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Unconventional Shale Gas Prospects in Indian Sedimentary Basins

Geology

KEYWORDS : Unconventional energy resources, Shale gas, shale reservoirs.

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ABSTRACT

Natural gas is rapidly substituting fuel to suffice the growing energy requirement of today's world. The rising oil prices, high input cost in exploration and production of hard oil resources and relative abundance of gas resources have fuelled the interest towards gas resources. As the consumption of natural gas is increasing rapidly, it is essential to identify and develop the available energy resources. India has the immense prospects of unconventional shale gas resources. Commercial exploration of these shale gas resources can effectively make the global natural gas curve more elastic. The commercial shale gas exploration requires exhaustive investigations of all the shale rock properties of hydrocarbon bearing shale beds having significant organic matter and maturity. This paper presents overview of shale gas resources as well as the prospective shale gas horizons in Indian sedimentary basins.

Introduction

Natural gas plays the key role in increasing energy demand. Its environmental soundness and multiple applications across all sections imply that natural gas will continue to play an important role in meeting the energy demand. But the gap between natural gas demand and supply has been increasing day by day. To bridge the gap between energy demand and supply, it becomes essential to go for the available alternative energy resources in the country. This has spurred the interest towards unconventional resources i.e. Shale gas, Coal Bed Methane, Gas hydrates, tight gas etc. Shale gas is the future energy basket for the mankind which has tremendous prospect worldwide even in India (fig 1) only it requires systematic and proper methodology for its delineation, exploration and development. Particularly USA and Canada have been contributing commercial shale gas production which is 20% of total gas production. India have tremendous prospects of shale gas in different sedimentary basins i.e. Cambay, Assam Arakan, Krishna – Godavary, Gondwana, Cauvery, Vindhyan etc. though all shales are not evaluated yet. It requires exhaustive investigation of the prospectiveshale horizons having significant shale volume, organic matter (> 3%) and maturity (gas window zone). Source rock evaluation can be made by using parameters like Total organic carbon content, rock eval pyrolysis, elemental analysis, vitrinite reflectance, gas chromatography, etc. Petrophysical analysis using SEM, XRD etc can help in detail mineralogical as well as clay mineralogy studies. Seismic attributes help not only to differentiate the shale pay horizon but also to identify the brittle zone i.e. the sweet spots for hydro- fracturing. Integrated logs with geological, geophysical, petrophysical, geochemical, geomechanical studies can help to identify the sweet spots for commercial shale gas exploration and exploitation.

Unconventional Shale Gas System

Shale is the fine grain sedimentary rock exhibits a wide variety of different geological ages, geographical areas and formations (Potter 1980). Unlike the conventional petroleum reservoirs, shale reservoirs are continuous (Jarvie 2007), low porosity (< 10%), low permeability (< 1mD) with variation in composition (Herge M et al 2004;Utpalendu, 2013). The hydrocarbon generating capability of shale is controlled by many factors such as total organic carbon content, thermal maturity, sorbed gas fraction, reservoir thickness, volume of gas in place, mineralogy, water saturation, fracture types, reservoir heterogeneity etc (Curtis, 2002; Law 2002).The shale can produce either oil or gas or both. It depends mainly on (i) quality and quantity of organic matter, (ii) type of kerogen, (iii) magnitude and maturity i.e. duration of heating to which they have been subjected (Boyer et al 2008). Shale rock itself can act both as source and reservoir rock for hydrocarbons. This may be due to two reasons i. e. (i) due to lack of micro- fracture for primary migration of gas or (ii) insitu cracking of oil into gas at greater depth and post mature zone due to higher geothermal gradient. After organic matter converted into hydrocarbon, its volume increases and exerts pressure on the surface of the source rock and creates microfactures or pathways for oil or gas expulsion from source rock to reservoir. But in certain cases hydrocarbon cannot expel from the source rock to reservoir. Hydrocarbon inside the source rock remains adsorbed onto the matrix and gets converted into oil or gas depending upon the types of organic matter and the source rock can also act as reservoir itself. Kerogen is a mixture of organic chemical compounds which constitutes a portion of the organic matter in shale. Kerogen is insoluble in normal organic solvents because of its huge molecular weight (> 1,000 daltons) of component compound. With increasing depth and temperature gradient organic matter get matured and passes through the stages of oil window at 60–160 °C and gas window at 150–200 °C both depend on time of the source rock is heated. The labile kerogen breaks down to form heavy hydrocarbons (i.e. oils), refractory kerogen breaks down to form light hydrocarbons (i.e. gases). The insitu hydrocarbon gas present within the shale sedimentary rocks is called shale gas which may be in the state of free gas or adsorbed gas or both. Unlike the conventional oil and gas, shale gas does not accumulate in a typical petroleum system (i.e. source rock, reservoir rock, seal or cap rock etc). The shale gas systems can be defined as the continuous type biogenic, thermogenic and combined biogenic-thermogenic gas accumulations characterized by wide spread gas saturation, subtle trapping mechanisms with short hydrocarbon migration distances. In shale rocks, gas can be accumulated in three forms: Gas is stored on the shale as adsorbed gas, within the intergranular porosity as free gas, within the natural fracture system as free gas. Shale gas may vary from area to area even in the same basin.This is due to the local changes in permeability which is highly depends on the both fracture intensity and fracture aperture width. Shale gas is unconventional natural gas that can be produced at neither economic flow rates nor in economic volumes unless the well is stimulated by a large hydraulic fracture treatment, a horizontal well bore, or by using multilateral well bores or some other technique to expose more of the reservoir to the well bore (Kent Perry and John Lee, 2007).

Shale gas prospects in Indian Sedimentary Basins

The first commercial shale gas production (1821) was from organic rich Devonian shale of Appalachian Basin which was economically marginal. After the great economic success of the Barnett Shale play in Texas the interest had spread in search for other sources of shale gas across the United States, Canada, Europe, Asia and Australia.The U.S. Energy Information Administration projects that the U.S. will produce 50% of its natural gas from unconventional sources by 2030. In 2005, approximately 10 trillion cubic feet (tcf) of conventional gas was produced in the U.S., versus 8 tcf of unconventional gas. Natural gas from shale accounted for about 6% of the gas produced in the U.S. (1.1 tcf). The majority of U.S. gas shale production came from four basins i.e. San Juan Basin, New Mexico, Antrim Shale of Michiga, Appalachian/Ohio shales and Barnett Shale, Fort Worth Basin, Texas. In India ONGC has started pilot project and drill 4 shale gas wells in Damodar Valley Mainly Cambay (in Gujarat), Assam-Arakan (in the North-East), Krishna Godavari, Cauvery and Gondwana (in central India) are the shale gas prospective sedimentary basins in India. Besides these, there are many other sedimentary basins which are not studied for their shale gas potential (Madan Mohan 1995; Raju 1969, Ravi Mishra 2009; Rajeev Mohan 2006; S. S. Sharma et al 2010). Although US geological survey estimated the recoverable shale gas reserves is 63tcf, proper studies and development can enhanced the estimated results and the actual value may be much more greater than it.

Cambay shale Formation in Cambay Basin is organically rich with average 700m thickness. The kerogen type of the shale is both type II and III both oil and gas prone. The original generation potential is about 8 mg HC/g rock and calculated maturity value ranges from oil window to gas window (0.4- 1.7). The maturity level of Cambay shale is higher (>0.7) at the Tankari lows, depressions of Broach and Ahmedabad- Mehsana blocks. In the northern part of the basin, most of the places Olpad formation is within gas window with marginal source rock potential (Benarjee et al 2002; Biswas et al 2007). Although the shales have good TOC value and gas prone kerogen, the prospect of shale gas is expected at higher depth and higher maturity level i.e. within gas window zone (Choudhary L R 2004). Gas is expected to be generated within the rock from cracking of kerogen and petroleum retained in the shales and accumulated due to lack of migration pathways. Although the petrophysical analysis is not included in this study, it is one of the important factors as the earlier studies (Bowker et al 2007)are showing the most of the commercial production of shale gas from brittle shale.

Raniganj, south Karanpura, North Karanpura etc coal fields are promising shale gas fields in Damodar Valley Basin. Gondwana sediments in India comprise of clastics sediments of fluviatile and lacustrine origin. Age is Upper Carboniferous to Lower Cretaceous. Sediments deposits can be divided into three types i.e. glaciogenic sedimentation, continental fluviatile and marine deposits. Damodar Valley Basin is part of the "Gondwana" basins of India characterized by their mostly non-marine sedimentary fill and narrow graben structures. Although filled with mostly Late Permian to Triassic terrestrial sediment, there is a significant thickness the Barren measures, so called as it is barren of coal. Barren Measure Formation of Permian age is identified as the shale gas prospective horizon based on thickness (600m), higher content of organic matter (4-20%) and higher degree of thermal maturity (>7). Based on available data, the south- western part of the Raniganj coalfield is expected to be the most promising area for exploration as well as exploitation of shale gas (AshutoshMondal and ManasRoychoudhury, 2010). The sediment deposition of Barren measure formation is thick at the end of Barakar Formation. Sediments comprise of dark grey to black shale with ironstone bands/nodules. Barren Measure is best developed (1150m) in the western part of the Raniganj coalfield at the Surajnager area (Datta 2003). Barakar Formation also shows good organic content and higher maturity value than Barren Measure formation. In Krishna Godavary basin, the prospective formation is theKommugudem shale formation of (upto 900m thickness) Permian age. The basin is a Late Permian to Tertiary age basin in eastern India consisting of a series of horst and graben. The cyclothemic sequences of carbonaceous shale, coal and sandstone are deposited under fluvio-lacustrine environment. Shales are dark grey to black hard compact, silty and occasionally carbonaceous. The inter-bedded sandstones in coal-shale are dirty white, medium to coarse grained, feldspathic. Glauconite and pyrites are often found. Kaolinite dominating along with chlorite, smectite and illite. The increasing accommodation to sediment influx further enhanced for preservation of organic contents and the coal-shale developed within the sequence acts as a good gaseous source facies (Prabhakaran et al; 2004). The shale is having more than 2% TOC and kerogen type II & III.The Cretaceous-Cenozoic Cauvery basin in south eastern India is another basin with prospective shales. The formations of interest are the early Cretaceous Andimadam Formation and the Sattapadi shale its stratigraphic equivalents. The shales are interpreted to have been deposited in marine environments. The Sattapadi Shale contains 2 to 2.5 weight percent TOC and is thermally mature for hydrocarbon generation in deeper parts of the basin. Ro values vary from approximately 1.0 percent to as much as approximately 1.5 percent. Kerogen types are predominantly type III with minor amounts of type II.

Discussion

Sedimentological, petrophysical studies suggest presence of heterogeneousshale reservoirs in Indian sedimentary basins having good shale volume and organic matter content. Shales in different Basin even in the same formation within the same basin show heterogeneity. Based on composition of the shale rock a variety of shales are present i.e. high silica content shales, carbonaceous shales, clay rich shale, micaceous shales, calcareous shale etc.The reservoirs are tight to very tight with low total pore volume. Geologically complex and low permeability (<0.1 md) gas reservoirs and it requires special (integrated,non-conventional) evaluation and technology. Diagenetically formed reservoirs anticipating which will be new plays for HC accumulation and also provide lead to the shale gas exploration. Shale gas exploration and exploitation in India as a whole have remained in preliminary stage. It requires integrated research. Technology is the key to successful development of shale gas resources.

Conclusion

Commercial success of shale gas exploration in United States of America has spurred interest around the world in evaluation of shale reservoirs for shale gas exploration and exploitation. Although the shale rocks occupy a large portion of Indian sedimentary basins and are forming the main source of significant petroleum generation and production, they have not been studied in great detail. The geological, geochemical, geophysical and petrophysical parameters of Indian sedimentary basins have good correlation with most of the world's commercial shale gas producing shale horizons but it is challenging task to determine the sweet spot for the shale gas exploration. Because of heterogeneous nature of shale reservoirs understanding the shale behaviour is very critical. Both conventional and unconventional techniques of petroleum exploration are required to delineate and evaluate shale lithofacies, vertical and horizontal variation of facies, mineralogy, variation in depositional environment, rock-physics etc which can lead to commercial shale gas exploration in India.

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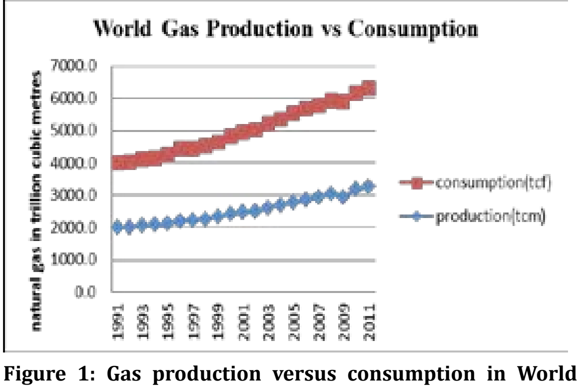

Figure 1: Gas production versus consumption in World (based on British petroleum energy statistical review, 2012)

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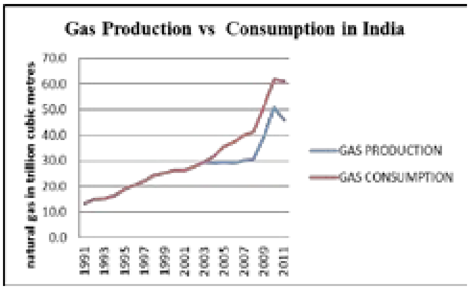

Figure 2: Gas production versus consumption in India (based on British petroleum energy statistical review, 2012)

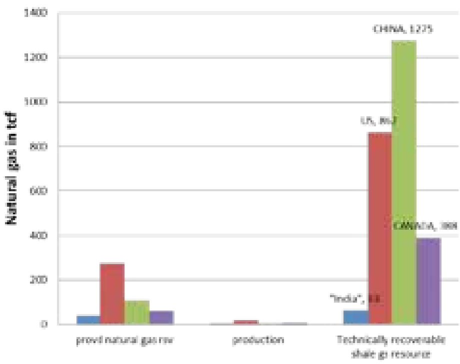

Figure3: Caparison of Shale gas resources of India, China and US (source: US Geological survey report, IEA report)

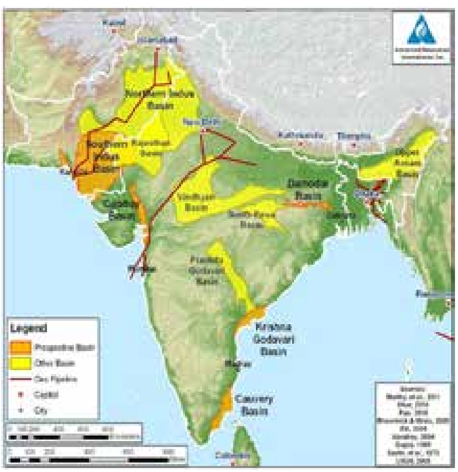

Figure 4: Map of shale gas prospective sedimentary basins in India.

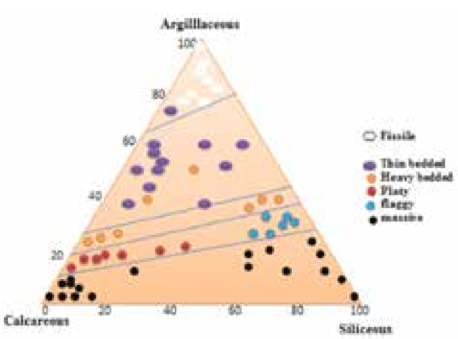

Figure 5: Triangular diagram showing fissility of shale based on mineral composition (modified after Potter et al, 1980)

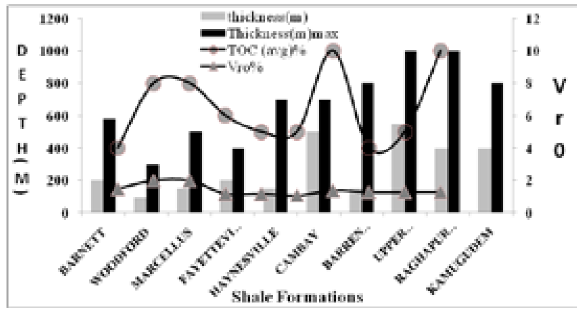

Figure 6: Comparison of gas prospective shale formations (data source: AAPG bulletin, ONGC bulletin)

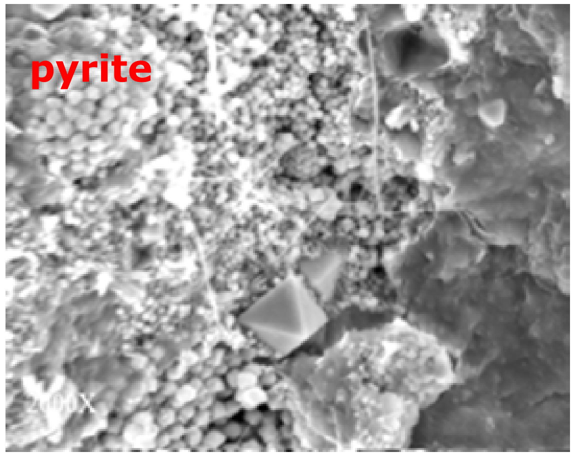

Figure 7: SEM image of Cambay shale, Cambay basin; showing the pyrite nodules and micro pores within the pyrite.

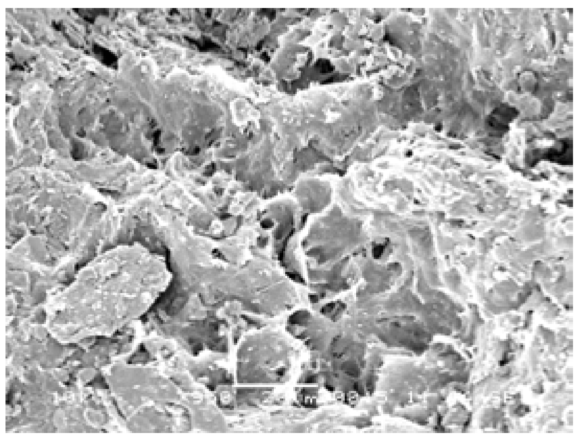

Figure 8: SEM image of Raniganj shale, Damodar Vallley basin; showing micro pores and quartz grains are coated with clay minerals, moderate reservoir quality.

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