Conducting Pre-Feasibility Studies for Coal Mine Methane Projects

Module 4 – Forecasting Methane Production from Gas Drainage Systems

Welcome

The United States Environmental Protection Agency (EPA) developed this course in support of the GMI and in conjunction with the United Nations Economic Commission for Europe (UNECE).
This course introduces principles for assessing the potential of developing projects to capture and/or use Coal Mine Methane (CMM). The general approach described in the course should be underpinned by mine-specific data and analyses, allowing the principles to be tailored to the unique conditions at each mine. Ideally, such an assessment will lead to project development and implementation.

What is the GMI?

The Global Methane Initiative (GMI) is a voluntary, multilateral partnership that aims to reduce methane emissions and to advance the abatement, recovery, and use of methane as a clean energy source.

GMI Partner Countries account for nearly 70% of total global manmade methane emissions, which is equivalent to approximately 5,000 MMTCO2e.

Conducting Pre-Feasibility Studies for CMM Projects: Course Modules

Module 1: Introduction and Objectives

Module 2: Mine Background Information and Evaluation

Module 3: Resource Assessment

Module 4: Forecasting Methane Production from Gas Drainage Systems

Module 5: Improvements to Gas Drainage

Module 6: Quantifying the Benefits of Improvements to Methane Drainage Systems

Module 7: Market, Risk, and Financial Analyses

Module 8: Case Study – Liulong Mine, China

Module 4: Introduction and Objectives Title Slide

What You Will Learn

After completing this module, you will:

- Be familiar with methods for forecasting gas drainage production.
- Understand how the forecast analysis depends on the quality and quantity of available data.

Time needed to complete this module – Approximately 30 minutes.

Forecasting CMM Production from Methane Drainage Systems

Project developers can rely on several types of approaches to forecast CMM production from methane drainage systems. The best approach depends on the amount and types of data available.

Methods to forecast CMM production include:

- Probabilistic methods
- Analytical methods
- Reservoir simulation

Forecasting: Probabilistic Methods

Used when the project developer does not have sufficient or reliable empirical data.

Probabilistic methods use a range of estimated values to predict the probability of different outcomes.

Therefore, probabilistic methods use randomness to solve problems that may be inherently deterministic (i.e., fully determined by the parameter values and initial values).

Forecasting: Analytical Methods

Used when the project developers have sufficient or reliable field data.

Analytical methods use a range of field data values to predict future methane production from gas drainage systems by applying analytical techniques.

These analytical techniques may include volumetrics analysis or field-derived production relationships.

Forecasting: Reservoir Simulation

Used when project developers have access to field and laboratory data on coal seam parameters.

Reservoir simulation provides a means to account for the complex mechanisms of coalbed methane gas desorption, diffusion, and flow.

This method allows the integration of field and laboratory data into a single geologic/reservoir model in order to evaluate pre-mining methane drainage strategies.

Selecting an Approach to Forecast CMM Production

Experts, including mining and reservoir engineers, develop models, simulations, and/or software for each of these approaches to forecast CMM production from methane drainage systems.

The amount and types of data that are available to a project developer often dictate which approach is the most appropriate.

Regardless of which approach is selected (probabilistic methods, analytical methods, or reservoir simulation), the model or software should be robust enough to tailor to a specific project. Project developers often work with technical consulting firms to decide on the appropriate approach.

Probabilistic Methods Transition Slide

Forecasting CMM Production through Probabilistic Methods

Estimating gas drainage production requires the knowledge of many variables, which may not always be available to a project developer. Therefore, project developers may need to rely on probabilistic methods, which use computational algorithms to predict the probability of certain methane drainage characteristics.

One example of a probabilistic method is the Methane Control and Prediction ("MCP") software that was developed by National Institute for Occupational Safety and Health (Note: the software is currently being updated). Publicly available, the MCP software predicts mine methane emissions and estimates degasification system production rates.

Probabilistic Method Approach

Probabilistic methods, such as the MCP software, use a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results.

- The underlying concept is to use randomness to solve problems that might be deterministic in principle.
- These simulations are used to predict the probability of different outcomes when the intervention of random variables is present.
- This method helps explain the impact of risk and uncertainty in prediction and forecasting models.

When to Use Probabilistic Methods

Developers use probabilistic methods when the available data are limited.

This approach can provide upper and lower limits for forecasted CMM production from gas drainage, but it is not as accurate as analytical techniques that are based on mining and coal reservoir characteristics.

For example, probabilistic analysis can be applied to forecast gas production from the drainage of gob gas, which is methane released from mined-out areas. In this example, the analysis would utilize a range of data, including mining parameters and coal production forecasts.

Parameters may include:

- Slotted casing length
- Distance (from surface) to slotted casing top
- Slotted casing diameter
- Slotted casing distance from top of coal
- Distance of gob gas borehole to tailgate
- Distance of gob gas borehole from start of panel
- Average exhauster vacuum

Examples of Probabilistic Method Outputs

In addition to forecasting gob gas drainage, probabilistic methods can also be applied to in-seam boreholes, cross-measure boreholes, or any other methane drainage techniques.

Analytical Methods Transition Slide

Forecasting CMM Production through Analytical Methods

To estimate the rates of gas production from methane drainage systems, project developers can use analytical techniques when adequate data are available.

These analytical techniques may include volumetric analysis or numerical calculations. Developers can use these techniques to forecast methane production for different scenarios, such as:

- The volume of gas in strata potentially affected by mining.
- Mine ventilation methane emissions.

After using analytical methods to forecast the variables above, project developers can then use these variables to forecast CMM production as they continue to plan further mine development.

Volumetric Analysis

Volumetric analysis is a technique used to estimate the volume of gas stored within a specific bulk reservoir rock volume (gas-in-place).

This method employs geological observations and relevant production information to predict the volume of methane adsorbed on coal surfaces as well as trapped in the pore spaces.

This technique often relies on data from core samples, wireline logs (continuous measurements using electrically powered geologic instruments), and geological maps.

Volumetric Gob Gas Prediction Models

One example of of analytical methods are volumetric gob gas prediction models. Gob gas prediction models typically simulate the gas present in the mined-out area of a mine, also known as the gob area, and take into consideration the affected gas bearing strata.

Input requirements include:

- Depth below surface
- Geomechanical properties of the adjacent strata
- Gas content and reservoir properties of the adjacent strata
- Proximity of the adjacent strata to mining
- Panel length
- Panel width
- Mining height and rate

Volumetric Gob Gas Prediction Model Example

The graphs below show example outputs from forecasting the production performances of gob gas boreholes using intelligent computing methods for optimum methane control in longwall coal mines. They show initial high rates of gas production and methane concentration for gob gas wells during the mining of a single longwall panel. As time increases, gas production and methane concentration decrease. The first boreholes in each panel typically produce the highest methane percentage, and subsequent boreholes produce lower quantities of methane.

- Gas Production vs Time Graph
- Methane Concentration vs Time Graph

Numerical Calculations

Numerical calculations are another analytical method used to study the interaction of multiple parameters in a complex system.

These simulations use numerical modeling to predict and provide analytical solutions using empirical data and measurements when they are available to the project developer.

One way to apply numerical calculations is through the use of equations.

If utilizing the calculation technique, developers may use parameter relationships to estimate the gas flow rate capacity of a horizontal gob borehole as a function of:

- gas composition
- borehole diameter
- wellhead vacuum pressure

Calculation Technique

As noted on the previous slide, another approach to analytical methods is to use numerical calculations, such as calculation equations developed by geologists and engineers that are found in various technical textbooks. If the calculation technique is being used, developers may apply the below relationship to estimate the gas flow rate capacity of a horizontal gob borehole as a function of gas composition, borehole diameter, and wellhead vacuum pressure.

Reservoir Simulation Transition Slide

Forecasting CMM Production through Reservoir Simulation

Reservoir simulation is the preferred and most accurate approach to forecast CMM production, provided a project developer has adequate and reliable data.

Advantages of Using Reservoir Simulation for Pre-mine Drainage Forecasts:

- Provides a means of accounting for the complex mechanisms of coalbed methane gas desorption, diffusion, and flow
- Allows integration of field and laboratory data into a single geologic/reservoir model in order to evaluate pre-mining methane drainage strategies
- Provides a basis for forecasting future production of pre-mining gas drainage systems
- Helps diagnose in-situ gas content reduction and drainage time as a function of pre-mining borehole spacing
- Predicts gas recovery from pre-mining degasification over time considering underground mining plans

Reservoir Simulation Parameters

Reservoir simulation requires knowledge of the characteristics of the coalbed reservoir, including the following parameters:

- Cleat permeability and orientation
- Porosity
- Initial gas content
- Adsorption isotherm
- Desorption pressure
- Diffusion coefficient
- Cleat spacing
- Pore volume compressibility
- Gas composition, gravity, and viscosity
- Depth
- Net coal thickness
- Stratification (layers)
- Ash content
- Drainage area
- Reservoir pressure
- Water saturation
- Gas-water relative permeability

Reservoir Simulation Examples

Developers can use reservoir simulation to derive pre-mining methane drainage plans based on mine plans and reservoir parameters that are available or estimated. Examples of commercially available software that are commonly used in the United States are COMET3 and GEM.

Reservoir Simulation Confidence

Reservoir simulation requires a significant amount of data, and the applicability of reservoir modeling for gas drainage system design depends on the availability and quality of such data.

Confidence in reservoir simulation results can be improved by comparing historical production or gas content reduction data against the outputs of the simulation.

Applying the Approaches in Practice

The availability and quality of data are the primary factors in determining and choosing an appropriate forecasting method.

While reservoir simulation is the preferred and most accurate approach, it also requires more work associated with gathering necessary data.

- Acquiring reservoir information requires drilling, coring, and testing wells, as well as laboratory work.
- Constructing reservoir simulations requires considerable time to assemble the data, construct the model, run the simulations, and interpret the results.

As a result, reservoir simulations are more expensive to complete than a probabilistic method, which relies on a range of data.

Importance of Forecasting Approaches

The forecasting approaches discussed in this module can be used to improve confidence in estimated gas drainage resulting from improvements to a gas drainage system (covered in Module 5). Having an accurate forecast for gas production can help select/justify the chosen approach to optimize gas production, improve gas recovery, optimize drainage efficiency, and minimize the costs of production.

Forecasting methane production is important because it forms the basis of the financial and economic analysis of the project.

Module 4 Summary

In this module, you learned:

- About the different methods that are available to predict methane drainage production, which include:
    - Probabilistic methods
    - Analytical methods
    - Reservoir simulation
- The quality and quantity of data will dictate the most appropriate method for predicting mine methane emissions and forecasting methane drainage production.

In Module 5, you will learn about the different methods and tools that are used to improve mine gas drainage. Improving mine drainage not only makes mining operations safer, but it can also increase coal production and result in the production of higher quality gas.

Thank you!

You have completed Module 4.

Glossary of Terms

Adsorption Isotherm — An empirical relation between the concentration of a solute on the surface of an adsorbent to the concentration of the solute in the liquid with which it is in contact.

Ash Content — The non-combustible residue left after carbon, oxygen, sulfur, and water has been driven off during combustion. The remaining residue or ash is expressed as a percent of the original coal sample weight.

Borehole — A narrow shaft bored in the ground, either vertically or horizontally.

Borehole Spacing — The measured distance between two or more boreholes drilled for production.

Capillary Pressure — The pressure difference across the interface between two immiscible fluids arising from the capillary forces. These capillary forces are surface tension and interfacial tension.

Casing — A large diameter pipe that is assembled and inserted into a recently drilled section of a borehole.

Cleats — Naturally occurring orthogonal joints in coal. They occur as two perpendicular sets of fractures.

Coal Mine Methane (CMM) — Methane released from coal due to mining activities. Like CBM, CMM is a subset of the methane found in coal seams, but it refers specifically to the methane found within mining areas (e.g., within a mining plan), while CBM refers to methane in coal seams that will never be mined. Because CMM would be released through mining activities, recovering and using CMM is considered emissions avoidance.

Coal Thickness — The measured or approximate thickness of the coal-bearing strata. Measured from the top of the coal-bearing unit to the top of the underlying unit.

Core — A cylindrical section of a naturally occurring substance, typically obtained by drilling through the subsurface with a hollow steel tube called a core drill.

Degasification — The process of removing gases from a coal mine.

Desorption Pressure — A phenomenon whereby a substance is released from or through a surface related to the surrounding pressure of the reservoir.

Diffusion Coefficient — A measure of the mobility of gases from one gradient to another.

Gas Composition — The gas composition of any gas can be characterized by listing the pure substances it contains and stating for each substance its proportion of the gas mixture's molecule count.

Gas Content — Volume of gas contained in a unit mass of coal and is generally expressed in cubic meters, at standard pressure and temperature conditions, per ton of coal.

Gas Drainage — Methods employed by underground coal mines, abandoned mines, and occasionally surface mines, for capturing the naturally occurring gas in coal seams to prevent it entering mine airways. Gas drainage systems include a combination of drainage boreholes and/or galleries, a gathering network, and vacuum pumps to draw gas to the surface. Gas can be removed from coal seams in advance of mining using pre-drainage techniques and from coal seams disturbed by the extraction process using post-drainage techniques. It is often referred to as methane drainage if methane is the main gas component target to be captured. Gas drainage produces coal mine methane of a higher quality than ventilation, generally in the 25 — 100 percent range.

Gas Gravity — The ratio of the density of the gas at standard pressure and temperature to the density of air at the same standard pressure and temperature.

Gas-In-Place (GIP) — The volume of gas stored within a specific bulk reservoir rock volume (e.g., coal).

Gas Production — The quantity of gas produced by pre-mine drainage and post-mine drainage boreholes and drainage galleries.

Gas Solubility — The solubility of a gas in a liquid is directly affected by temperature and pressure. As temperature increases solubility decreases; this is described by Le Chatelier's Principle. As pressure increases solubility increases; this is described by Henry's Law.

Geophysical Log — The collection of geological and hydrologic information in wells by lowering and raising probes on a wire. It is typically more useful to employ a suite of different geophysical logs when collecting information.

Global Methane Initiative (GMI) — Launched in 2004, the GMI is an international public-private initiative that advances cost-effective, near-term methane abatement and recovery and use of methane as a clean energy source in three sectors: biogas (including agriculture, municipal solid waste, and wastewater), coal mines, and oil and gas systems. Focusing collective efforts on methane emission sources is a cost-effective approach to reduce greenhouse gas (GHG) emissions and increase energy security, enhance economic growth, improve air quality and improve worker safety.

Gob (Goaf) — Broken, permeable ground where coal has been extracted by longwall coal mining and the roof has been allowed to collapse, thus fracturing and de-stressing strata above and, to a lesser extent, below the seam being worked. The term gob is generally used in the United States; elsewhere, goaf is generally used.

Historical Production — A record of the amount of coal or natural gas produced from a given mine or CMM project. Often used as an analogous CMM project example for forecasting future gas production and emissions during a pre-feasibility study.

In-Situ — It can mean "locally", "on site", "on the premises", or "in place" to describe where an event takes place and is used in many different contexts. For example, in fields such as physics, geology, chemistry, or biology, in situ may describe the way a measurement is taken, that is, in the same place the phenomenon is occurring without isolating it from other systems or altering the original conditions of the test. The opposite of in situ is ex situ.

Longwall — One of three major underground coal mining methods currently in use. Employs a shearer which is pulled mechanically back and forth across a face of coal that is usually several hundred feet long. This mining method can produce large quantities of coal and gas.

Longwall Panel — Large blocks of coal that are mined with a longwall shearer.

Methane — Methane is a potent greenhouse gas. Methane's lifetime in the atmosphere is much shorter than carbon dioxide, but it is 28 times as efficient at trapping radiation than CO2 over a 100-year period. Methane is the main precursor of ground level ozone pollution, and thus affects air quality. Methane is also an energy resource that can be captured and used. Methane in mines poses safety risks, due to its explosiveness when mixed with air.

Permeability — The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it.

Porosity — The measure of void or pores space present when a solid and is represented by volume percentage of void in the solid. It defines the maximum possible amount of methane that can be retained in the coal.

Pre-Mine Drainage — Drilling in-seam boreholes to extract gas from the coal seam in advance of mining operations.

Probabilistic Methods — Methods based on the theory of probability or the fact that randomness plays a role in predicting future events.

Relative Permeability — The ratio of effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation.

Reservoir Pressure — An indication of how much fluid (gas, oil, or water) is remaining in the reservoir. It represents the amount of driving force available to drive the remaining fluid out of the reservoir during a production sequence.

Reservoir Simulation — Provides a consistent and reliable way to account for the complex mechanisms of coal seam gas desorption and diffusion. Also provides the opportunity for field and laboratory data to be integrated into a single geologic/reservoir model to evaluate exploration and development strategies.

Solubility — The property of a solid, liquid, or gaseous chemical substance called solute to dissolve in a solid, liquid, or gaseous solvent.

Strata — A layer of sedimentary rock or soil; refers to a layer of coal in this instance.

Tailgate — Gate roads are driven to the back of each panel before longwall mining begins. The gate road along one side of the block is called the maingate or headgate; the road on the other side is called the tailgate.

Water Saturation — The saturation of an undisturbed reservoir with no prior production from any earlier well.