Gas Hydrates: A Possible Future Energy Resource

Energy is one of the main drivers for the sustainable development of any country like India. More than 80% of global energy requirements including India are met by fossil fuels. However, India produces only 30% of her energy requirements indigenously, and spends a huge amount of money in importing the remaining. Moreover, discovery of major oil/gas fields has remained almost stagnant during the last few decades. The rising demand for carbon emission-free energy and dwindling trend of conventional fossil fuels necessitates looking for an alternate source of energy. Gas hydrates, crystalline form of methane (99.9%) and water, are envisaged to provide one of the best feasible solutions for the future generations because of their huge potential and natural occurrences. The successful production tests in Mckenzie delta of Canada in 2008, in Alaska of USA in 2012, and in Nankai Trough off Japan in 2013 have provided an impetus to the scientific and technological community for the delineation & assessment of gas hydrates, followed by development of production technology.

Background

Gas hydrates are found globally in shallow sediments along the outer continental margins and permafrost regions, and are considered to be a major fuel resource for the future because of their vast potential (1-120 x 10^{15} m^3 of methane) and global occurrences (Boswell and Collett, 2011). The energy potential of gas hydrates is so huge that even 15% production from global reserves can meet the world's energy requirement for about 200 years (Makogon, 2007). Since methane is the cleanest of all hydrocarbon fuels, its use will cause less pollution to the atmosphere. Therefore, it is important to identify the prospective zones and evaluate their resource potential using geo-scientific methods before the viable techniques for commercial production of gas-hydrates are fully developed. Countries such as the USA, Japan, Canada, South Korea, China, Taiwan, New Zealand, Australia, Germany, Norway etc. are pursuing R&D for the exploration and exploitation of this new resource. Many have formulated national programs on gas hydrates. This has provided possibilities of energy security for many Asia-Pacific countries such as India, South Korea, China, Taiwan and Japan.

The Ministry of Petroleum & Natural Gas and the Ministry of Earth Sciences have formulated national gas hydrates programs (NGHP) in India. The Directorate General of Hydrocarbons, Oil and Natural Gas Corporation Limited, Oil India Limited, Gas Authority of India Limited, CSIR-National Geophysical Research Institute, CSIR-National Institute of Oceanography, ESSO-National Institute of Ocean Technology, Indian Institute of Technology at Kharagpur, Kanpur, Dhanbad have been pursuing active research on gas hydrates for evaluating the resource potential and developing viable technology for ground truth validation and safe production.

Globally, gas-hydrates have been identified by geophysical, geochemical and geological surveys, and by drilling and coring (Boswell and Saeki, 2010; Ruppel, 2011). Gas hydrates are detected mainly by seismic experiment with identifying an anomalous reflector, known as the bottom simulating reflector or BSR, which lies at the base of gas hydrates stability zone. A stability thickness map along the Indian margin (Fig.1) has been prepared to help identify BSR on seismic sections. From the analysis of available seismic data, gas hydrates have been identified in the Krishna-Godavari (KG), Mahanadi and Andaman offshore regions, which are validated later in Miocene to Pleistocene/recent sediments by drilling & coring during the Expedition-01 (Collett et al., 2008, 2014; Kumar et al., 2014) and Expedition-02 (2015) by NGHP.

The bathymetry, rate of sedimentation, sediment thickness, geothermal gradient, total organic carbon content indicate that gas hydrates may be found in the Kerala-Konkan, Saurashtra, Kerala-Laccadive and Cauvery basins also (Sain et al., 2011). It is prognosticated that the amount of methane stored within gas hydrates along the Indian margin is more than 1500 times the country's current natural gas reserve, and only 10% of this vast resource production can meet India's overwhelming energy requirement for about 100 years. All the potential basins are shown in Fig.1. A suite of geophysical approaches has been developed by the Indian researchers for the characterization and quantification of gas hydrates (Sain & Gupta, 2012 and references therein; Shankar et al., 2013, 2014; Wang et al., 2013, 2014; Satyavani et al., 2015, 2016; Jana et al., 2015, 2017; Ojha et al., 2016).

A Landmark Event and Important Viewpoints

Very often gas hydrates are discussed in terms of its impact on slope instability and climate change (Gupta and Sain, 2013). A plausible answer to these and some more pertinent questions was sought from the landmark 9th International Methane Hydrates R&D (IMHRD) Workshop on "Science & Technology of Gas Hydrates: When can they be produced efficiently & safely?", steered by an International Committee; organized by CSIR-National Geophysical Research Institute at Hyderabad under the guidance of a Local Advisory Committee. The abstracts that provide global overview on exploration & exploitation, results on theoretical development and applied research, and progress of gas hydrates activities in 10 different countries can be found in http://www.ngri.org.in/pdffiles/events/Fiery-ice_2014_Abstracts.pdf. Here some highlights are provided.

When gas hydrates can be made commercial: It all depends on energy security of a country in terms of availability of natural gas and oil and other renewable energy resources; type of

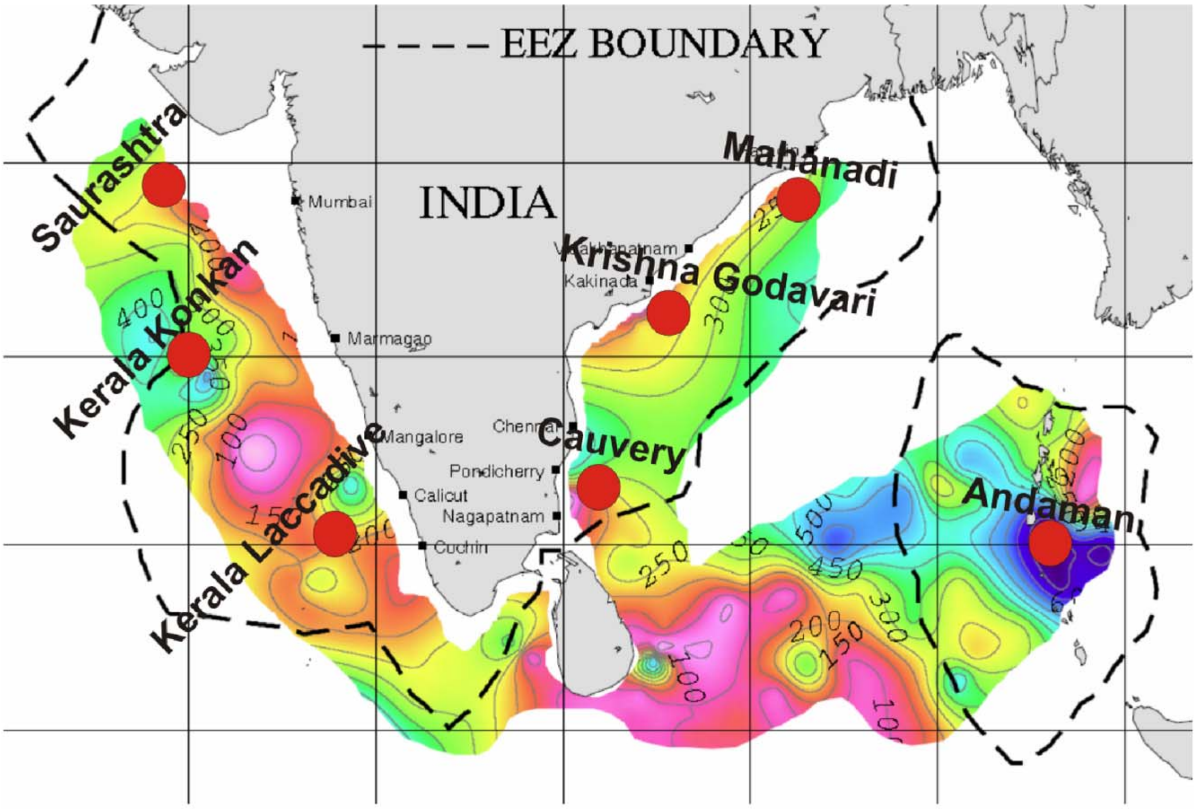

Fig.1. Gas hydrates stability thickness map of India within the EEZ boundary (dashed line). The most prospective basins (Krishna-Godavari, Mahanadi and Andaman) and less-explored but potential basins (Kerala-Konkan, Saurashtra, Kerala-Laccadive and Cauvery) are superimposed on the map. Lightest pink represents the minimum (0) and darkest blue represents the maximum (700) thickness in m below sea floor (mbsf) (modified after Sain et al., 2011).

geological reservoir and its geographical location; global prices of natural gas and oils; and governments' initiatives. According to an expert in the IMHRD Workshop, Japan is planning for the next round of field tests in 2018, and the full-scale commercial production may be expected by 2028. The United States is currently behind Japan towards realizing the full-scale commercial development due to boom in shale gas production. Korea has been planning for the first field test production in 2018; of course it relies on results of some critical tests and data analysis. India is also planning for a field test at least at one location in the KG basin within the next 2-3 years time after having established gas hydrates in sand reservoirs through drilling and coring during the NGHP Expedition-02 in 2015.

Resource Estimation & Drilling Criteria: The most popular method to estimate the resource potential is the 'volumetric method', which is described as:

GH Resource = Area * Layer Thickness * Net Gross Ratio * Porosity * GH Saturation * Cage Occupation Ratio.

Although BSR is the main criterion for choosing the drilling location, one must be careful in understanding the amplitude behavior, as it is influenced significantly by the presence of underlying gas and tuning effect due to thin layers. It may be mentioned that there is no full-proof method for choosing the drilling location. Seismic velocity, resistivity, attenuation, permeability, strong reflector at top of GH zone, fan or channel system can be considered in conjunction with BSR. It is important to study the pore pressure in the region before deciding the location to avoid drilling hazard.

Response to Geo-science data: The response of gas hydrates present within the sediments to seismic (P- and S-wave velocities), electromagnetic (resistivity), well logs (gamma ray, resistivity, density, sonic, porosity etc), seismic attributes (attenuation, blanking etc) and core data are different in sand and clay reservoirs. Since the top of gas hydrate-bearing sediments is not generally identified on seismic data, it is desireable to have sonic and resistivity log data to decipher the same.

Climate Change & Slope Instability: As discussed in the Gordon Research Conference held in 2012, the methane emission from marine gas hydrates reservoir into atmosphere is very unlikely. Even in the case of a big blowout, there would not be a huge release of methane as it gets dissolved in water. The engineering research carried out using highly sensitive pressure sensors at Nankai Trough, where production test was carried out at 12 degree slope, did not indicate any issue related to slope instability. However, dissociation of gas hydrates might weaken the host sediments and submarine landslides cannot be ruled out. Some kind of modelling related to slope failure need to be carried out as a guidance for safe production. The porosity, permeability and geotechnical properties of sediments are to be studied carefully, as they respond to stress changes caused by production. Considerable uncertainty remains with regard to subsidence during long term production testing. The oil industry has been dealing with this problem during conventional oil production. It is possible to develop an engineering solution for gas hydrate production based on experience of oil industry. Slope failures are observed in the KG basin. The depth of submarine slope failure, close to the boundary of gas hydrate stability zone, suggests a link between slope failure and gas hydrate dissociation.

Gas Hydrates System: Gas hydrates are formed in shallow sediments (in pore spaces of channel sand or in fracture shale) where temperature is low, pressure is high and methane concentration exceeds the solubility limit. Fault or fracture system may exist within the sedimentary formations through which methane gas migrates from below into the stability zone and forms gas hydrates. High sedimentation rate causes preservation of more organic matter and generation of fewer sulfates and more methane. Dissolved gas moving into sand channel would result into microbial gas hydrates by diffusion process. If faults cut across such diffusive system, gas hydrates might be formed thermogenically or biogenically or both. Multi-scale and multi-disciplinary approaches are required to understand the gas hydrates system. This can provide answers to some questions such as 'why one gets more saturation at some places and low concentration at other places', 'whether fresh gas is entering into the system', 'how fracture system works' etc.

Multidisciplinary Approach: An integration of geophysical, geological, geochemical and microbiological study along with engineering aspects is necessary to obtain a comprehensive understanding on (i) genesis of gas hydrates (how gas has been formed, migrated, preserved); (ii) resource evaluation; (iii) impact of dissociation; and (iv) feasible production methodologies. Integration of multi-parametric multidisciplinary approach is a must to understand the dynamics of the fracture and reservoir systems.

Global Status of Exploitation: Although a viable production technology does not exist anywhere in the world right now, but a lot of technological progress has been made. Norway has been considering CO_2 sequestration as feasible for simultaneous CO_2 storage and methane production from on land gas hydrate reservoir using a mixture of CO_2 & N_2. Japan has demonstrated production of ~20000 m^3/day of gas & 200 m^3/day of water for six days based on depressurization method, which appears to be cost-effective for production of gas hydrates from marine environment. South Korea has been planning for environmental impact assessment on production of gas hydrates from deep-water in the Ulleung basin. China is trying to implement the principle of fluidization mining, in which uncontrollable gas hydrates are changed into controllable gas hydrates by seabed closed lifting system. Joint Industry Partnership (JIP) in USA has confirmed safe drilling through gas hydrate reservoir (Leg I Exp. in 2005) and documented high-quality gas hydrates in Green Canyon and Walker Ridge. Germany has focussed on methane production with sequestration of CO_2 in methane hydrates reservoir below seafloor through an initiative called SUGAR (SUbmarine GAs hydrate Reservoirs) from Exploration to Exploitation as well as monitoring of hydrate exploitation operations. New Zealand has been pursuing modelling of gas hydrate formation using Petromod® and identifying localised gas hydrates in Hikurangi margin. Taiwan carried out multidisciplinary exploration program, theoretical modelling and molecular simulation study, and has been following the same. India carried out dedicated gas hydrate coring/ drilling/ LWD/ MWD operations under NGHP Expedition-01 at 21 sites (39 wells), and recovered gas hydrates samples in KG, Mahanadi and Andaman basins. Gas hydrates have been established in sand reservoir in KG basin during the NGHP Expedition-02 in 2015. Laboratory studies are being pursued to understand the formation and dissociation kinetics of gas hydrates, and NGHP looks forward for test production atleast at one site. Singapore has been pursuing research to mitigate the challenges on sand and water management during production for sustainable energy production and alleviation of CO_2 emissions simultaneously by replacement of CH_4 trapped into hydrate deposits with CO_2. Since gas hydrates is a dynamic system that never reaches thermodynamic equilibrium, one needs to pursue research by bringing this fact into reservoir simulator at some stage.

Future of Gas Hydrates: The geo-scientific community has been pursuing research for the delineation and assessment of gas hydrates in sand reservoirs, and understanding gas hydrates system. In the mean time it is hoped that suitable economically viable exploitation methodology is developed. The production tests in Canada, USA and Japan, and the initiatives taken by some other countries including India have provided great hopes on viable production of gas hydrates. With the fast growth, it is expected that gas trapped below gas hydrates can be exploited before producing gas from gas hydrates reservoir. By leveraging the available technologies, it is expected that gas hydrates may be produced commercially and safely within another decade or so. Some critical parameters such as the porosity, permeability and geo-technical properties can be delineated through geo-scientific studies, which are required as input to develop suitable production technology. There lies a huge scope to pursue research on 'biogenic or thermogenic origin of methane', 'gas hydrates system', 'diffusion or advection process', 'resource potential', 'nature of host sediments', 'fractures vs. pores', 'varying saturation from place to place', 'methods for identifying massive gas hydrates', 'parameters for drill sites', 'laboratory study', 'production tests', 'technology advancement for exploitation', - all are very important to industries for considering gas hydrates as a major energy resource of the future.

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