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Coalbed Methane Resources of India: Present Scenario of Exploration and Future Prospects- A Review

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Abstract: The demand for unconventional energy resources have been increasing day by day because of the depletion of conventional energy resources. India has been blessed with huge reserves of coal deposits distributed over various states of the country. The government put effort on searching for the alternative sources of energy and thus an intense importance is given for the search of unconventional resources of energy like Coalbed Methane, Shale Gas, Gas Hydrates etc. Out of these unconventional resources, Coalbed Methane plays a vital role in replacing conventional energy resources like natural gas. Coalbed Methane resources of India have been studied and the information and data generated on various aspects Coalbed Methane resources have been reviewed in this paper. The geology of the coalbed methane genesis, factors controlling CBM genesis, types of CBM genesis have been explained. The established coalbed methane deposits of India in different coalfields have been described and their resource position have been documented. With respect to technology developed towards the production of coalbed methane like vertical well construction, hydraulic fracturing, surface horizontal drilling and other related aspects are reviewed. An attempt is made to review the economic feasibility of CBM production at this moment are presented. Emphasis on given present data pertaining to possible environmental implications during exploitation of coalbed methane in general.

Keywords: Coalbed methane, coalification, thermogenic and biogenic origin, hydraulic fracturing, economic aspects, environmental implications.

I. INTRODUCTION

The demand for conventional energy resources is rapidly increasing day by day which is leading for the depletion of these resources in the country.

The depletion of these resources made India to search for alternative sources of energy say unconventional resources. Intense importance is given for the search of unconventional resources of energy like Coalbed Methane, Shale Gas, Gas Hydrates.

Out of these unconventional resources, coalbed methane is considered to be the most viable and challenging resource of energy. Coalbed Methane can definitely be the alternative supplementary energy source for the present and future generations.

As our government is looking for the alternate source of energy these unconventional resource made it more challenging among the world's leading producers.

The demand for CBM is very high all over the world specially in the countries like Soviet Union, Canada, China, Australia, United States. As the fifth largest coal producer in the world, India had good prospects for commercial production of CBM and thus holds significant prospects for exploration and exploitation. Coal gas is considered as a valuable resource of energy with reserves and production having grown nearly every year since 1989.

All the current CBM producing blocks occur in the Gondwana sediments of eastern India which host the bulk coal reserves of India. The majority of the best prospective areas for CBM development are situated in Damodar Koel valley and Son valley.

CBM projects exist in south, east and north areas of Raniganj coalfield, the Parbatpur block in Jharia coalfield and the East and west Bokaro coalfields, and north, east and west blocks of Son valley. Presently, commercial production has commenced from Raniganj South CBM block operated by M/s. GEECL since July 2007.

In this paper, we discuss about the geology, present prospects and future prospects of coalbed methane reserves with special emphasis on Indian deposits.

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II. GEOLOGY OF COALBED METHANE

A. Definition and Formation

Coalbed Methane is an unconventional form of natural gas found in coal deposits or coal seams. The term CBM refers to methane adsorbed into the solid matrix of the coal. It is also called as 'sweet gas' due to its lack of hydrogen sulfide. Coalbed Methane is rich in methane (88-98%) emanates from coal due to change of in-situ pressure conditions. Coalbed Methane is formed during the process of coalification, the transformation of plant material into coal. Coalbed Methane is technically defined as an a natural gas recovered from coal seams. Due to its large internal surface area, coal can store large volumes of methane.

Most coalbed methane has been produced in situ by microbial, thermal, or possibly catalytic degradation of organic material present in coal, much of the coal containing CBM lies at shallow depths making wells east to drill at low cost. With increased pressure at greater depths, the coal fractures are closed which leads to low permeability and enables the coal gas to be sealed within. This way the methane gas is closely packed within the coal deposit. CBM is mainly composed of methane (CH_4) with variable additions of carbon dioxide (CO_2), elemental nitrogen (N_2), and heavier hydrocarbons, such as ethane (C_2H_6), and traces of propane (C_3H_8), and butanes (C_4H_{10}).

B. Origin

Coalbed Methane is generated during the process of Coalification. Coalification is the process of transformation of vegetal matter into coal that is from peat to anthracite (Fig. 1). The thick vegetal matter was buried in sedimentary basins over a period of time with increasing over-burden and were compressed by the weight of the sedimentary layers. Eventually, the biochemical and thermal alteration of these plant materials begins with formation of the peat and ending up with anthracite through lignite, sub-bituminous and bituminous coals due to geothermal gradient and increased pressure with increasing burial depth. This results in the reduction conditions that is the oxygen levels are decreased due to loss of water resulting in increased carbon percentage.

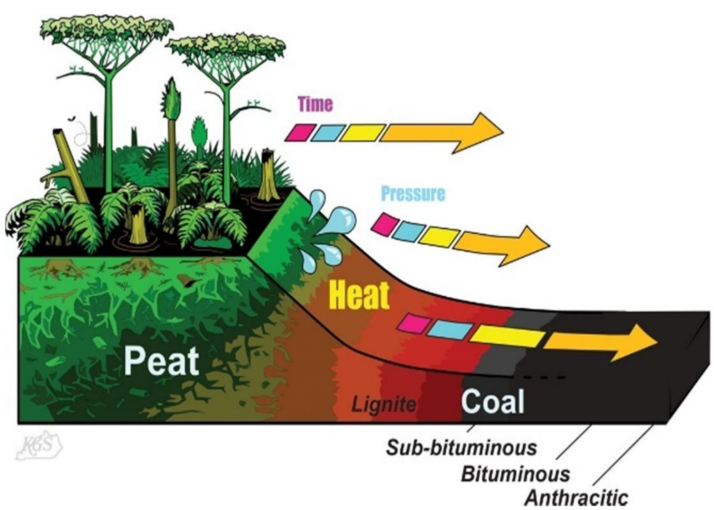

Fig. 1 Coalification
Source: http://www.uky.edu/KGS/coal/coal-form.php

Initially the peat is converted into lignite which is also called as “brown coal”. With the continuing effects of temperature and pressure transforms lignite into matured coal what is known as “sub-bituminous” coals. Further chemical and physical changes make these coals become much harder and blacker, forming “bituminous” or “hard coals”. The progression in the organic maturity can be continued under necessary conditions, finally forming “anthracite.”

Various theories have been proposed to explain the physical and chemical changes during coalification. Coalbed methane is assumed to be either of biogenic or thermogenic (Fig. 2). Biogenic coalbed gas is generated by the breakdown of organic coal matter by microorganisms at low temperature (usually less than 56°C). Biogenic CBM is contained in many shallow and thermally immature coal seams. Thermogenic gas is produced from coal organic matter by chemical degradation and thermal cracking mainly above 100°C where microbial methane generating activity becomes biochemically weak. Thermogenic gas is generated at the high-volatile bituminous coal. The higher rank coal is expected to have generated more thermogenic CBM than relatively lower rank coal, which would translate into a higher CBM content if the gas has not been lost.

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1) Biogenic Origin: Biogenic coalbed gas is a product of microbial origin formed at low temperatures during the decomposition of organic matter in peat and coal. Micro-organisms generate primary biogenic gas[1] during the earliest burial of organic matter ranking from peat to sub-bituminous coal[2]. The resulting methane is commonly produced as bubbles in the form of "swamp gas". Owing to this shallow burial, primary biogenic gas cannot be accumulated in economic deposits, except in cold regions where it may be solidified as methane hydrates (clathrates) in permafrost[3].

Microbially generated methane gas can be accumulated in sediments only after moderately deep burial of organic matter tightly sealed byan overlying seal. In most of the cases, the coal had intermittently been buried to depths where the geothermal gradient caused heat sterilization of coal. Subsequent upliftment may cause cooling and may have allowed reintroduction of coal seams with methanogenic microbial associations via introduction of meteoric waters into permeable coalbeds. The newly generated Coalbed methane is called secondary biogenic gas.

Biogenic methane can be generated either by fermentation of methyl or by carbon dioxide reduction. Biogenically derived gas in coalbeds is predominantly composed of methane and contains only traces of C_2+ hydrocarbons (i.e., dry gas). The CO_2 content is usually <5 vol%.

2) Thermogenic Origin: Thermogenic coalbed gases are generated at higher temperatures during coalification. The process of coalification encompasses physical and chemical changes that occur in coal shortly after deposition and continue during the thermal maturation. During coalification, the carbon in residual solid organic matter becomes more aromatic while the hydrogen-rich aliphatic components (e.g., CH_4, C_2H_6) are liberated and expelled along with water and carbon dioxide during the generation of coalbed gases[4].

In general, the formation of thermogenic gas can be divided into two stages, namely, an early stage and a main stage. Early thermogenic gases are produced from hydrogen-rich high-volatile coals and are commonly characterized by substantial amounts of ethane, propane, and other wet gas components.

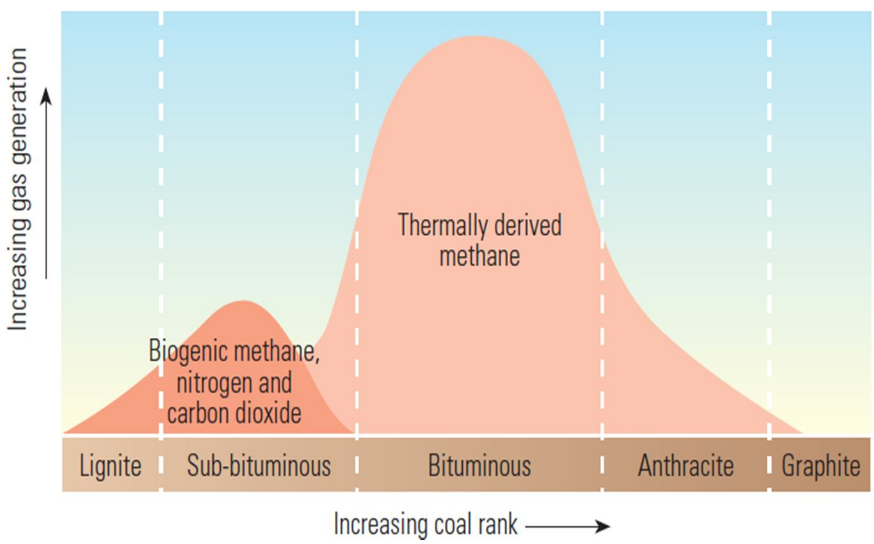

Fig.2 Thermogenic and Biogenic origin of Coalbed methane
Source: https://www.researchgate.net

III. COALBED METHANE DEPOSITS IN INDIA

Government of India has explored eight blocks of coal seams that produce CBM in the states of Jharkhand, Madhya Pradesh and West Bengal for exploitation and production. Five contracts were signed, two each in the States of Jharkhand an MP and one in West Bengal in July 2002. Methane is contained in all types of coal seams or coal beds.

There are some promising CBM reservoirs in many coal mining with good geological settings lead a way for growth of CBM industry. Presence of methane within the coal horizons of Raniganj, Jharia and East Bokaro coalfields was known almost since the inception of mining activities in these coalfields.

India having 17 coal fields with a total coal reserve of 200 billion tons, only three basins are viable reserves for CBM, namely Raniganj (West Bengal), Jharia (Jharkhand), and Singrauli (Madhya Pradesh). The reserves of these mines are good candidates for CBM production (Table 1).

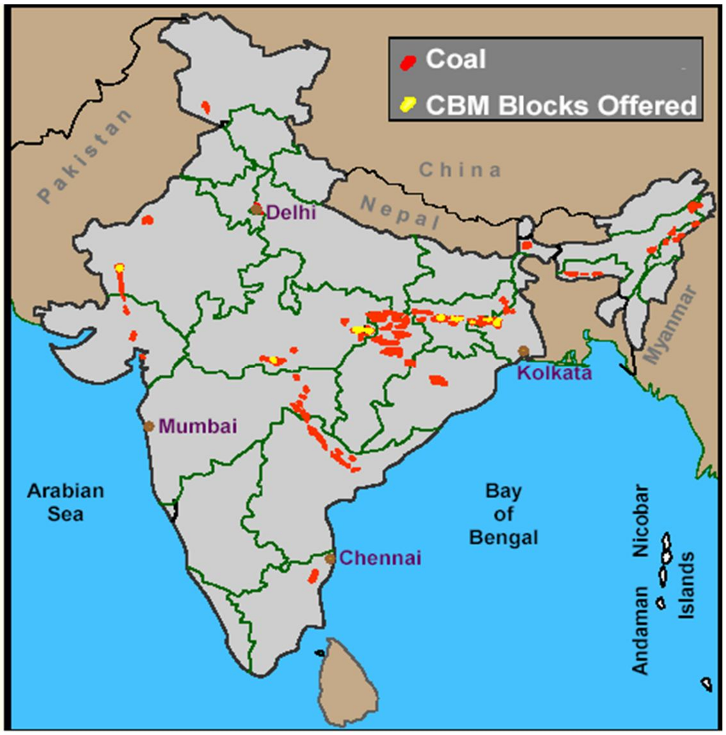

Fig.3 Map showing coal an CBM Blocks in India
Source: https://www.researchgate.net

So far, four blocks of coal covering an area of about 6000 mile^2 have been leased for CBM production. These are vertical wells completed in a single coal seam with the process of hydrofracturing. Coal seams are generally thin at greater depth. Some very thick seams (in Bihar and Odisha provinces) at shallow depths may turn out to be good producers (like the Powder River basin of the United States) but attempts to produce CBM have not yet been made.

Table. I Prognosticated Resource of CBM

Sl. No	State	Coalfield/Block	Area of delineated block (Sq.KM)	Prognosticated CBM Resource as per DGH	
				In trillion cubic feet	In trillion cubic feet
1	West Bengal	North Raniganj	232	1.030	29.17
		East Raniganj	500	1.850	52.38
		Birbhum	250	1.000	28.32
Sub Total			982	3.88	109.87
2.	Jharkhand	Jharia	69.20	2.407	68.16
		Bokaro	93.37	1.590	45.02
		North Karanpura	340.54	2.181	61.75
Sub Total			503.11	6.178	174.93
3	Madhya Pradesh	Sohagpur	495	3.030	85.79
		Satpura	500	1.000	28.32
Sub Total			1495	4.03	114.11
4.	Gujarat	Cambay Basin	2400-3218*	11* to 19.4	311*- 549.39
Grand Total			2980.11 – 3798.11	710.39-948.73	710.39-948.73

Source: www.coalindia.com

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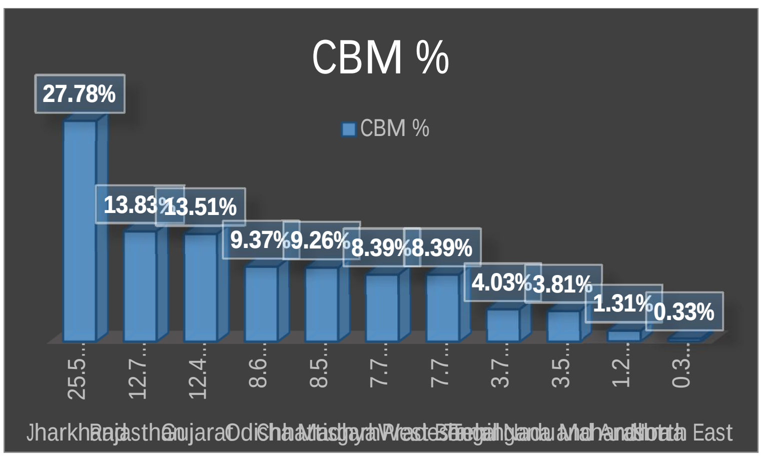
IV. RESOURCE POSITION

India is potentially rich in Coalbed Methane resources in almost every coal reserves. The major coal fields and CBM blocks in India are shown in Graph. 1. The Directorate General of Hydrocarbons of India estimates that deposits in major coal fields (in twelve states of India covering an area of 35,400 km^2) contain approximately 4.6 TCM of CBM. The quantity of Coal Bed Methane (CBM) resources in India was 91.8 trillion cubic feet as on May, 2016 (Table 2).

TABLE II CBM Resources in India, May 2016

State	Quantity (cubic ft.)	CBM %
Jharkhand	25.5 trillion	27.78%
Rajasthan	12.7 trillion	13.83%
Gujarat	12.4 trillion	13.51%
Odisha	8.6 trillion	9.37%
Chhattisgarh	8.5 trillion	9.26%
Madhya Pradesh	7.7 trillion	8.39%
West Bengal	7.7 trillion	8.39%
Tamil Nadu	3.7 trillion	4.03%
Andhra Pradesh and Telangana	3.5 trillion	3.81%
Maharashtra	1.2 trillion	1.31%
North East	0.3 trillion	0.33%

Source: DGHIndia



Graph.1 CBM reserves as on May 2016

V. TECHNOLOGY USED IN CBM PRODUCTION

Coalbed Methane is produced by removing water pressure which holds CBM in place. Methane that is stored in place by water pressure tends to move along with the water as it is pumped to the surface, where it is captured and transported through pipelines. Fracturing fluids are often first injected into the coal to break up the coal, making it easier for the water and gas to flow on the surface. The following techniques are used in the production mechanism of CBM.

A. Vertical Well Construction

Coalbed methane(CBM) wells are like the conventional oil and gas wells in the well construction system. Firstly, freshwater zones are drilled through and cased off. Then the production casing is predominantly set through all the coal seams with additional rathole provided to pump water from the lowest seam efficiently. An additional casing string may be needed to case off mine voids encountered below surface casing and prior to drilling the active coal seams with production casing sizes 4.5 or 5.5 inches in outer diameter whereas larger sizes might be needed in highly permeable seams.

1) *Well Construction:* Vertical well drilling can be done with small footprint air rigs which can access locations in the steep terrains. A small cutting pits are required to capture returned solids and formation fluids carried back by the air stream (Fig. 4).

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Bentonite mud systems mixed with freshwater provide fluid loss and hydrostatic control. Mu system is used for hole stability in soft unconsolidated formations.

Initially, the hole size is determined by the amount of fluid that can be produced which allows the different casing strings to be landed and cemented in place. These holes are drilled using a rotary rig that uses air hammer bits or fluid hammer bits and the typical tricone rotary bit.

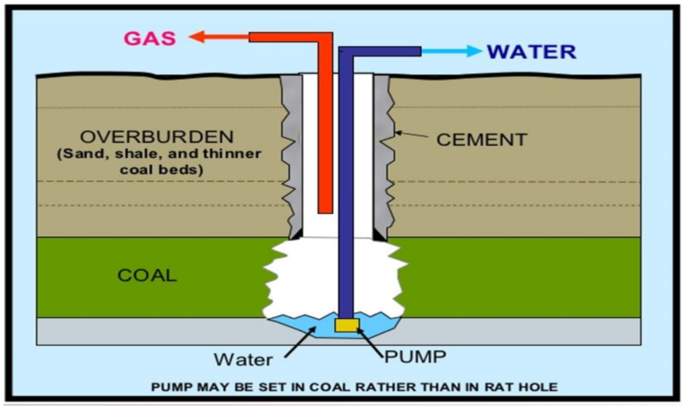

Fig.4 Schematic of CBM Well
Source: slideshare.net

Air is the preferred drilling fluid for CBM which is environmentally safe. Then the casing designs are started by considering fluid volumes of the expected production and work back out of the hole followed by surface casing and mine casing. After completion of these, production casing is designed to withstand fracturing stimulation treatment pressures and large enough to allow production of water and gas. Now, the casing is cemented to provide pipe support, zonal isolation, and well control. CBM wells are similar to conventional wells in the process of cementing; however, the cement blends used must control fluid loss and maintain circulation to prevent damage to the cleat system. The final stage is completion processes which are similar to oil and gas well completions with some procedure changes required to protect the cleat system that occurs naturally in all coals. This system provides the permeability and porosity characteristic of the coal seam where free gas and water are stored.

B. Hydraulic Fracturing

This is the most important process used in CBM production. It is used after the drilled hole is completed. It is simply the use of fluid and material to create and restore small fractures in a formation and placing proppant (solid material typically sand) into the fracture (Fig. 5).

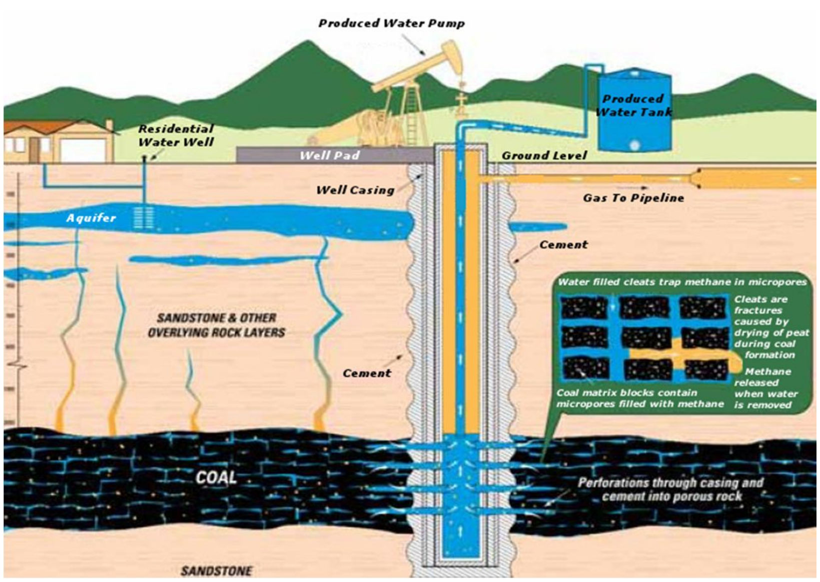

Fig. 5 Hydraulic fracturing and extraction of CBM
Source: http://frack-off.org.uk

Fracturing is different from drilling, casing and cementing operations. A cemented steel casing string used as insolation for an effective hydraulic fracturing. The cemented casing string also provides a seal to prevent movement of fluids within the well or outside of the casing. Holes are introduced that penetrate the casing, cement and a short distance into the coal to produce the water and gas from the coal seam. A high pressure water and sand slurry is directed at the casing to cut a hole or slot through the casing and into the coal. Hydraulic fracturing is then done by installing a plug inside the casing that presses against the casing to hold itself in place.

The Average treatment might be approximately 250,000 litres in volume. The pressures of injection depend on the depth of the interval being fractured and typically range from 10 MPa to 40 MPa. The volume injected and the pressure response observed are dependent on site details and the stimulation design.

C. Surface Horizontal Drilling

In-mine horizontal methane drainage boreholes have been proven very effective in reducing methane emissions to safe levels in advance of mining (Fig 6). In-mine boreholes are primarily drilled to shield methane emissions during long wall development, or to degasify the long wall panel. Their productive life is short, usually less than 2 years before mine through. Lastly, drilling in-mine horizontal boreholes and maintaining their wellheads and the underground gas transmission pipelines connected to vertical boreholes used to safely transmit the gas produced to the surface, require routine maintenance and integration with already difficult mining operations.

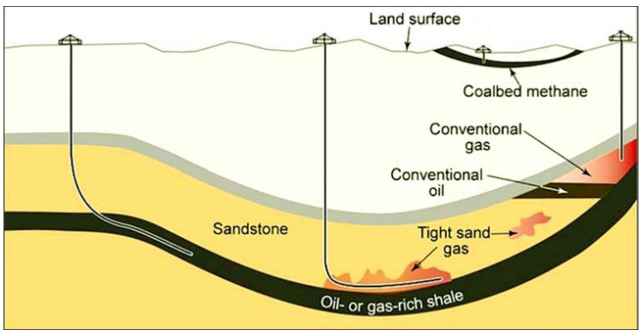

Fig. 6 Surface Horizontal Drilling of CBM
Source: https://worldhdd.com

Surface drilled horizontal CBM wells have been proven effective in coalbed methane degasification in advance of mining. Earlier in the oil and gas industries, and later the coalbed methane (CBM) and coal mine methane industries, surface horizontal, directional drilling was recognized as a way of combining the best elements of vertical well and horizontal in-mine drilling. Drilling from the surface is safer than from in-mine, does not hinder mining operations and can be carried out years in advance of mining to maximize degasification effectiveness and economic viability.

VI. ECONOMIC ASPECTS

The commercial success of any gas project depends on a number of critical factors including gas production rates, capital requirements, operating costs, gas markets, and economies of scale. Economic analyses of coalbed methane (CBM) projects allow management teams to make informed decisions regarding financial investments, development, and operations of such projects. The reserve classifications for CBM wells are classified as below.

1) Proved reserves are defined as a “amount of energy sources estimated with reasonable certainty used for recovery in the future from the known reservoirs under existing operating and economic conditions.
2) Producing reserves are defined as the reserves that can be recovered using current technology an existing economic conditions from that portion of a reservoir which can be reasonably evaluated.
3) Nonproducing reserves include shut-in and behind pipe reserves.
4) Shut-in reserves are expected to be recovered from completion intervals open at the time of the estimation; from wells which were shut-in market conditions or pipeline connections or from wells not capable of production for mechanical reasons.
5) Undeveloped reserves are expected to be recovered from new wells on undrilled acreage or from deepening existing wells to a different reservoir.
6) Probable reserves are defined as the reserves that have decreased level of certainty in being recovered.

7) Possible reserves are less certain than probable reserves and can be estimated with a low degree of certainty.

Once the reserves are proven, the development of one or more project maps is a common and important first step in the economic analysis. Next the geologic assessment of CBM fields is accomplished by several means. Analyses of coal cores and geophysical logs obtained on or near the property can provide such information as coal thickness, coal density, and gas content. Interpretation is generally enhanced by mapping these data across the project area, as has been done for total coal thickness.

A. Methods of Evaluation

The data collected are used to conduct a volumetric analysis to determine gas-in-place for the project area or individual well-spacing units according to the following formula.

$$\text{GIP} = Ah\rho G_c$$

where GIP=gas-in-place, standard cubic feet
A=area, acres
h=coal seam thickness, ft.
ρ=coal density, tons per acre-foot
G_c=coal seam gas content, cubic feet per ton

Geologic mapping of coal-seam structure based on coal core and geophysical log data provides an indication of where the higher coal permeability occurs. Permeability information considered together with the calculated gas-in-place enables geologists and engineers to make informed initial estimates of (1) CBM recovery factors (recoverable fraction of the initial gas-in-place), (2) optimum well spacing (acres per well), and (3) project-area economic development potential. Further, the future production is evaluated using the historical production data which are used to perform the decline curve analysis.

B. Evaluation Model of economic aspects

The economic model utilized to evaluate a CBM project incorporates the (1) gas-in-place derived from the geologic assessment, (2) forecasts of future gas production from existing and/or scheduled future wells, (3) schedule of future drilling and development, and (4) known or assumed economic parameters. Economic parameters, which must be known or reasonably assumed in the economic model, are as follows:

1) *Working Interest*: It is the percentage ownership in each well and, accordingly, the percentage of capital and operating costs which must be paid by an owner, which may also include the project operator.
2) *Net Revenue Interest*: It is the percentage of total gas sales revenues that will be received by the specific owner.
3) *Gas Shrinkage*: It is the expected percentage reduction of the produced gas volumes due to compressor and gas processing fuel, third-party pipeline retainage, and other losses.
4) *Energy-Content Adjustment*: It is the factor applied to convert from the produced volumetric gas volume, typically in thousands of cubic feet (Mcf), to an energy-content amount.
5) *Gas Sales Price*: It is the forecasted future gas prices.
6) *Capital Costs*: These are the costs to drill, complete, and connect new wells to pipeline sales, and for installation of pipelines, gas compression, saltwater disposal, and other facilities costs.
7) *Operating Expenses*: these are the per-well or per-volume-unit cost to operate CBM wells and other infrastructure.
8) *Production Taxes*: It is the severance and added-value taxes imposed by states, counties, and other jurisdictions, usually on a gas-volume basis.
9) *Escalation Rates*: It is the assumed annual escalation percentages commonly applied to gas sales prices, capital costs, and operating costs.
10) *Discount Rate*: It is the annual rate at which future net revenues are discounted to determine their present value.
11) *Effective Date*: It is the date to which cash flows are discounted, usually near the date of the evaluation.

The final stage in the economic aspects is economic output that is the gross production of the wells is reduced by royalties and gas shrinkage to determine the net production, which is then multiplied by the gas sales price to determine net revenue.

VII. ENVIRONMENTAL IMPLICATIONS

Coalbed Methane is extracted from coal beds through drilling of wells, as large amounts of water must be pumped from the coal bed area in order to reduce the pressure in bed. On dewatering, the methane is can be escaped from the coal and flows into the well itself. The reserve classifications for CBM wells are the same for other types of oil and natural gas wells.

Water treatment is an important issue for many miners in the CBM industry. The groundwater becomes polluted, cloudy and drastic decrease in content on dewatering. As the quality of water is low, that is the water typically has high salinity level, therefore it cannot be disposed of or used in irrigation or for human consumption. Several methods are used to dispose of the well water; the most common is to return the water into the subsurface rock formations. Dewatering from the rock make the pore spaces left open and tends the rock to collapse. This is known as compaction or subsidence. There is also a high possibility of spontaneous combustion of dewatered coal beds due to the reaction of the coal with atmosphere.

Methane migration is another process formed by CBM wells that occurs when the methane leaks into populated areas and contaminates water. Some believe that the extraction of coalbed methane gas from coal mine operations along with the additional well development amplifies the migration.

As methane is a greenhouse gas, it is believed to be the most important of all agents that contribute global warming. Limiting the amount of methane to release into the atmosphere is beneficial for the environment.

VIII. CONCLUSIONS

In India, multiple gas seam existence accounts for 91.8 Trillion Cubic feet as on May, 2016. Although India has 17 coal fields with a total coal reserve of 200 billion tons, only three basins are viable reserves for CBM, namely Raniganj (West Bengal), Jharia(Jharkhand), and Singrauli (Madhya Pradesh).

India with ~4.6 TCM of methane reserves in coal bed can enrich its per capita energy demand by successful exploitation of CBM. India, standing in fifth position with numerous CBM resources can become the alternative for conventional energy resources. The demand for Coalbed Methane can be the best alternative for depleting conventional energy resources.

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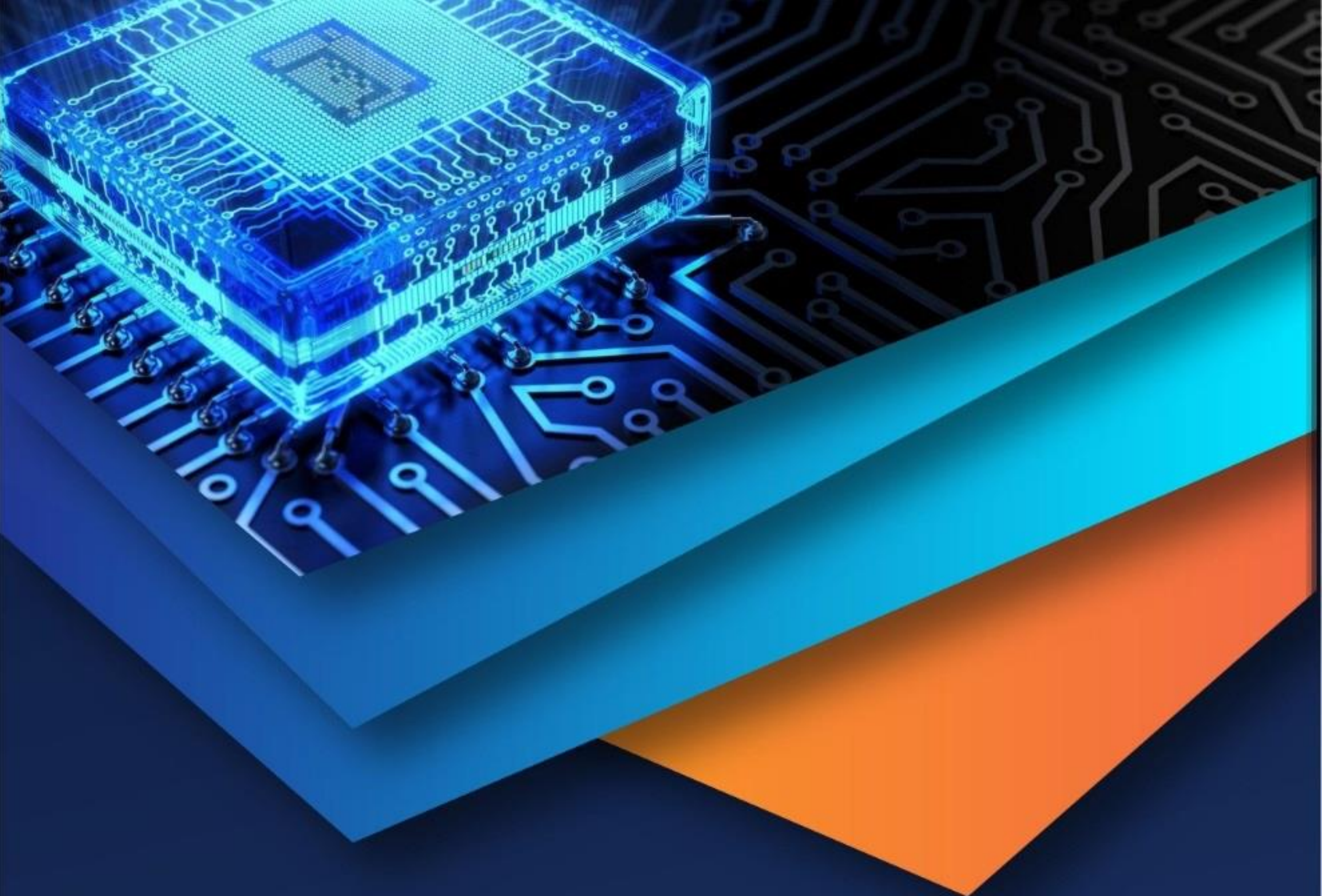

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