh air from the belt road (inlet 1) leaks into the goaf along the ribside to a depth up to 300 m, the leaked air partly travels further towards face start-up line, and partly penetrates across the unconsolidated goaf, but mostly turns back along the unconsolidated goaf edge to join the main air stream behind the chocks within 50 m in the goaf; it then merges with air leakage from the face and rail road (inlet 2), and travels along the goaf boundary strip inside the retaining wall until the start-up line, before reporting to the return roadway. Figure 5 (b) shows the 3D Iso-Surfaces of oxygen concentration at 7% and 18%, between which is the oxidation zone where the heating of residual coal is mostly to occur. As can be observed from the plot, this area is spatially distributed in the goaf on the belt road side up to 200 m, 50 m behind the face, and along the retaining wall side about 60 m into the goaf. Beyond this area are the cooling zones (oxygen level is above 18%) where excessive air leakage will dissipate any oxidation heat to support the self-heating process, and the choking zone (oxygen level is below 7%) where the oxygen level would be insufficient for coal to undergo active spontaneous heating.

CFD model results show that the use of Y type ventilation can induce serious air leakage spatially into the goaf with a wide range of oxidation zones that are conductive to spontaneous heating. The most likely areas for spontaneous combustion to occur in the goaf (at mining level) are the goaf edge on the belt road side some 200 m behind the face and 60 into the goaf; within 50 m behind the chocks, and the unconsolidated areas some 60 m inside the retaining wall along the bleeder (return) road till the start-up line. Goaf gas composition along the retaining wall must be carefully monitored to detect the onset of any heating and avoid delayed control actions against the occurrence of a possible heating in these areas. Obviously any proactive measures such as goaf inertisation should be targeted towards these areas.



**(a) Oxygen distribution in the goaf**



**(b) Spatial distribution of potential spontaneous heating zones**

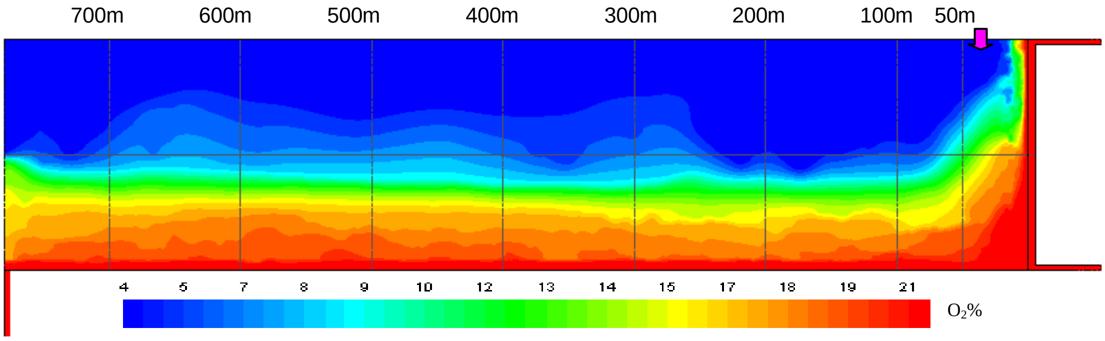
**Figure 5 - Oxygen distribution and spatial distribution of spontaneous heating zones in the goaf**

## PARAMETRIC STUDY OF GOAF INERTISATION STRATEGIES

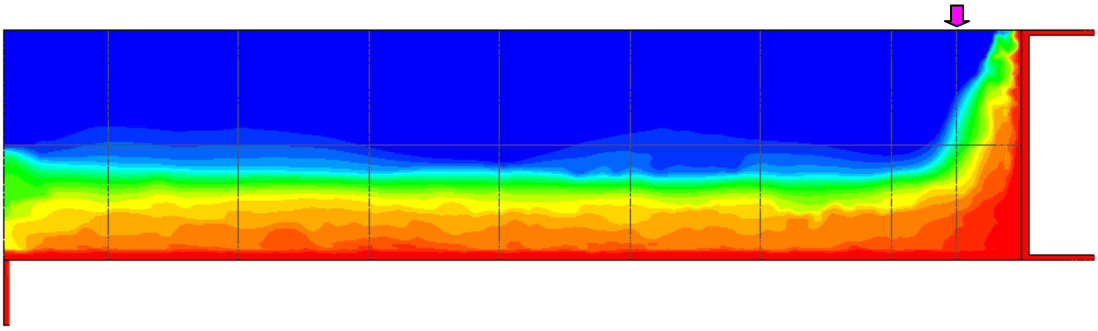
An effective method to prevent the development of self-heating in longwall goafs is to implement proactive inertisation by pumping inert gas such as nitrogen or carbon dioxide into the goaf to minimize the area of potential oxidation zones. To develop the optimum inertisation strageties, a set of parametric studies were conducted using the CFD model to identify the optimum injection point behind the longwall face.

### Inertisation from belt road side

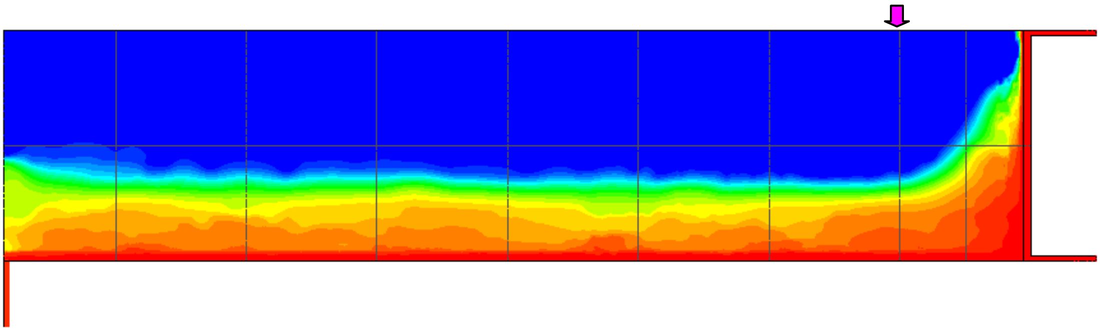
Figure 6 shows a comparison of oxygen distribution in the goaf at the mining level after inert gas (pure nitrogen) injection at 30 m, 50 m, 100 m and 200 m behind the face on the belt road side at a rate of 0.25 $m^3$/s. It can be seen that the oxidation. zones (refer to Figure 5a) on the belt road side and behind the chocks has been eliminated by injecting inert gas at more than 50 m behind face while the inertisation has limited effect inside the retaining wall side, unless the injection is conducted at some 200 m behind face. It also indicates that inert gas injection point should not be too close (i.e., less than 50 m) to the face where the goaf is not completely compacted and air leakage is relatively high, the inert gas will be easily dispersed by air leakage as soon as it is injected.



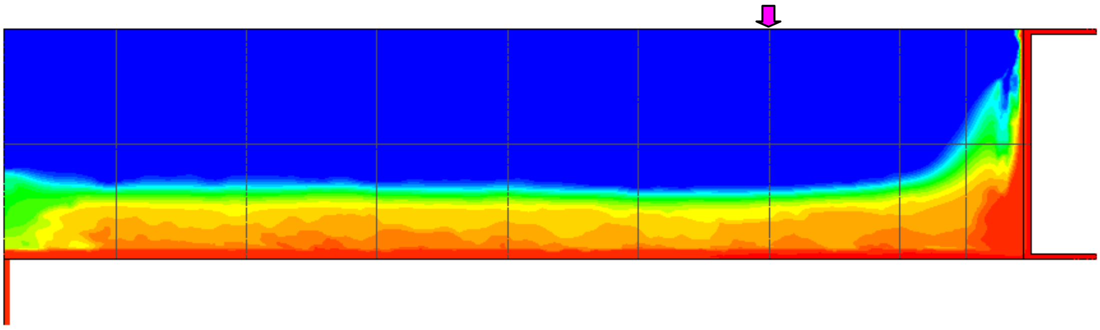
**(a) Inert gas injection at 30 m behind face**



**(b) Inert gas injection at 50 m behind face**



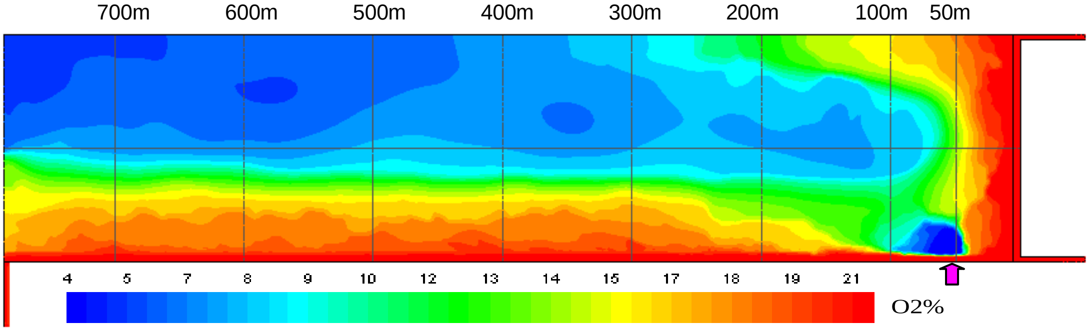
**(c) Inert gas injection at 100 m behind face**



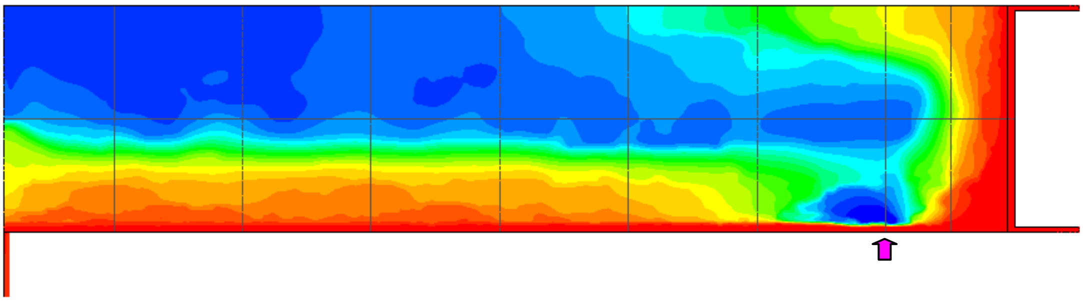
**(d) Inert gas injection at 200 m behind face**
**Figure 6 - Goaf inertisation on oxygen distribution - injection on belt road side**

## Inertisation from retaining wall

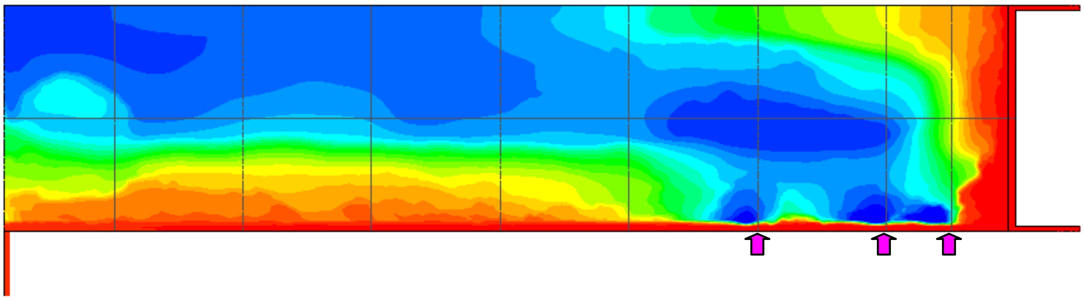
Figure 7 shows the effect of goaf inertisation when injection is carried out on the retaining wall side. CFD modelling results show that injection on the retaining wall side only has a limited effect on areas around the injection point, as much of the inert gas will be flushed away by air leakage inside the retaining wall. Again, this demonstrates that good inertisation effect cannot be obtained if injection is carried out at high air leakage area. There is almost no inertisation effect in oxidation zones on the belt road side and immediately behind the chocks. Consequently, goaf inertisation should not be conducted on the retraining wall side, unless it is needed to deal with localised heating in combination with other control measures such as multiple injection points (Figure 7.c and d), foaming or temporary stoppings to minimise air leakage into these areas.



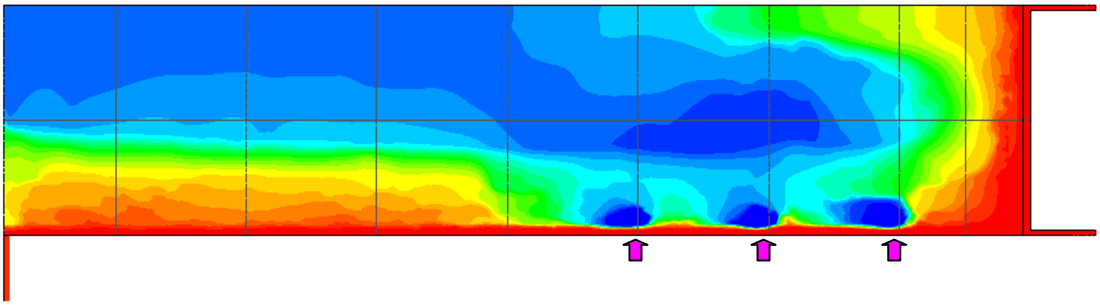
**(a) Inert gas injection at 50 m behind face**



**(b) Inert gas injection at 100 m behind face**



**(c) Inert gas injection simultaneously at 50, 100 and 200 m behind face**

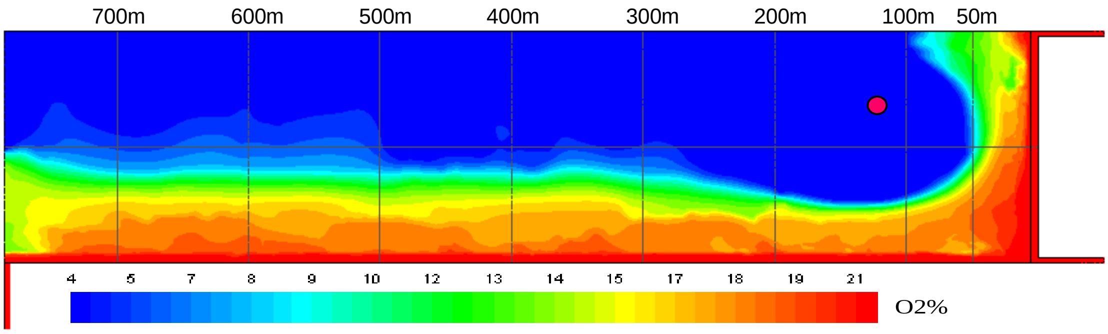


**(d) Inert gas injection at 100, 200 and 300 m behind face on the retained wall side**

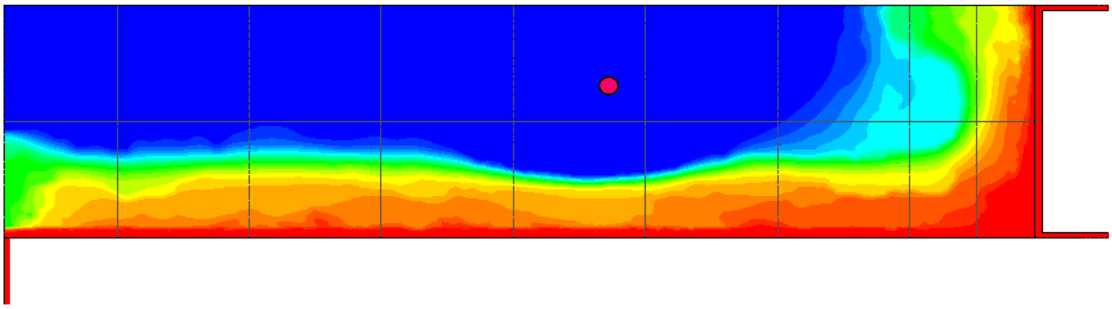
**Figure 7 - Goaf inertisation on oxygen distribution - injection from retaining wall**

### Inertisation using surface goaf wells or boreholes

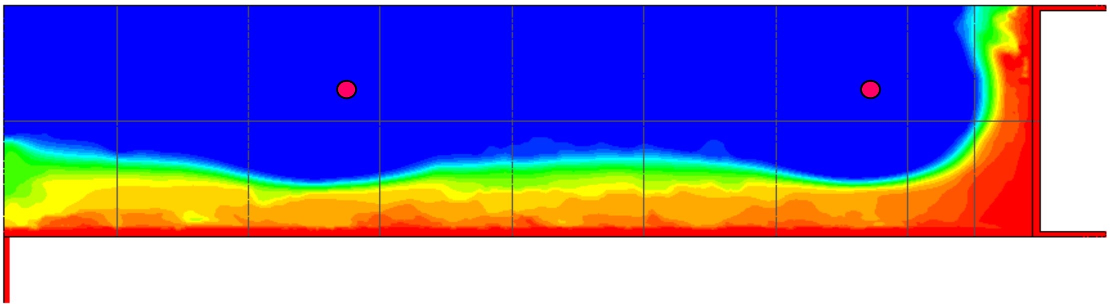
Under certain circumstances when underground access becomes prohibitive (e.g. mine evacuation), inertisation can be conducted using existing wells or boreholes which are usually used for gas drainage. In this case, it is assumed that the surface wells are located at 60 m away from belt road side at an interval of 200 m, and the first well is 130 m behind face. Figure 8 shows the goaf inertisation effect of inert gas injection from a single surface well/borehole and a combination of two or four goaf wells. It can be seen that the inertisation of high oxygen areas in the goaf can be more effectively achieved by injecting inert gas via surface goaf wells/boreholes. Modelling results show that a combination of surface wells should be used to inject inert gas for goaf inertisation when surface access can be obtained, rather than delivering inert gas underground. At least, the practice of using a single borehole for inertisation at about 100 m following the face, as shown in Figure 8.a, should be adopted for longwall systems using Y ventilation (or bleeder road).



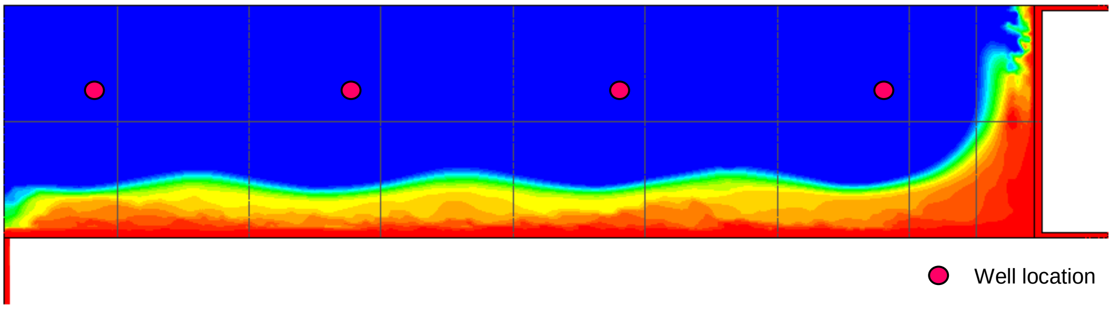
**(a) Inert gas injection from the first surface well**



(b) Inert gas injection from the second surface well



(c) Inert gas injection from the first and third surface wells



(d) Inert gas injection from all surface wells

Figure 8 - Goaf inertisation on oxygen distribution - injection from surface wells/boreholes

## CONCLUSIONS

Three dimensional CFD modelling has been developed to investigate the distribution of spontaneous combustion zones for a Chinese longwall face using Y type ventilation. Modelling results show that the most likely areas (7~18% oxygen) for spontaneous combustion to occur spatially in the goaf are the goaf edge on the belt road side some 200 m behind the face and 60 m into the goaf; within 50 m behind the chocks, and the unconsolidated areas about 60 m inside the retaining wall along the bleeder (return) road till the start-up line. Air leakage is most excessive in the unconsolidated goaf boundary inside the retaining wall along the bleeder road.

Both goaf gas monitoring and proactive inertisation are recommended to minimise the occurrence of spontaneous goaf heating. Optimum goaf inertisation can be achieved by pumping inert gas (nitrogen at a rate of 0.25 $m^3/s$) at least 100 m behind the face on belt road side, or ideally, if surface access permitting, via surface goaf hole(s). Goaf inertisation on the retraining wall side will only be effective for localised heating, and should be used in combination with other control measures to minimise air dilution in these areas.

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