

**SIMULATION BASED DEGASIFICATION SYSTEM DESIGN
FOR THE SHIHAO MINE OF THE SONGZAO COAL MINING
ADMINISTRATION IN SICHUAN CHINA**

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ABSTRACT

A United Nations (UN) administered degasification technology transfer project, funded by the Global Environmental Fund (GEF) is underway at the Shihao Mine of the Songzao Coal Mining Administration in the province of Sichuan, Peoples Republic of China. This mine exploits multiple seams at depths ranging from 300 to 600 m below surface. In-seam boreholes and frequently spaced in-mine vertical boreholes, developed from underlying galleries constructed specifically for this purpose, currently degasify the seams in advance of mining at the Shihao Mine. Because of ventilation system constraints and the in-situ gas content, longwall mining of the coals at this mine could not proceed without some form of pre-mining degasification.

This paper presents a simulation based degasification plan of long, in-seam horizontal boreholes for the Shihao Mine. Simulations with a coalbed reservoir program assessed time dependent degasification characteristics of both vertical and in-seam horizontal boreholes. The simulations used input data from reservoir and desorption tests conducted at the mine site. The results produced system design nomograms to assist mine engineers in defining the appropriate borehole spacing necessary to degasify the seam in the time available for pre-mining drainage.

The predicted effectiveness of the current vertical degasification scheme was compared with that for a horizontal borehole program and served as the basis for the recommended in-seam borehole configuration for the project at the Shihao Mine. The horizontal borehole degasification program requires substantially less gallery and borehole development than the present vertical degasification scheme.

INTRODUCTION

The coal mines of the Songzao Coal Mining Administration are located 175 km south of Chongqing, in the Sichuan Province in southwestern China. Seven coal mines are in various stages of operation and construction in this region where mineable coal reserves are estimated at 850 Mt. Five mines operate presently, and combined produce approximately 3.2 Mt of coal per year.

The Shihao Mine of the Songzao Coal Mining Administration extracts the 1 m thick No. 6 and No. 7 seams, and the 3 m thick No. 8 seam using longwall mining techniques. These seams are anthracite in rank, have in-situ gas contents in excess of 20 m³/t, exhibit low coal cleat permeabilities, and are prone to outbursting (the No. 7 and No. 8 seams in particular). From 1971-1990, there were 355 outbursts in the Songzao mines, 75 occurring in 1989 alone.

Methane drainage systems have been installed in all of the Songzao mines to minimize methane emissions to mine ventilation systems and reduce the severity of outbursts. At Songzao, eight vacuum pump stations process approximately 64.3 million m³ of methane per year, of which 40 percent is used by local industry and residences. The remaining recovered gas is vented to the atmosphere.

At the Shihao Mine, the No. 6 and No. 7 seams are mined in descending order whenever possible to reduce gas emissions and minimize the severity of gas outbursts from the lower, gassy, No. 8 seam. In addition, mine operators rely on extensive in-mine drilling to degasify all three seams in advance of mining and for outburst relief. For the No. 6 and 7 seams, mine operators develop multiple short boreholes in-seam, in advance of mining as necessary. Prior to mining the thick and gassy No. 8 seam, Songzao operators develop degasification boreholes from underlying galleries driven specifically for methane drainage purposes. As shown on Figure 1, these boreholes are driven to intercept the No. 8 seam at 15 m centers in advance of mining. For two longwall panels, each 120 to 150 m in width, 1000 m in length, three degasification galleries are driven from which over 1,300 boreholes are developed.

These degasification systems, the later in particular, are capital intensive, and in addition, achieve relatively low methane capture efficiencies (estimated at less than 20 percent).

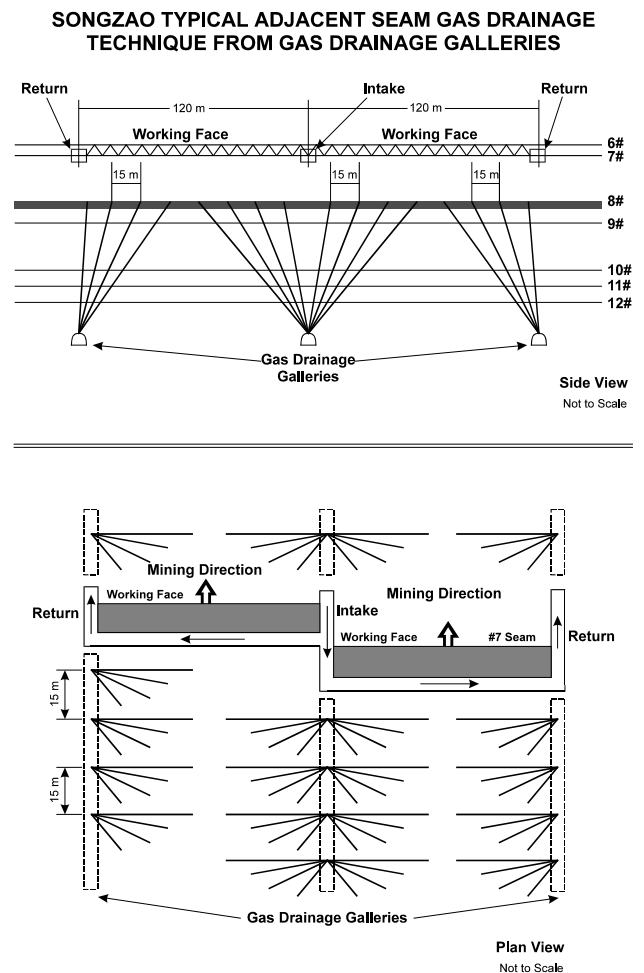


Figure 1: Degasification of the No. 8 seam at the Shihao Mine from underlying drainage galleries.

Proposed Degasification Plan

One objective of the UN managed, GEF funded project at Songzao is to improve underground methane drainage techniques through the application of long (to 1000 m), in-mine, directionally drilled boreholes. In particular, this technique could reduce degasification system costs, and improve: mine safety, drainage system capture efficiencies, and recovered gas qualities.

Shihao Mine: At the Shihao Mine, project plans are to directionally drill long horizontal boreholes into the No. 8 seam from the underlying degasification galleries as shown on Figure 2. Because of increased connectivity between the horizontal wellbore and the reservoir, greater gas production and fewer boreholes are anticipated. Additionally, the proposed plan would eliminate some degasification level infrastructure, and provide for increased degasification periods because the boreholes could be developed earlier, with less dependence on gallery development efforts. Recovered gas quality would also improve because of reduced wellhead and gathering line infrastructure requirements, which decreases the potential for mine air intrusion into the gas collection system.

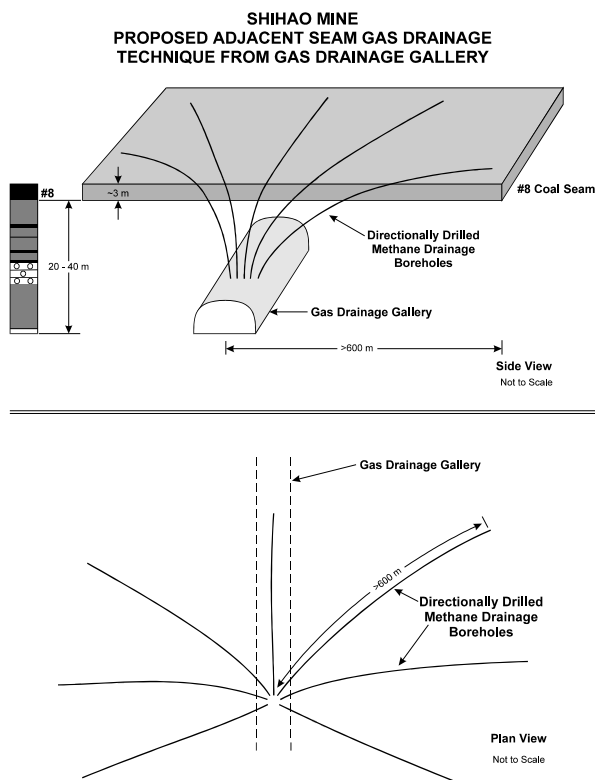


Figure 2: Proposed system of degasification for the No. 8 coal seam at the Shihao Mine using long directionally drilled boreholes.

Reservoir Testing and Simulation

Methane desorption tests and in-mine injection tests were conducted to determine the critical reservoir characteristics of the No. 8 coal seam at the Shihao Mine. These reservoir characteristics were used to provide input to computer simulations to define optimal borehole configuration and degasification time to adequately reduce the residual gas content of the No. 8 coal seam prior to mine-through. The results of these simulations are the focus of this paper.

NUMERICAL SIMULATIONS

Simulations of the current vertical and the proposed horizontal degasification boreholes were conducted using the two-phase, three dimensional, finite difference, coalbed reservoir simulator, COMET, developed by ICF Lewin, Inc. Simulations were developed to determine the horizontal borehole characteristics necessary to achieve the effectiveness of the present vertical borehole system, and develop nomograms for mine engineers to determine the necessary borehole spacing based on degasification time and desired degasification effectiveness.

Input Parameters

Critical input parameters required of the COMET program are typically obtained from reservoir tests. These are reservoir pressure, absolute permeability, in-situ gas content, matrix porosity, and desorption characteristics. Values used for these parameters are presented, following a description of the grid geometry and the boundary conditions used to represent the horizontal and vertical boreholes and respective drainage volumes.

Grid Geometry

The COMET program can be used to assess three dimensional grids of Cartesian, radial, or spherical geometry. For the horizontal borehole simulations, a Cartesian grid was constructed taking into consideration geometric (and solution) symmetry along the longitudinal axis of the borehole. The program requires that the size and location of each block comprising the grid is specified. In order to minimize solution dependency on grid block size, grid blocks were sized in a logarithmic manner with the smallest blocks assigned at locations where large gradients of pressure and gas concentration are anticipated (adjacent to the wellbore for example). Boreholes drilled vertically through the coal seam were simulated using a radial grid geometry. With the wellbore at the axis, a grid of concentric annuli, logarithmically sized such that the smallest annuli are assigned adjacent to the wellbore, was established.

Boundary Conditions

Both horizontal and vertical grids were established assuming that there will be no pressure or flow interaction between adjacent wells. No-flow boundary conditions were assigned to each perimeter grid block and overall grid sizes were based on wellbore length and spacing. Grids for horizontal simulations were extended longitudinally along the

wellbore to encompass four typical longwall panel widths (600 m). All grids assumed uniform coal thickness throughout.

Coal Reservoir Characteristics

Coal seam reservoir characteristics were obtained from an assessment of the desorption and injection test data (TerraTek, 1994, Tesseract, 1994) collected for the No. 8 seam at the Shihao Mine.

Reservoir Pressure: The reservoir pressure was determined from the injection tests as 3.74 MPa at a depth of 399m below surface. Extrapolated linearly to surface this corresponds to a pressure gradient of 9.37 kPa/m which is slightly less than the hydrostatic pressure gradient assuming fully saturated conditions.

Absolute Permeability: The absolute permeability of the coal cleat system was determined from the injection test analyses. Defined as the geometric mean of the absolute permeability of the face and butt cleats the absolute geometric permeability of the No. 8 coal seam is 0.2 md, where:

$$k_a = (k_x k_y)^{0.5}$$

where: k_a = geometric mean of the absolute permeability of the coal cleat system (md),

k_x = absolute permeability of the face cleat system (md),

k_y = absolute permeability of the butt cleat system (md),

For the simulations conducted, the absolute permeability was assumed to be isotropic throughout the reservoir as information relating to butt and face cleat frequency, or relative horizontal stress, was not available in order to ascertain relative anisotropism.

Relative Permeability: Site specific relative permeability characteristics of the coal cleat system to water and gas were not determined for the Shihao Mine. Relatively few tests of this type are performed due to costs and sampling requirements however, several estimates are available from published sources. These sources were used for the simulations conducted for the Songzao mines (Mavor, et al., 1990).

Cleat Spacing: The mean spacing of the face and butt cleats were defined by mine personnel to range from 0.2 m to 0.6 m (Niu, 1995). For the simulations conducted, a value of 0.4 m was used.

Porosity: The porosity of the coal cleats was obtained from estimates used to correlate the injection test data. A value of 1% was used in the simulations.

Methane Storage Capacity: The coefficients of the Langmuir equation which defines the sorption capacity of the coal relative to pressure were obtained from laboratory tests of samples collected at the Shihao Mine. The Langmuir volume, defined as the maximum gas storage capacity of the coal, and the Langmuir pressure, defined as the pressure where the

storage capacity of the coal is one-half of the Langmuir volume, determined from the laboratory test are shown in Table 1 and are presented in in-situ, dry, and dry ash-free formats.

Property	Lab Determined Value
Langmuir Pressure (kPa)	2006
Langmuir Volume - in-situ basis (scc/cc)	35.96
Langmuir Volume - dry basis (scc/cc)	37.26
Langmuir Volume - dry ash-free basis (scc/cc)	45.13

Table 1: Results of laboratory conducted adsorption tests of a sample collected at the Shihao Mine.

Using the laboratory data the adsorption/desorption characteristics as a function of pressure can be expressed by the Langmuir relation where:

$$V = 45.13 P / (P + 2006)$$

and: V = dry ash free gas content (scc/cc)
 P = pressure (kPa)

The Langmuir characteristics of the No.8 Coal seam are plotted on Figure 3 for in-situ, dry, and dry ash-free conditions.

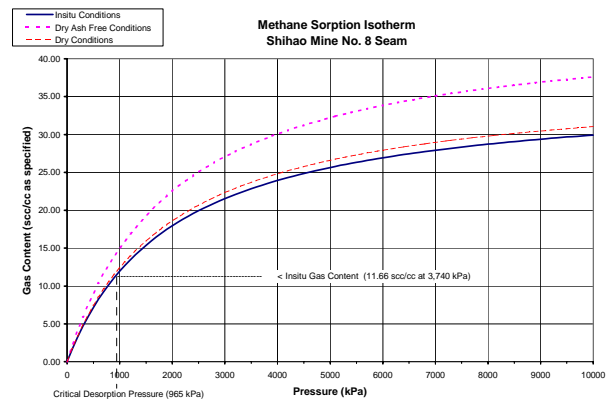


Figure 3: Langmuir Isotherm determined with samples of the No. 8 coal seam.

In-situ Gas Content and Desorption Time: The in-situ gas content and desorption time was determined from five samples of the No. 8 seam which were collected at the Shihao Mine. The volume of gas desorbed by the samples was summed with the lost gas fraction (USBM technique) and the residual gas, determined by grinding the sample after removal and monitoring the gas released. An average gas content of 8.23 scc per gram was determined. The total gas desorbed plotted as a function of time is used to determine desorption time; the time required for 63% of the gas to desorb from the coal. The average desorption time determined was 110 hours.

Plotting the in-situ gas content at the determined reservoir

pressure (3.74 kPa) on the in-situ Langmuir isotherm as shown on Figure 3, indicates that the No. 8 coal seam is under-gas-saturated. With this condition gas mobility is achieved only after wellbore pressure is reduced below 965 kPa.

DEGASIFICATION ANALYSIS

Initial simulations were conducted to assess the effectiveness of the present degasification system comprised of vertical boreholes developed on 15 m centers in the No. 8 seam. These simulations were used to determine a horizontal borehole pattern which would be as effective as the present degasification system, and predict the volume of gas recovered by each technique.

Volume Degasified

To compare methane drainage effectiveness between vertical and horizontal borehole systems, the wellbore influence beyond the end of the horizontal borehole needs to be assumed. For a 500 m horizontal in-seam borehole this zone was set to 100 m. This distance was selected as it represents the approximate width of four typical longwall panels (600 m total).

Although it has been shown by simulation that the draw-down effects beyond the end of a horizontal borehole are minimal, this may not actually be the case with multiple, evenly spaced boreholes distributed over a large area. These wellbores interact and extend the draw-down influence over a greater volume than that presented by a single wellbore simulation.

Degasification Time

The larger the degasification volume simulated (adjusted by increasing the borehole spacing) the greater the duration of borehole effectiveness with respect to gas drainage. In order to compare drainage effectiveness of similarly drilled holes over a range of spacings, a common degasification time of 5 years was selected.

Vertical Borehole Simulation

Vertical boreholes drilled into the No. 8 coal seam from galleries below were simulated assuming 15 m equidistant grid patterns. Borehole performance curves were established over a degasification period of 5 years and show cumulative gas production as a function of time (Figure 4) and drainage effectiveness based on percentage of gas recovered as a function of gas-in-place and degasification time (Figure 5).

Horizontal Borehole Simulations

Simulations were conducted for 500 m, in-seam, directionally drilled boreholes spaced 15 m, 30 m, 60 m, and 90 m apart into the No. 8 Coal seam. Borehole performance was evaluated over a period of 5 years. Figure 6 shows the predicted cumulative gas production as a function of borehole spacing, while Figure 7 illustrates the effectiveness of the horizontal boreholes as a function of gas recovered relative to that in-place as a function of degasification time and spacing.

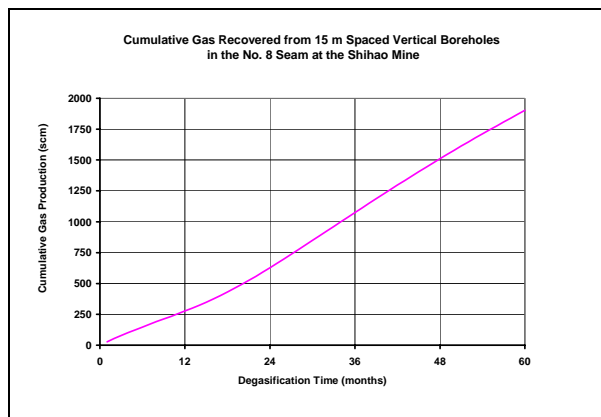


Figure 4: Predicted cumulative gas recovered from 15 m spaced vertical boreholes in the No. 8 seam at the Shihao Mine.

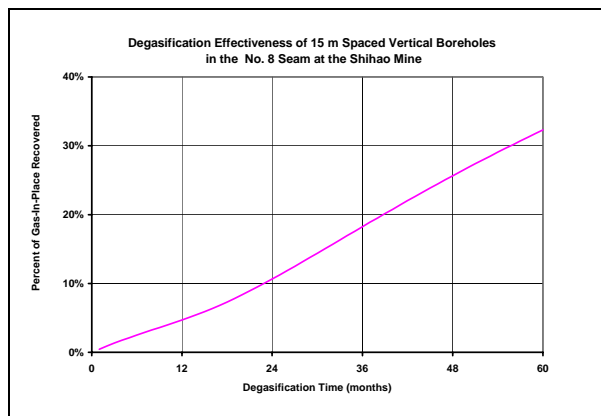


Figure 5: Predicted degasification effectiveness from 15 m spaced vertical boreholes in the No. 8 seam at the Shihao Mine.

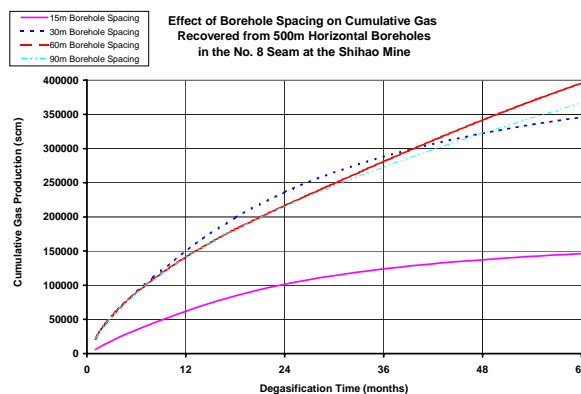


Figure 6: Cumulative gas recovery for horizontal boreholes in the No. 8 seam as a function of degasification time and spacing.

8 seam as a function of degasification time and spacing.

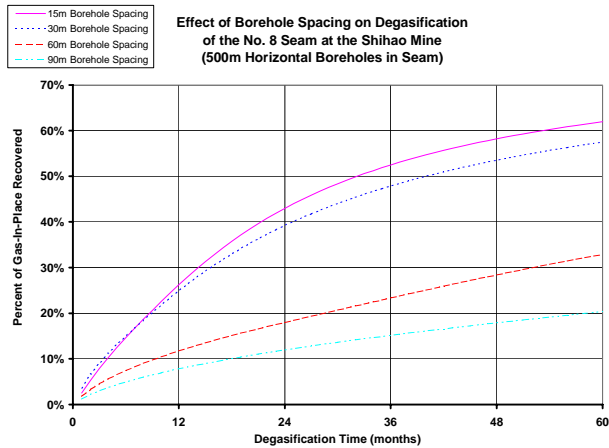


Figure 7: Methane drainage effectiveness of the in-seam horizontal boreholes as a function of degasification time and borehole spacing.

Comparison of Results

Borehole Spacing: The simulations indicate that degasification effectiveness, defined as a percentage of gas recovered to that in place, improves with decreased borehole spacing as shown on Figure 7 as anticipated. The simulations also indicate that the horizontal boreholes would need to be spaced 60 m apart to achieve the same degasification effectiveness as the 15 m spaced vertical boreholes.

APPLICATION TO THE SHIHAO MINE: Using an area equivalent to a typical panel length and four panels in width (approximately 1000 m x 600 m), the present vertical borehole program requires 2,667 vertical holes and 5 degasification galleries. With the horizontal in-seam borehole concept, only 16 boreholes and a single degasification gallery would be required.

Gas Recovery: The results of the simulations indicate that as expected, horizontal boreholes will produce significantly more gas than the vertical wellbores and that degasification effectiveness can be improved with fewer, further spaced horizontal boreholes. Using mean cumulative gas production data after 60 months for the two borehole orientations, the horizontal boreholes are predicted to produce 166 times more gas than the vertical boreholes.

CONCLUSIONS

Coalbed reservoir simulations were conducted with data obtained from in-mine reservoir tests to estimate the degasification effectiveness of the present degasification program for the No. 8 coal seam at the Shihao Mine. The results of these simulations were compared with those of a cost effective degasification program involving in-seam horizontal boreholes, also developed from underlying drainage galleries.

These simulations indicate that:

- degasification effectiveness (defined by dividing the volume of gas recovered by that in place) improves with decreased borehole spacing for both vertical and horizontal borehole orientations,
- degasification effectiveness is significantly greater for horizontal borehole configurations than for vertical borehole configurations
- significantly fewer horizontal boreholes are required to achieve the degasification effects attained with considerably more vertical boreholes.

Results Relative to Current Mine Practices

Figures 5 and 7 allow a comparison of the effectiveness of the current technique practiced at the mines (multiple vertical boreholes) with the horizontal in-seam boreholes proposed for the project. These figures indicate that horizontal in-seam boreholes of 500 m or more in length, spaced 60 m apart would effectively remove 32% of the gas in place after 60 months. This effectiveness is similar to that which is predicted using the current technique practiced at the Shihao Mine and is consistent with the overall methane drainage system capture efficiency estimate of 20 percent.

To qualitatively compare the costs of the present vertical system with that proposed, consider that 16 horizontal boreholes would be required to degasify 4 longwall panels compared to 2,667 vertical boreholes. Also with the horizontal boreholes, a single gallery is required to degasify 8 longwall panels, whereas with the vertical boreholes, 5 galleries are required to degasify 4 longwall panels.

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