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Tight Reservoirs: An overview in Indian context

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Summary

To sustain the supply of hydrocarbons resources world is looking towards unconventional reserves of hydrocarbon along with conventionals. Today, the most common unconventional hydrocarbon resources are Shale Gas, Coal Bed Methane, Tight Reservoirs, Basin Centered Gas etc (Fig.1). Few countries have already started production from unconventional reservoir like tight sands though at a lower rate. In India so far, 26 basins have been recognized and they have been divided into four categories based on their degree of prospectivity with total area of 3.14 million sq. km (Source, DGH). Some nationalized and foreign companies operating in the country have started exploration of these resources which will add substantial amount of hydrocarbons to the energy basket of India. Tight gas reservoirs are known from around the world, estimated global recoverable resources are about 1,500 tcf, mainly on account of the typically low recovery factors. Countries like USA, Canada, China, and Australia are the pioneer in this field. In Indian basins Krishna-Godavary basin, Cauvery basin, Cambay basin, fields of Frontier basins like Vindhyans hold the good reserves in tight reservoirs. Many wells have been drilled in these basins and a good amount of in place reserves have been established.

Recent development of new technologies of formation evaluation, drilling and stimulation/HF especially in US and Canada has made low productive unconventional Tight Gas Sands, Shale Gas and CBM as attractive resources for production. Economical production of Tight Gas reservoirs is very challenging as it exists in reservoirs with microDarcy range permeability and low porosity but has a huge potential in India for production in the future.

Keywords: *Unconventional, Hydro-fracture, Simulation, permeability, tight*

Introduction

Tight gas reservoirs characterized with low porosity and permeability, small drainage radius and low productivity, require significant well stimulation – hydraulic fracture treatment – or the use of horizontal or multi-lateral wells to produce at economic rates. Tight gas refers to natural gas reservoirs locked in extraordinarily impermeable, hard rock, making the underground formation extremely 'tight'. The tight reservoirs are characterized by low permeability, large pressure gradient across reservoir, often layered and complex, high transient decline rate and comingled production.

Typical lithology of tight reservoirs are sandstone/siltstone and rarely carbonate with permeability as low as (<0.1md). Tight gas reservoirs are generally gas-saturated with little or no free water. Special recovery processes and technologies like hydro-fracturing, steam injection etc are used to produce hydrocarbons from theses reservoirs.

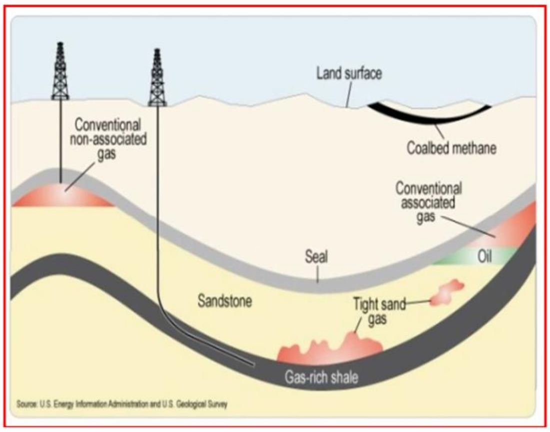

Fig. 1. Schematic geology of natural gas resources

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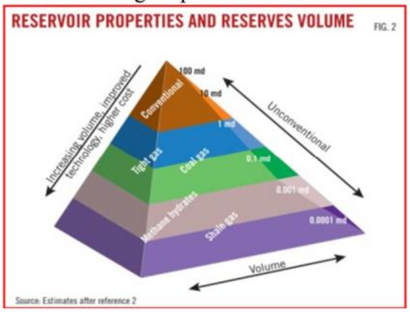

Fig.2. Reservoir properties and reserves volume

Geology of Tight Reservoirs

Tight reservoirs are basically of low porosity and permeability and are mostly associated with conventional reservoirs, which could be sandstone, siltstone, limestone, dolomite, sandy carbonates shale and chalks with significant thickness. Tight reservoir sands are continuous and stacked sedimentary layers charged with hydrocarbons. Unconventional hydrocarbon reservoirs act as source as well as reservoir itself. Many tight gas sands and shales are naturally fractured and/or layered. Development of tightness and different geological complexities in sandstone reservoirs are due to different geological events. It is due to loss of porosity through diagenesis, occurrence of most porosity in secondary pore spaces. In comparison to the normal sandstones the tight gas sands would have lesser void and connections (Fig. 2). Development of tight reservoirs includes two factors i.e. primary and secondary, the primary factors are the provenance, mineralogy, grain size, its sorting, flow regime, sedimentary depositional environment and the lithification. The secondary factors include diagenesis (compaction, cementation, dissolution) followed by tectonics and development of fractures. The regional and local tectonics plays a very important role in the evaluation of the tight gas sands. Pressure and thermal gradient are affected by the tectonics and are also very important. The most common tight sands generally consist of highly altered primary porosity, with authigenic quartz growth, coupled with secondary pore developments. Conventional cores and its thin section studies with the help of XRD, SEM etc is used to know the exact nature of the matrix.

Successful exploitation of a tight gas sand reservoir requires basic understanding of the rock pore structure and properties as well as processes affecting those properties. The conventional cores are the direct evidence and it helps in understanding nature of facies, the depositional environment, sand texture, digenetic alteration, reservoir morphology, sand distribution and its orientation. The different sedimentary structures control tightness of the reservoir as well. The thin section analysis of the rock infers detail mineralogy, texture, sorting of grains, matrix and cementing material and the type of porosity (Fig.3).

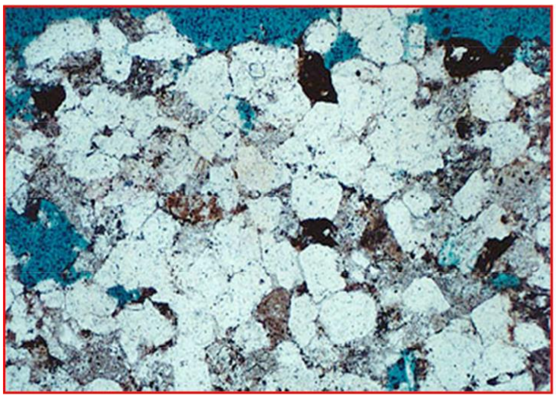

Fig. 3.Thin section of tight gas sandstone.

In Indian sedimentary basins tight reservoirs consist of mainly Sandstone, Silty sandstone, siltstone, argillaceous limestone and dolomites.

Petrophysical Parameters

Tight reservoirs are the reservoirs of low porosity that may average 3 to 6% and permeability from below microDarcies to a few milli Darcies. Optimum exploration of tight sands depends upon its petrophysical evaluation and geological understanding. Most of the TGR activities around the world are focused mainly on clastics. Well log interpretation is an additional tool to identify the environment of deposition and tightness of the reservoirs. Many suits of logs viz. borehole imaging, spectral gamma ray, NMR along with normal logs like resistivity, porosity and density are important for the evaluation of the tight reservoirs. Due to presence of clay minerals the total Gamma ray shows high gAPI which misleads the reservoir as non-reservoir. This ambiguity is resolved with the help of Spectral Gamma Ray log which infers the presence of radioactive minerals in the reservoir. Due to low porosity the resistivity log shows high resistivity of the order of 70 Ωm. Since tight reservoirs are mostly shaly sands the thermal neutron absorbers in shaly sands affect the neutron porosities which cause neutron porosity very high. As a result neutron density logs can miss hydrocarbon zones in the tight reservoirs. NMR porosities are not affected by shale of rock mineralogy. NMR logs differ from conventional neutron and density porosity logs, NMR signal amplitude provides detailed porosity free from lithology effects. Relaxation time gives other petrophysical parameters such as permeability, capillary pressure, distribution of pore sizes and hydrocarbon identification.

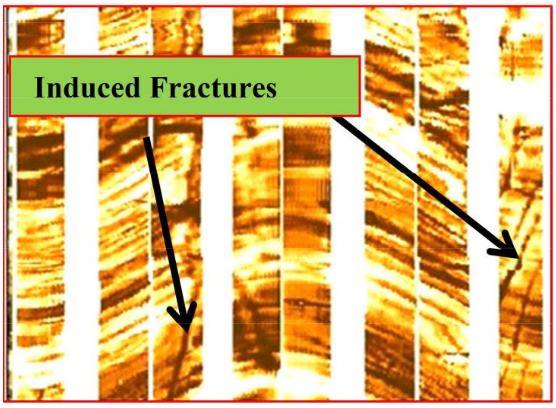

Fig.4. Image log showing development of fractures

Structural features, such as fault and fractures can be interpreted for orientation, genetic relationship and morphology on the borehole images (fig.4). Borehole images provide vital information on the stress regime which is key to successful planning of hydro-fracturing of a well. The sand size and pore size distribution can be inferred from NMR logs.

With the help of **Rock Physics** one can discover and understand relations between Seismic Attributes (Velocity, Impedance, AVO, Reflectivity & Attenuation) and Rock and Fluid Properties (Fractures, Gas vs. Oil vs. Water, Rock type, porosity, mineralogy Stress, Pore, Pressure & Temperature). The main objective of the rock physics is to derive a methodology to map the extent of the reservoir in order to reduce the sub-surface uncertainties for the field appraisal campaign. 3D-3C VSP technology was successfully used for delineation of tight gas sands in Sulige gas field, Ordos basin and north-west province of China.

Reservoir properties

Because of the low permeability of these tight reservoirs it is very difficult to get hold of their dynamic reservoir properties and in turn to characterize these reservoirs. Production rates from many tight reservoirs are marginal, but these reservoirs account for a large percentage of the long-term supply of oil and gas. A reservoir study is performed in conjunction with a detailed geologic study to identify key well characteristics or field trends to be used as exploration tools and to predict reserves. A reservoir study can identify infill-well potential and the potential for increased productivity and reserves. Many tight formations are extremely complex, producing from multiple layers with permeability that often enhanced by natural fracturing. Origin of Fractures are due to folding and faulting, solution of evaporates, high pore pressures, regional present day stress field and regional fractures. Reservoir studies can resolve the problem of unusual producing behavior of tight reservoir wells. Low productivity wells can be made more economical by detailed analysis of fractures, porosity & permeability, identification of infill wells and multiple layers for completion. Detailed reservoir parameters decide the successful and economical simulation programme. Recovery factor from tight reservoirs globally stand at around just 7-20%. Recovery is a function of the extent to which fractures extend from each well. One must determine what level of reservoir characterization is needed to optimize production from tight reservoirs efficiently.

Simulation Techniques

To induce the tight reservoir for taking production, processes like hydraulic fracturing, steam injection and acidization are used worldwide. Hydraulic fracturing is the fracturing of rock by a pressurized liquid. Hydro-fracturing, commonly known as fracking, is a technique in which water is mixed with sand and chemicals, and the mixture is injected at high pressure into a well bore to create small fractures (typically less than 1mm), along which fluids such as gas, oil etc may migrate to the well. The radial distance of influence of the process from the well bore is typically 150 yards. Hydraulic pressure is removed from the well, then small grains of proppant (sand or aluminium oxide) hold these fractures open. (Fig.5)

The first experimental use of hydraulic fracturing was done in USA in the year 1947 with first commercial success in 1949. As of 2010, it was estimated that 60% of all new oil and gas wells worldwide were being hydraulically fractured. As of 2012, 2.5 million hydraulic fracturing jobs have been performed on oil and gas wells worldwide, more than one million of them in the United States itself. Hydraulic fracturing has raised environmental concerns and is challenging the adequacy of existing regulatory regimes. These concerns have included ground water contamination, risks to air quality, migration of gases and hydraulic fracturing chemicals to the surface, mishandling of waste, and the health effects of all these, as well as its contribution to raised atmospheric CO2 levels.

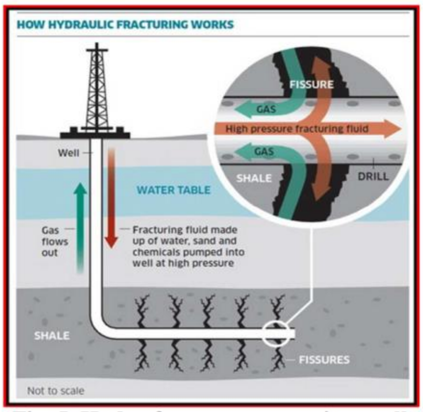

Fig. 5, Hydro fracture process in a well

Steam injection is another common method of extracting heavy crude oil. It is considered an enhanced oil recovery (EOR) method and is the main type of thermal stimulation of oil reservoirs. There are several different forms of the technology, with the two main ones being Cyclic Steam Stimulation and Steam Flooding. Both are most commonly applied to oil reservoirs, which are relatively shallow and which contain crude oils which are very viscous at the temperature of the native underground formation.

A type of stimulation treatment, acidizing is performed below the reservoir fracture pressure in an effort to restore the natural permeability of the reservoir rock. Well acidizing is achieved by pumping acid into the well to dissolve limestone, dolomite and calcite cement between the sediment grains of the reservoir rocks. There are two types of acid treatment: matrix acidizing and fracture acidizing.

A matrix acid job is performed when acid is pumped into the well and into the pores of the reservoir rocks. In this form of acidization, the acids dissolve the sediments and mud solids that are inhibiting the permeability of the rock, enlarging the natural pores of the reservoir and stimulating flow of hydrocarbons (fig.6). While matrix acidizing is done at a low enough pressure to keep from fracturing the reservoir rock, fracture acidizing involves pumping highly pressurized acid into the well, physically fracturing the reservoir rock and dissolving the permeability inhibitive sediments. This type of acid job forms channels through which the hydrocarbons can flow.

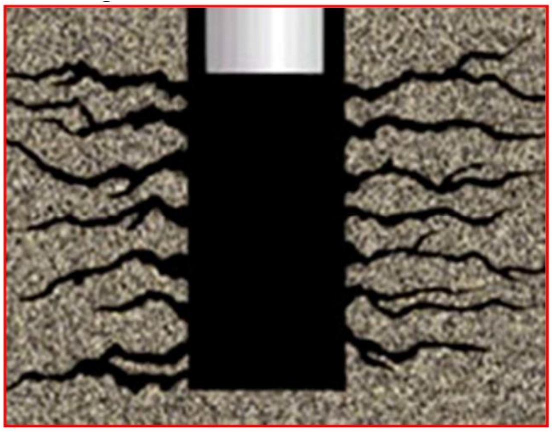

Fig. 6. Well Acidizing, Source: MPG Petroleum

Global Scenario

Few countries like USA, Canada, China and Australia are the pioneer in the development of tight reservoirs. At present about 50% of daily US gas production is recovered from tight and unconventional reservoirs. There are many tight gas fields in USA. The Appalachian Basin (Lower Silurian), Medina Group (Cretaceous and Tertiary), Devonian age reservoirs in the East and Midwest, Alberta basin, Michigan basin, Anadarko basin, The Spraberry Field of western Texas has a number of pools containing billions of barrels of oil in place. In the northern fields of Mexico, the reservoir rocks of Tamaulipas, Agua Nueva and San Felipe limestone (Cretaceous) are tight, coarse grained, compact and have low porosity but have joints and fractures to give permeability enough for commercial production. The Cretaceous limestone reservoir of Mara and La Paz oil field in western Venezuela have low permeability much of it below 0.1mD, the thick section of approx 600m is highly productive anywhere within the section where fracturing develops. Changbei gas field in North Shaanxi Province, Sulige & Chuangzhong gas field & Ordos basin, China are a large, thin and tight reservoir with low porosity (5.2%), low permeability (0.7mD) with good production of gas. Tight gas fields are also being developed around the world e.g. Yucal Pacer field in Venezuela, Aguada Pichana in Argentina, Timimoun in Algeria and Aloumbe in Gabon, Sui area in Balochistan of Pakistan, Warro field in Western Australia. Like the better-known shale gas revolution in the United States, tight gas is transforming China's gas production - accounting for a third of total output in 2012 and it is planned will to increase the country's gas production nearly seven fold by 2030. The current global distribution of recoverable tight gas reserves is & Canada- 20.4 TCM, China & Australia- 15 TCM, CIS-5.4 TCM, Middle east -3.4 TCM & Others - 1.4 TCM. (Total.com).

Indian Scenario

Tight reservoirs occur in almost all the producing basins of India and in frontier basins viz. Bengal & Vindhyan basin. Exploration of tight reservoir has already started in KG-PG, Cauvery and Cambay basins. Tight reservoirs in Indian sedimentary basins hold a huge potential of hydrocarbon reserves (fig.7).

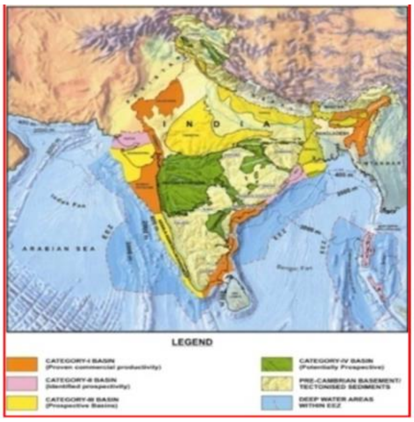

Fig. 7. Sedimentary Basins of India, Source, dhindia.org

Exploration of deeper and synrift sequences in the last decade in KG and Cauvery basins resulted into many discoveries. Field like Mandapetta in KG and Bhuvanagiri and Parivarmangalam-Vijyapuram show presence of tight reservoirs and pose difficulty in exploration & exploitation of hydrocarbons. After hydro fracture job few wells in KG and Cauvery basins are producing oil & gas with considerably low rate. Field in Cambay basin viz Limbodra, Gamiz, Vasna, North Sobhasan, Nawgaon, Sadra etc have also been identified as new field for the exploration of tight reservoirs.

In the **KG Basin** gas was struck in East Godavari sub basin near Mandapeta in the year 1988. Recently Penugonda, South Mahadevpattanam and Malleshwaram fields have been discovered with very good potential for exploration of tight reservoirs. The estimated inplace volume of tight reservoirs is approximately 50 BCM.

Two discoveries, Raghavapuram Formation sandstones and the deeper Golapalli Formation sandstones were also made. Both these Cretaceous sandstone packages are of very low permeability. Petrography of core material coupled with routine core analysis demonstrates that a combination of mechanical compaction and clay authigenesis has considerably reduced porosities and permeability.

The **Cauvery Basin** is a pericratonic rift basin. The Early Cretaceous Andimadam sandstone has porosity in the range of 8-10% with low permeability. The Late Cretaceous Bhuvanagiri formation which represents a syn-rift cycle has a low porosity and permeability. In addition the Lower Cretaceous sandstones in the Nannilam area have in general low porosity and permeability hence require fracturing for production testing. New synrift sequence in Periyakudi area of Nagapattinam sub basin have been discovered which flowed oil and gas from two sandstone layers with varying pressure after successful hydro-fracturing. The existence of different pressure regime in these two sandstone needs re- examine the pore pressure studies and to geologically understand the reason for the large difference in pressure in these layers separated by shale. Fields of KG and Cauvery basins were discovered long ago but are marginally contributing despite a large reserve base and production potential. A production of 70 - 90 MMTOE of oil / gas is envisaged from these HP-HT/tight reservoirs by 2030.

Ravva field on the eastern offshore of India is an established producer of oil and gas. The well RX-7 drilled in this basin in the north part of the block PKGM-1 (Cairn Energy) encountered oil in the early Miocene section. However the same could not be produced because of low permeability of reservoirs.

Mukta and Bassein formations have proved to be hydrocarbon bearing in the Mumbai offshore basin as well as in their wedge out area lying on the southern plunge of Bombay high. Mukta and Bassein formation in the wedge out area appeared to be a tight reservoir with poor porosity (<10). The understanding of heterogeneity of the reservoir in this area has lead to better exploration control.

Cambay Basin contains thick, over pressured low permeability tight reservoirs in the Eocene section. Tight-gas reservoirs in Cambay Basin hold approximately 413 BCF of economically recoverable tight gas (Oilex). Total reserves at Cambay basin amount to 0.55 TCF, according to the study, carried out by NuTech Energy Alliance, a US oilfield services company. Oilex says its gas and condensate reserves will rise by 248 BCF and 11m barrels as a result of exploration activity at Cambay. Studies indicate a very good correlation between the Cambay Eocene reservoirs and the Eagle Ford and Haynesville /shale" plays in the USA Basin offers further scopes for exploration and production from deeper tighter unconventional reservoirs of Cambay Shale & Olpad formations, including fractured trap which constitute 2/3 sedimentary thickness.

Vindhyan Basin, a Proterozoic basins of India is under exploration for the last few years. Discovery have been made in Son valley, few wells flowed gas during production testing from Rohtas limestone at a depth of around 1500m-1600m. The discoveries have opened a new window for exploration in proterozoic sediments. The reservoir rock is limestone and is very tight due to its argillaceous nature as well as silica fillings and quartz overgrowth. Development of primary porosity and primary fractures are almost absent and porosity is around 2 - 4%.

In **Assam and Arakan Basin** the different pays within Tipam and Barails remain as prolific oil & gas producers in all the main fields of Upper Assam Shelf. In some localities, the pay sands of middle and lower Tipams along with few pays within Barails and Kopilies in Geleki field are interpreted as tight in nature and may be identified for HF job. Similarly, one of massive pay sand within Tipam in Lakwa field has lately found its upper part of the reservoir as silty and tight in nature and tested to be hydrocarbon bearing as well.

In **Mizoram** ONGC has discovered non commercial gas in a tough and geologically challenging field, well drilled about 130 km north of its capital Aizawal. First time hydrocarbon was struck in lower Bhuban formation of fold belt area in the state. According to the primary estimate the potential of the area is approximately 3 BCM (In-place). Hydro-fracture is planned to access actual potential of the well. The reservoir is sandstone and is tight in nature. Barmer Hill of Barmer Basin in **Rajasthan** which feeds the most prolific reservoir oil blocks like Mangala and Bhagyam is the main source rock. Cairn India also plans to drill a well at the source rock and recover oil through fracking. Typically 90% of the hydrocarbon reserves remain in the source rock while around 2% migrate and get trapped in reservoirs. About 8% of the reserves are usually lost in migration. So, possibly, the reserves in the source rock are several times larger.

In **Bengal Basin** one well Ichapur-1 drilled by ONGC flowed noncommercial quantity of oil and gas from basal sand pack of Oligocene formation. The reservoir was found to be poor in porosity and permeability.

Way Forward: A major goal of petroleum industry is to increase hydrocarbon reserves whether it is from conventional or unconventional reservoirs. Because of its unique and difficult nature the interest towards development of tight reservoirs is still under achieved. At the same time few countries have established themselves as pioneer and started good amount of production using latest available technologies. This not only increases their reserve base but making them self-reliant as well. Few suggestive measures are proposed to develop tight reservoirs in India to add substantial amount of oil and gas to energy basket of the country.

- A comprehensive study is required for all the explored / partially explored / unexplored basins of India for mapping the tight reservoirs across the country. Preparation of porosity and permeability map with help of seismic / facies change of all fields using available data for proper planning of exploration and development. Convention coring as well side wall coring in all the zones of interest in new wells should be collected. A systematic preservation and study of all cores collected in older wells as well as new one will help to formulate road ahead.
- Needs to develop strategy for a steady growth for data bank required for evaluation and exploration of tight reservoirs. In the course of exploration of conventional oil and gas many zones were missed or left due to poor log response, its tight nature and low productivity during production testing. An exhaustive study for exploration and development of those missed / left zones is the need of the hour for assets which are developed and already under production form conventional reservoirs. New infrastructure will not be required as asset have fully developed infrastructure for production facility hence a little effort will require to connect the new pools from tight reservoirs for production enhancement.
- Important issues for such formations relate to the identification of "sweet spots" as well as the optimum well and completion design for specific

reservoir zones. Planning and execution of Horizontal / multilateral wells, infill wells / suitable mud to avoid less exposure to formation in tight gas reservoirs be addressed. More wells to exploit huge potential by infill drilling and should be completed with slotted / pre-perforated pipe to take maximum production. Increase reservoir contact by drilling of high angle, horizontal, multilateral and further frac heavily to create artificial permeability. At the same time have some mechanism to avoid post HF shutting of well to avoid reduction in productivity.

- For a successful simulation programme attempt to be made to target the sweeter zone. Understanding of diagenetic changes and structural complexities in heterogeneous tight reservoir can identify the least resistance area for simulation. Record MDT/RFT pressures in future wells to record representative virgin reservoir pressure. All reservoirs contain some natural fractures. It is just a determination of where & when their abundance is great enough to effect flow. State of the art simulation and HF jobs can be applied by engaging companied having expertise in this field.
- Successfully used new technology in some wells of Middle East namely *hydraulic fractures while drilling* can be used in suitable fields. This technology requires development of elevated down hole pressure to initiate and propagate hydraulic fractures while drilling. This technology will help us to create as many fractures as required during drilling. The created fractures may be thought of as synthetic sweet spots that lead to increased stimulated reservoir volume.
- Priority be given to already discovered field in India like KG-PG, Cambay & Cauvery Basin where good potential in tight reservoirs have been established. Since the production rate is comparatively low, the planning must consider the minimum cost and maximum output in a particular field.
- To monitor and guide the entire process constitutions of a centralized multi-disciplinary team of geoscientist. Team will ensure update on new technologies available in the world and its implications in Indian basins, new finds of tight reservoirs and its characters, economics involved and ultimately formulation of plans for timely and judicious exploration and exploitation of these reservoirs. Team can engage domestic as well as international repute companies who are expert and established in the exploration and exploitation of tight reservoir business for successful planning of future exploration strategy. Considering the unconventional nature and difficult to explore and exploit the untapped hydrocarbons in India a special dispensation for government can be solicited for development of tight reservoir fields in India.

Conclusions

Higher gas prices, reduction in production, heavy fiscal burden due to import, the country must find more energy at a reduced cost to the environment. Tight Gas Sands (TGS) represent approximately 70% of the unconventional production and significant reserves are yet to be developed. Because of its difficult exploration & exploitation nature, the geoscientist and engineers involved in day to day bushiness of oil and gas exploration shows less interest. But improvements in techniques of geological and seismic interpretation tools, latest technology for petro physical evaluation, improvement in drilling and production technology and lastly the status of energy demand of the country, we are forced to think beyond the conventional. We do not know how much extra resource can be obtained from existing fields by improved recovery (resource growth). We do not know the volume of resources that are yet undiscovered (yet-to-find). We can only estimate approximately how much will come from unconventional sources. It is about what to drill, how to drill, how to complete & what to do to make the tight formation produce economically on larger scale. The government is eager to support unconventional gas development and formulation policies for future additions to the energy basket of India. Ultimately a strategy to make the countries future brighter to be followed stringently to be in the race as an energy secured nation.

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