COALBED METHANE PRIMER: FROM A “NUISANCE” TO A “DARLING ENERGY RESOURCE” IN FIFTY-PLUS YEARS

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ABSTRACT

This two part paper is a primer on Coalbed Methane (CBM) development, and as such is a collection of information gleaned from a variety of sources. Part one describes in brief the origin and development history of CBM in the USA, including the catalyst (Tax incentive) that helped accelerate the development, as well as some thoughts on CBM global potential. Part one initiates discussion on the fundamentals of CBM reservoir engineering and the importance of critical attributes of coal beds in the production of methane. Part two continues with this discussion by describing CBM storage, transportation, and permeability aspects of coalbed, then introduces some of the well completion practices that are followed by the industry and their applicability in the production of CBM. Finally, some of the problems associated with the production of CBM are mentioned.

Part One

INTRODUCTION AND A BRIEF HISTORY OF COALBED METHANE DEVELOPMENT IN THE US

Coalbed gas had played a significant role in the history of oil and gas development in the San Juan Basin (SJB) of New Mexico / Colorado, but not until the late 1980s, SJB was referred to as the birth place of modern CBM production.

Figure: 1, Coal Bed Methane Resource Basins in the U.S.

Geologic Setting of San Juan Basin

The San Juan Basin (SJB) is an asymmetric-structural basin formed during Cenozoic and Mesozoic time periods and straddling the New Mexico - Colorado border.

Figure: 2, Cross Section (diagram) of San Juan Basin
The northern and western edges of the Basin are formed by a structure known as “the Hogback Monocline”. Along the Monocline, Cretaceous and Tertiary age depositional horizons dip steeply into the Basin, and all of these sedimentary units are either exposed at the surface or sub-crop beneath a thin layer of alluvium-colluvium or moraine deposits. Within the stratigraphic section of the Basin lie three distinct Cretaceous Age fluvial-lacustrine-marine sequences of sediments averaging 5,000 feet in thickness. Cretaceous Age rocks had been the focus/target of conventional oil and gas exploration and development in the basin. The stratigraphic horizons in the area include Dakota, Mancos Shale, Mesaverde Group (the Point Lookout, Menefee, and Cliff House Formations), Lewis Shale, Pictured Cliffs, Fruitland and Kirtland (Sandstone Member).

![Figure: 3, Stratigraphic sequence in SJB area](image)

**Historical perspective: Oil and Natural Gas Development in San Juan Basin**

The actual commercial development of conventional natural gas in SJB had come in several waves, starting in the 1920s from the shallower Kirkland formation, to deeper and deeper zones, to the Mesaverde and Dakota formations. Thousands of conventional gas wells were drilled, continuing through the 1970s and into the 1980s. In the early stages of natural gas exploration in the basin, the coal beds were penetrated in search of conventional gas reservoirs that lay deeper bypassing coal beds. Coal beds are found locally in the Fruitland and Menefee formation, which have generated their own hydrocarbons and lack the production characteristics of conventional reservoirs.
These coal beds initially were not considered to be a significant and economically viable source of natural gas. Several wells completed in the lower Fruitland Formation in the northern New Mexico part of the basin showed anomalous production characteristics: they produced large volume of water; and gas production gradually increased, leveled off, and then produced at a constant rate for more than 30 years. These wells were either inadequately cemented or were not cemented to the surface. In addition, some wells were completed as open holes. As a result, there were scattered conventional wells (gas) that produce commingled gas form the conventional reservoirs and coal bed, causing this anomalous characteristic. Although coal beds played a significant role in the history of oil and gas development in the SJB, the problems associated with coal gas (high startup and extraction cost of pumping, storage, disposal of produced water, and corrosion potential due to CO$_2$) and a lack of sufficient historical data to establish production trends made the Fruitland coal seam gas uneconomical and a high-risk proposition for businesses.

It is difficult to pinpoint exactly when the coal bed methane production in the basin began. Some suggests that the first coal bed methane well in the SJB was drilled by Amoco (Pan American Petroleum/Stanolind) in 1951 at Ignacio Blanco-Fruitland field in Colorado. The famous CBM well (San Juan 32 – 7 # 6-17) was completed in the lower Fruitland formation and was drilled by Phillips Petroleum Company in 1953. This well is cited in the literature as one that had been producing for more than 40 years with minimal decline in reservoir pressure. Its gas production gradually increased, leveled off, and then produced at a constant rate for an extended period of time. However, for a long time it was not realized that this well was producing gas from coal bed / seam.

Perhaps, the modern era of CBM exploration and development had started in 1977 when Amoco Production Company drilled Cedar Hill Field discovery well (Cohan gas com # 1) in the Fruitland coal beds that produced CBM. Amoco was possibly the first company in the US that intentionally tried to
Coalbed methane (CBM) is simply methane found in coal beds/seams. Coalbed methane contains very little heavier hydrocarbons such as propane or butane or gas condensate; thus it is sold and used the same way as conventional natural gas. Its production mechanism and behavior, however, are different from conventional natural gas. The presence of this gas in coal is well known from its occurrence in underground coal mines.

**Coal Mine Methane (CMM)**

This is defined as the methane component of gases liberated from coal seams during the mining process in working mines and/or abandoned mines or trapped in coal seams that are expected to be mined. CMM can be recovered from underground mines before, during, or after mining operations. The table below shows various categories of CBM and the methane concentration in each. The characteristics of each of these categories of resources differ in terms of production technology and gas composition. Exploitation of each type of CBM resource has its advantages and disadvantages as well.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Methane Concentration (%)</th>
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<tbody>
<tr>
<td>Virgin Coal Bed Methane (VCBM) or CBM</td>
<td>&gt; 95</td>
</tr>
<tr>
<td>Coal Mine Methane (CMM)</td>
<td>35 – 75</td>
</tr>
<tr>
<td>Abandoned Mine Methane (AMM)</td>
<td>35 – 90</td>
</tr>
<tr>
<td>Ventilation (Mine) Air Methane (VAM)</td>
<td>0.05 - .8</td>
</tr>
</tbody>
</table>
Coal Bed Methane

Significant volumes of methane can be extracted from coal seams that cannot be mined because they are either too deep or thin, of poor or inconsistent quality, or represent difficult mining conditions. This is referred to as Coalbed methane (CBM) or virgin coalbed methane (VCBM). For all practical purposes there is no difference between CMM and CBM. However, a distinction is often made between CMM and CBM, because some government jurisdictions and multilateral agencies recognize CMM as being more environmental friendly than CBM, on the premise that CMM will inevitably be leaked into the atmosphere when the coal is mined (if the gas is not recovered first). Methane is a “Green House Gas”.

ORIGIN OF COALBED METHANE (CBM)

Almost all coal beds contain methane. Organic (plants biomass – both land and aquatic) debris accumulates as sediments on the surface of the Earth including ancient swamps and bogs where it is preserved rapidly enough to prevent decay and get compressed and converted to coal. This material is first converted to peat as the majority of the water is expelled. As the Earth’s crust subsides, and more sediment is piled on top of the organic material, it sinks deeper and deeper into the sedimentary layers. With increasing burial depth, the temperature and pressure rises over geological time, and the material is progressively converted to coal. With the continued burial, ranks of coal start to form, from peat to lignite, to sub-bituminous, bituminous and finally anthracite. Low-rank peat and lignite have high porosities and high water content, and the methane is the result of biogenic process. The gas in higher-rank coals is a result of thermogenic process. Biogenic methane formation decreases, because temperatures rise above the most favorable range for bacteria. As coal matures into bituminous types, more water is expelled, porosity decreases and the heat breaks down complex organic compounds to release methane and heavier hydrocarbons (ethane and higher). Inorganic gases may also be generated by the thermal breakdown of coals. As the coal matures to anthracite, less methane is generated and little porosity or water remains in the matrix.

Figure: 5, Diagram showing “coal maturation” characteristics
The "coalification" process can stop at any time, depending on geologic conditions, leaving what we see today as varying ranks of coal. Much of the coal bed gas generated escapes to the surface or migrates into an adjacent reservoir or other rocks, but a proportion of the methane produced is trapped within the coal itself, primarily adsorbed in the coal matrix.

GLOBAL POTENTIAL OF COALBED METHANE

Coal deposits are the most abundant and widely distributed fossil fuel in the world. A vast amount of methane is associated with global coal deposits. Until recently (25-30 years?) it was considered a mine safety hazard and a source of nuisance in the coal mining industry. However, in the last 20-25 years methane from coal beds has been harnessed as a source of energy. CBM has become an important component of the U.S. natural gas portfolio, contributing more than 10% of the nation’s natural gas production in 2006. This has caused many other nations to enthusiastically expand and focus their efforts upon CBM development (exploration and exploitation) aiming to capture this gas from un-mined coal beds as well as mining operation, and harness the energy resources and limit "Green House Gas" (GHG) emission.

In other words, coalbed methane has become a darling source of energy in many countries including Australia, Canada, France, Germany, India, Poland, the Czech Republic, the U.K., the U.S., and many others. For example, the government of India has taken several steps to encourage and accelerate exploration and exploitation of CBM. This effort appears to be paying off. Indian authorities have auctioned off 26 blocks (in three rounds) for CBM exploration and development. In 2006 (the third round of auction), ten blocks attracted 54 bids. The first two rounds together attracted 30 bids. On July 16, 2007, GEECL announced the first commercial sale of CBM in India, making India one of eight countries in the world to produce CBM commercially. Reliance Group is expected to join this group by the end of 2007, and ONGC following suit in 2008.

World wide CBM resource (in-situ reserve) is variously estimated between 6,000 Tcf and 24,000 Tcf. Rough estimates of large potential CBM in-situ reserves include:

<table>
<thead>
<tr>
<th>Country</th>
<th>Reserve Range</th>
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<tbody>
<tr>
<td>FSU</td>
<td>4,000 Tcf to 16,000 Tcf</td>
</tr>
<tr>
<td>U.S.A</td>
<td>700 Tcf to 1,000 Tcf</td>
</tr>
<tr>
<td>Peoples Republic of China</td>
<td>600 Tcf to 3,300 TCF</td>
</tr>
<tr>
<td>Australia</td>
<td>220 Tcf to 300 Tcf</td>
</tr>
<tr>
<td>Canada</td>
<td>300 Tcf to 600 Tcf</td>
</tr>
<tr>
<td>India</td>
<td>50 Tcf to 280 Tcf</td>
</tr>
</tbody>
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These estimates may not be very accurate because: (1) in many countries coal resource estimates are based only upon mine-able coal and ignore deeper resources; (2) there is absence of or limited data pertaining to coal resources in many countries, including gas content data; and; (3) variable depth limits are set on coal resource assessments among countries. Technically, recoverable reserves are much lower. In the US, for example, various numbers have been tossed around, with one estimate of 243 Tcf
from five western US basins. However, the US Department of Energy (DOE) has adopted a 100 Tcf figure in its discussions. Furthermore, the US Geological Survey last November issued a "mean case" estimate of technically recoverable US CBM reserves of 67 Tcf (World oil –August 2006).

The U.S. does not top the list of the countries with coal bed methane resources; however, it is the most advanced in terms of CBM development and production technology, followed by Australia. In 2006, the US CBM production was a little over 2 TCF. Only the USA exploits significant quantities of this resource so far. However, considerable efforts are underway internationally for exploring and testing virgin CBM wells. In the U.K and most other European countries, the potential of CBM (excluding CMM) development is limited with current technology due to low coal seam permeability. However, coal-mine methane from abandoned (closed) mines have been exploited in many European countries using conventional mine gas drainage equipment. France, Czech Republic, Germany, the U.K. and the U.S.A, all have successful projects that produce methane from abandoned coal mines. It is believed that coalbed gas recovery schemes at working and abandoned coal mines can generally be implemented at lower cost, and are less dependent on natural coal seam permeability than CBM projects.

**RESERVOIR ENGINEERING FUNDAMENTALS OF COAL BED METHANE**

A good understanding of CBM reservoir characteristic helps to explain its producing behavior. There are many similarities between CBM reservoirs and conventional natural gas reservoirs. However, there are also significant differences. Four important areas of CBM reservoir characteristics help explain CBM production behavior: (i) the structure of coal beds, (ii) the gas storage mechanism, and (iii) gas transportation mechanism, and (iv) the permeability. Coal is a source rock and a reservoir rock. The depositional environment and burial history of the coal affect the composition of the gas as well as the gas content, diffusivity, permeability, and gas storage capacity of the coal.

**Structure of coal (porosity)**

Generally speaking, CBM reservoirs are made up of blocks consists of matrix and pores (micro-pores), separated by networks of natural fractures (micro-porosity) and therefore characterized by duel porosity system i.e. micro-porosity and macro-porosity. The naturally occurring fractures are small, regularly spaced (perhaps several per inch), and are referred to as the "cleat system". The micro-pore system consists of pores within the coal matrix ("macerals" or "coal substance") itself, stores bulk of the gas, and has negligible permeability. The macro-pores represent the cleats (fracture network) within the coal bed. The cleats consist of “face Cleats” and “butt Cleats”. The face cleats are continuous and account for the majority of the coal bed's permeability. Butt cleats are generally orthogonal to the face cleats and are not continuous. Face and butt cleats are interspersed throughout the coal matrix and form a system of fracture network within the coal bed. The fracture network provides conductive capacity for gas production due to its large permeability but has very little storage capacity. Porosity of coal may range
from less than 0.1% to 10%. Typically the fractures porosity (cleat space) of coal is about 1% of the coal volume. The porosity of higher rank coal is lower (< 5%).

Figure 6, Photograph (above) of a coal sample showing fractures and cleat system and schematic diagram (below) of physical structure of coal.

Bibliography


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(To be continued in part 2)