Research of innovative technologies for degasification of lignite seam

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Abstract. Gas outbursts are great problem in coal mines, especially in coal mining of thick coal seams. In Velenje Coal mine up to 160 m thick coal seam presents a large volume reservoir of coal gas. An average gas mixture ratio in Velenje coal gas is approximately $CO_2:CH_4 \geq 2:1$ from which high proportion of carbon dioxide is adsorbed on lignite structure, while methane is free in coal fractures. "In-situ" monitoring is provided in the mine with the support of laboratory analysis, such as desorption and adsorption laboratory tests, and coupled numerical modelling of gas migration under the influence of stress change is also performed. Individual research work is focused on coupled geomechanical modelling of coal pillar. Modelling is performed with two programs – Flac3D and TOUGH2. Different models in Flac3D were prepared. Further on, the focus will be on the modelling of gas pressure changes and gas migration around the borehole at the longwall Pesje K. -50/C.

Keywords: gas outbursts, thick coal seam, coal gas, Flac3D modelling, TOUGH2 modelling

1 Introduction

Gas outbursts present high risk by the coal mining of thick coal seam, where thick coal seam up to 160 m in Velenje Coal Mine presents a large volume reservoir for coal gas and production of coal causes changes in stress and pore pressure around the longwall coal face and coal gas can emit. When outburst occurs, the rock/coal/gas system changed from a stable to an unstable state with the release of a significant volume of gas over the duration of the outburst [1]. Outbursts with CO_2 are more violent, more difficult to control and more dangerous because of the greater sorption capacity of carbon dioxide [2]. At Velenje Coal Mine, coal seam has an average gas mixture ratio of approximately $CO_2:CH_4 \geq 2:1$ with high proportion of carbon dioxide which is adsorbed on lignite structure or it is captured in the coals matrix and methane, which is free in coal fractures.

Coal gas concentrations has been monitored in various boreholes that were drilled in coal pillars at different areas in coal mine. Also, coal gas pressure inside boreholes has been measured under the influence of the retreating longwall coal face. For determination of the detailed gas content, sorption (adsorption and desorption) tests were performed on coal samples coupled with numerical modelling of gas migration under the influence of stress change.

My individual research work mainly concerns the coupling geomechanical modelling of coal pillar, which is under dynamic stresses of longwall top coal caving. Modelling is performed with two programs – Flac3D and TOUGH2. Numerical modelling is widely used in coal mining for understanding the behaviour of coal under dynamic stresses. With coupling we will be able to understand how the coal gas is migrating under dynamic stresses and how the gas migration is influencing the gas outbursts. Flac3D is a three-dimensional explicit finite-difference program for engineering mechanics computation. With the TOUGH2 we will be able to model behaviour of the coal gas under different permeability changes. TOUGH2 is a general-purpose numerical simulator for multi-dimensional fluid and heat flows of multiphase, multicomponent fluid mixtures in porous and fractured media [3].

1.1 Coal geology

The Velenje coal seam is one of the thickest coal seams in the world and is located in N Slovenia near the town Velenje. The lignite seam is lens-shaped with thickness up to 165 m in the central part and the seam pinches out towards the margins and lies in the Velenje basin. Under the lignite seam lays coal-bearing strata, which consists of shales, clayey coal and lignite and is up to 50 m thick. The footwall lies on more than 250 m thick green sandy silts. Above the coal seam, a thin layer of marls with lacustrine molluscs was detected and after that thin layer is up to 350 m thick lacustrine strata consisting of clays, marls and silts. This strata is overlain with 90 m thick sandy-silty formation. The most upper part of the basin consists of terrestrial silts, overlain by recent fluvial sediments [4].

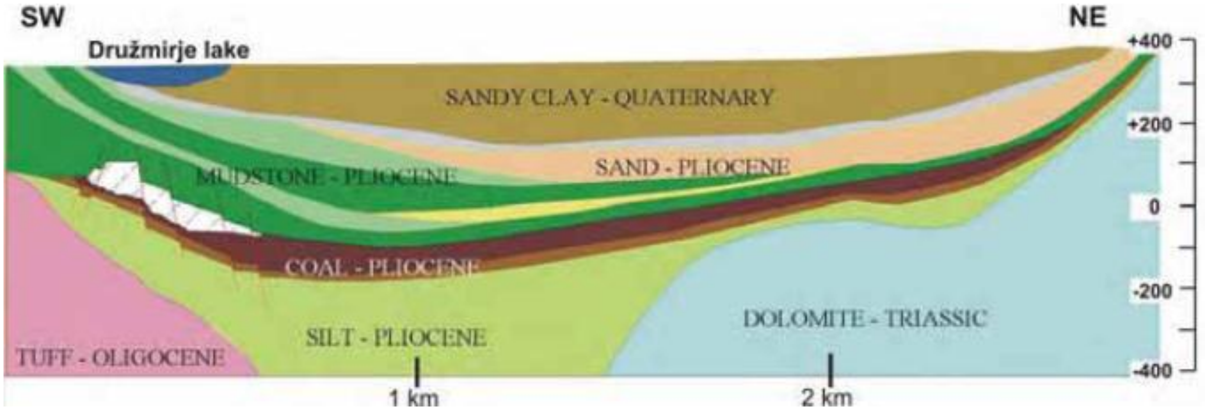

Figure 1: Shematic geological cross-section SW-NE (Veber and Dervarič, 2004)

2 Experimental

2.1 Coal gas origin and migration

Coal gas in Velenje lignite has three main gas components: CO_2, CH_4 and nitrogen. Table 1 represents concentrations of separate gas components in coal gas. The main causes of the changing concentrations are numerous origins of the coalbed gas and chemical processes, meanwhile the gas is being transported by diffusion, adsorption and desorption processes [5].

Table 1: Coal gas components and their concentration distribution

Gas	Concentration (min, max) [vol. %]
CO_2	18 – 98.8
CH_4	1.1 – 100
N_2	7.2 – 67.3

Movement of gas through coal is widely believed to occur under two processes, starting with diffusion in which gas is desorbed from the coal matrix into the fracture network (Fick`s diffusion law), and movement within the fracture network according to pressure difference as described by Darcy`s law [6].

2.2 Coal permeability

The longwall top coal caving (LTCC) method with high productivity, which is found in Velenje Coal Mine, causes large stress releases which increases the rock mass permeability in surrounding coal. Increase in coal permeability could cause coal gas to migrate from the surrounding coal into roadways. To prevent gas outburst the task is to drain the coal gas from the coal panels before it is excavated.

Coal seam has in the first place natural fractures or cleats, which act as a major system for gas flow inside a coal seam. Advanced numerical model presents an opportunity to realistically simulate rock mass response to longwall operations, the associated gas liberation and flow through the fractured rock mass without resorting to field experimentation [7].

Durucan and Edwards in 1986 developed an exponential equation which can give the best fit to the stress – permeability correlation:

$$K = (1{,}12 - 0{,}03\sigma_3)K_i e^{-(1{,}12-0{,}03\sigma_3)C\sigma_3} \qquad (1)$$

Where, K_i and C are constants, σ_3 is the radial stress applied and K is the permeability at stress σ_3. Constant C, which represent the compressibility of coal (i.e. the degree of reduction in permeability under stress), is the behaviour of the micro-structure of coal under stress and it can be determined individually for each seam. Constant K_i defines the relative incidence of existing fissures and fractures in coal. [8]. Coal with higher value of K_i would have higher permeability.

2.3 Numerical modelling of longwall face in Velenje coal mine

Numerical modelling is widely used in coal mining for understanding the behaviour of coal under dynamic stresses. When the stress results are known then with stress-permeability correlation by Durucan and Edwards the permeability can be defined which is used for data in the coupled geomechanical program TOUGH2. The objective for the model analysis in Flac3D is to gather stress changes around the pressure borehole for monitoring gas pressure changing in dependence of advanced longwall face. First, the geometry of the model was defined. The geometry of the longwall face Pesje K.-50/C was chosen due to the fact that the pressure measurements were successful at this longwall face and due to its half of the planned excavate coal pillar lying under fresh hanging wall and the second half lying under pre-mined longwall faces. Longwall face Pesje K. -50/C was 150 m wide and 684 m long. The mining method is divided into coal face slicing in height of 4 m and top coal caving in average height of 11 m.

The model was simplified and Mohr-Coulomb constitutive model was chosen. The Mohr-Coulomb model is the conventional model used to represent shear failure in soils and rocks [9]. The Mohr-Coulomb criterion is represented with the principal stresses σ_1, σ_2, σ_3. In Table 2 rock properties which were used for the modelling and which correspond to the geology of the Velenje basin where coal seam lies are represented.

Table 2: Rock properties of the modelled material

Rock type	Density [kg/m^3]	Bulk module [Pa]	Shear module [Pa]	Cohesion [Pa]	Angle of friction [°]	Tension [Pa]
Overburden	2260	$5.2*10^8$	$2.17*10^8$	$2*10^6$	35	$0.23*10^8$
Hanging wall	1870	$4.8*10^8$	$2*10^8$	$7*10^5$	30	$0.08*10^8$
Coal	1260	$4.51*10^8$	$1.68*10^8$	$1.5*10^6$	30	$0.92*10^8$
Floor strata	1870	$4.7*10^8$	$2*10^8$	$7*10^5$	30	$0.44*10^8$

2.4 Results of the modelling

After 17827 steps equilibrium was reached and the distribution of maximal principal stresses vary from 7.75 MPa at the bottom of the model and to 1 MPa from the surface down (Figure 2).

In the second step excavated area of the longwall face K. -50/C was modeled. To represent an excavation, a null model is used. The stresses within a null model zone are automatically set to zero [9]:

$$\sigma_{ij}^{N} = 0 \quad (2)$$

After 1000 steps, maximal principal stresses around the coal face were 10.4 MPa (blue colour in the grid).

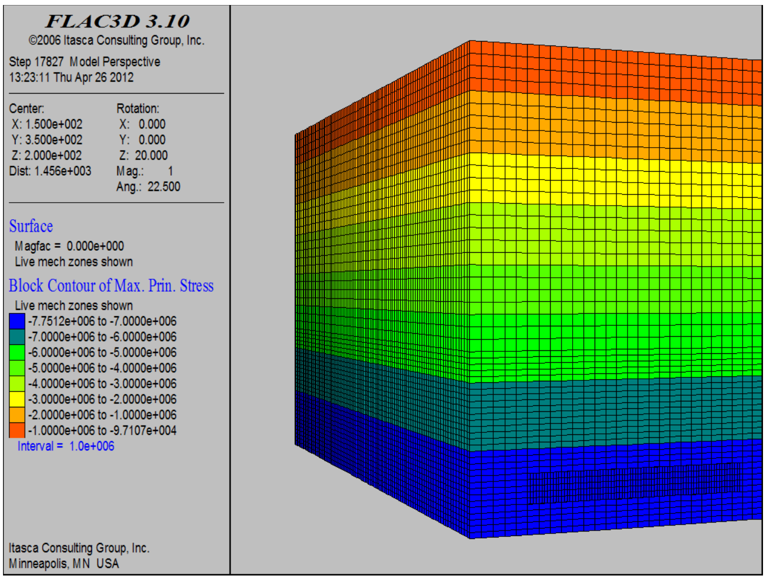

Figure 2: Maximal principal stresses (Pa)

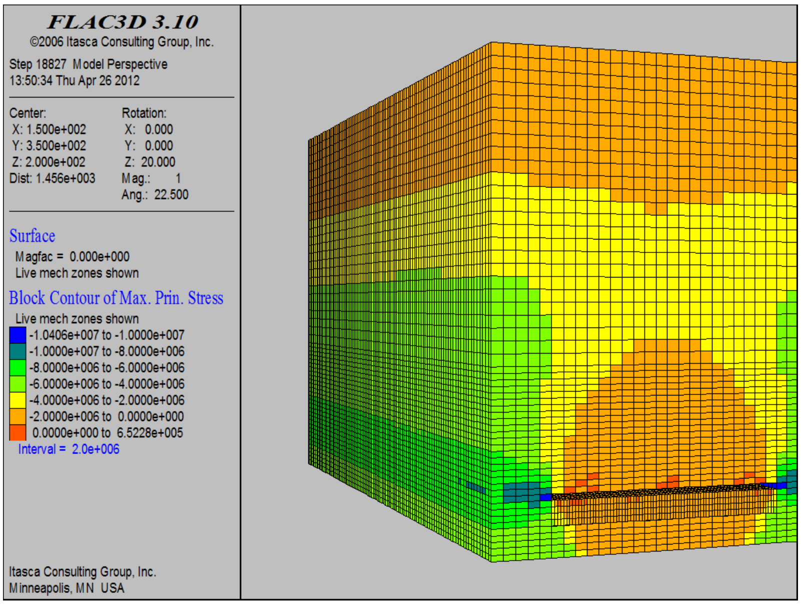

Figure 3: Maximal principal stresses after the excavation (Pa)

3 Conclusions

The future work will be focused on the modelling with Hoek-Brown constitutive model. More complex models will be defined. Material properties will be converted into rock mass data using empirical relationships widely used in geomechanics. Modelling of the caved area is another important step that affects the accuracy of obtained results [10]. Therefore, this step needs to be taken into detail. Analysis of the consolidation tests in the goaf will be studied.

Also, the dynamic model will be used at the location of the gas pressure borehole JPK 34/10 where we successfully monitored the coal seam pressure under the influence of the longwall dynamic.

Geomechanical modelling with TOUGH2 will be performed. For the input data it is needed to characterize fluid hydrogeological parameters and relations of the permeable media with permeability, porosity and capillary pressure, thermo-physical properties of the fluids, initial and boundary conditions of the system with sink and sources.

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For wider interest

In the last few years the importance of coal as an energy source is raising again, due to development of Clean Coal Technologies (CCT). However, coal combustion produces billions of tonnes of carbon dioxide each year and all of that is released to the atmosphere. Because of the problems with greenhouse gas emissions at Velenje Coal Mine we launched a research group on Clean Coal Technologies (at the end of year 2007). The task of the research group is to find new technologies for cleaner use of coal. Clean Coal Technologies research group also applied for two international projects. First is Development of Novel Technologies for Predicting and Combating Gas Outbursts and Uncontrolled Emissions in Thick Seam Coal Mining, which will improve coal excavation, safety and working conditions in the mine (CoGasOUT). The project is partially founded by Research Fund for Coal and Steel. The second project entitled Greenhouse Gas Recovery from Coal mines and Coalbeds for Conversion to Energy (GHG2E) is funded within the 7th framework programme. During both projects, "in-situ" monitoring is provided in the mine with the support of laboratory analysis, such as desorption and adsorption laboratory tests, coupled with numerical modelling of gas migration under the influence of stress change. Results will improve mines around the world with new technology to combat outbursts and high gas emissions.