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Gas Hydrate Opportunities and Instability Challenges with Consideration of Environmental Impacts

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ABSTRACT: Energy demand after the industrial revolution is increasing exponentially but the supply is not even close because of the diminishing fossil fuels. Since, the easy oil has been exploited, researchers are looking for potential crude generation in harsher environment. The harsher environment would mean usage of sophisticated technologies to extract and at deeper levels, which is not considered economical. The anthropogenic activities such as burning of fossil fuel, coal, wood etc. has caused adverse effect on the environment like global warming. Therefore, unconventional source of energy like gas hydrates can be used as clean energy since the emission of CO_2 is drastically reduced. Gas hydrate stability is controlled by several factors like, temperature, pressure, gas composition, ionic impurities in water, thickness of the zone. This paper pertains to study the phase behaviour of the gas hydrate with respect to pressure and temperature, furthermore, the environmental implications of gas hydrates which can trigger catastrophic events like tsunami, submarine landslide ocean acidification etc. Special attention is also placed on the opportunities and challenges of gas hydrates policies in consideration to environmental impacts in order to push forward the global developments of the sustainable energy Furthermore, we briefly discuss the environmental implication related to the exploitation of gas hydrate as the future energy resource as it is the paramount importance in the development of novel gas hydrate production technologies.

Keywords: Climate Change, Gas Hydrate, Environmental impact, Seafloor Instability.

I. INTRODUCTION

The atmosphere and the ocean are the two element that acts as a Carbon sink and it is expected to undergo significant change due to the rise in the atmospheric CO_2 because of, burning of fossil fuels, oil, wood, coal etc. [1, 2]. Due to the increased anthropogenic activities, CO_2 levels have raised to a critical level, where all of the bio-diversity is getting affected, leading to an altered ecosystem, change in ocean circulation pattern, changes in the biotic diversity and temperature increase, decrease in salinity, change in pH and ultimately the melting of polar ice leading to foreseen increase in the sea levels by 0.5m within next 50 to 100 years [3]. Some of the scientist working in this field believe that, the CO2 produced can have an unwavering effect on sea level raise of 1m [4]. The greenhouse gas like CO_2 produced from different sources can play havoc with nature [5-10]. Since the ocean is the largest carbon sink, it can uptake anthropogenic CO_2 and may alter the seawater chemistry of the world's ocean with serious consequences of the marine biota [11-15].
The nature tends to work in mysterious ways and thus they tend to repair itself when subjected to any external changes but recent studies have suggested that the significant impacts will persist for hundreds of thousands of years after the CO_2 emanation ceases [16, 17]. But, due to rapid industrialization and high demand in energy, it has become the need of the hour of every Nation to produce as much as energy possible to keep the world running, without giving nature a second thought. Many anthropogenic activities, conventional energy sources which are basically non-renewable in nature. According to BP Statistical Review of World Energy 2020 oil continues to hold the largest share of 33.1%, coal 27.0% natural gas 24.4% and renewables 5% [18]. Even though the energy demand for oil is exponentially increasing and easy oil has cease to exist engineers and scientist are working relentlessly to find hydrocarbon in extreme temperature and pressure zones as well as alternative energy resource. One such resource is called Gas Hydrates.

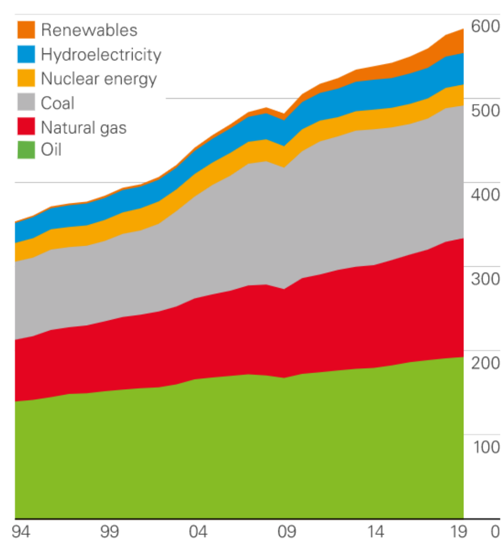

Fig. 1. Primary Energy – World Consumption [18].

II. COMPOSITION, STRUCTURE & OCCURRENCES OF GAS HYDRATES

Gas hydrates (CH_4 $5.75H_2O$) are crystal structure with hydrogen bonded void water molecules that traps a guest molecule. Gas hydrates are characterized based on the type of gas molecule trapped by the water molecules [19]. On the molecular scale, a single guest molecule is en-clathrated by the hydrogen bonded voids in these non-stochiometric hydrates. Guest molecules of distinct sizes combine with the hydrogen bonded water molecules to form 3 distinct yet a well-defined structure SI, SII and SH [20]. The cubic structure I predominates the Earth and generally contains (0.4-0.55nm) guest, viz. methane, CO_2, ethane etc. Whereas, SII is man-made having guest molecule of size 0.6-0.7nm, viz propane, iso-butane etc and SH are rare in nature with molecules of size 0.8-0.9 nm and contain molecules like Argon, Krypton, O_2 and N_2 [21] as shown in Fig. 2.

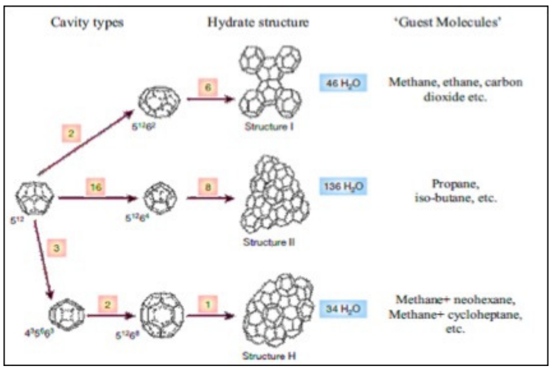

Fig. 2. Cavity types and unit crystal of methane hydrates.

The numbers in coloured blocks represent the number of cage types and the water molecules in a unit lattice [22]. Gas hydrates are mainly spread in the slope of the seabed sediments with depth of 400 to 1000m at temperature below 10C, with pressure greater than 3.5 MPa (Fig. 3).

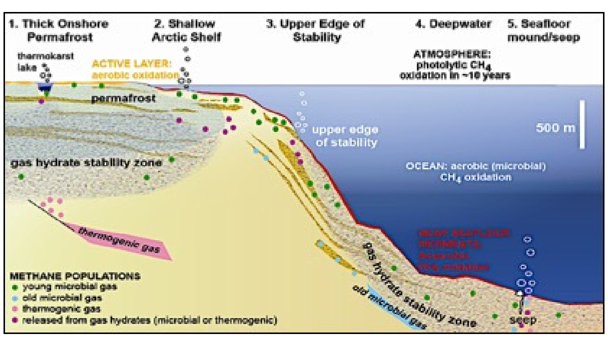

Fig. 3. Methane hydrate spread in ocean and on land [29].

Gas hydrates are not only found in seabed, but also in the perma-frost regions of Russia, Canada and other countries. But Ocean is the major depositional place for gas hydrates [23]. The present paper discusses the implication of gas hydrate instability and the environmental implications surmounting like impact on global warming, marine organism, seafloor with a possibility of submarine slide and slump surface which was first distinguished by McIver [24-28]. Also, the extensive need to study the Environmental Impact Assessment of the seafloor by conducting baseline survey, significant risk associated with it and at the last the environmental monitoring and survey for the longer run to know if there any subsidence cause when the gas hydrate is dissociated for the commercial purpose.

Even though other hydrates are also present in nature, methane hydrate is dominant of all. The global volume of methane bound gas is still uncertain but it was estimated to be $1.8 \times 10^{16} - 3.4 \times 10^{17}$ m^3 in global submarine [30] gas hydrate reservoir with as high as 7600×10^{15} m^3 [26] and low as $0.2 \times 10^{15} m^3$ [31]. It is also considered to be clean as it contains high purity of methane molecules and also when burnt produces very less residue, which makes it environmentally friendly compared to other by products SOx, NOx and other carcinogenic gases which gets released as by-products from Coal, CBM, shale [32]. Gas hydrates are mainly formed in the permanently frozen regions and outer continental margins where the methane concentration exceeds its solubility limits [33].

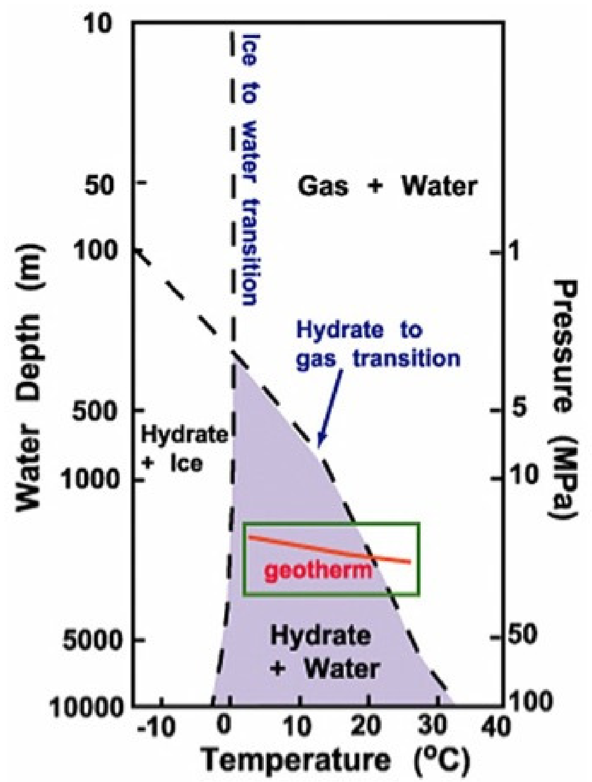

Fig. 4. Phase diagram of gas hydrate with respect to temperature, pressure and depth [34].

Gas hydrates are found to exist in fracture fillings in clay dominated matrix in shallow sediments. The NGH in marine setting are formed by hoarding of particulate organic carbon (POC) which is microbial transformed into methane, the sedimentation rate, thickness of the gas hydrate pay zone depends on the time POC and methane produced stayed within the gas hydrate stability zone and its distribution from deep seated sediments by ascending pore fluids and gas into the stability zone [35-38]. The methane which gets trapped as the hydrate compounds comes from the microorganism which gives out methane as the byproduct, by consuming the detrital organic matter. The amount and the rate of supply depends on the methane supply. There are two known source of major methane hydrate formation in a Hydrate Stability Zone (HSZ). The HSZ occurs from around 530m depth from Northern latitudes and 250m of the Southern latitudes [39]. The two-methane source include HSZ and deep methane influx. Deep methane influx is produced by the bacteria that decomposes organic rich sediments which provides a constant influx within the marine layer of 99.99% of pure methane with trace element of impurities like Ethane, propane, carbon-di-oxide, hydrogen sulphate [39]. In some areas, the influx rate of the natural gas has been estimated as high as $2.05 Kgm^2/yr$ at 12.3℃. Hydrate formation is favoured in coarse sediments, and they help in decisive step in understanding the hydrate lithology, since coarse grain sediments have high permeability value than the fine grained. When the upwelling methane gas enters the HSZ, it gets dissolved in the pore space of the coarse sediments and exist in three phases as shown in the Fig. 4. viz., free gas, dissolved in solution and as solid hydrate. Thus, a precise temperature and pressure is required to convert methane to methane clathrate structure. The solubility of methane increases at elevated temperature and pressure; therefore, the ascending fluid cools off as they rise and encounters the region of methane insolubility. At this point the methane crystallizes out of the solution becoming more insoluble [40]. Once the methane is saturated with the ocean water existing between, he coarse sediment grains, at right temperature and pressure, the ice crystal starts to form in the crystal lattice and trap the methane molecules within the lattice. The guest and the host are not chemically involved rather by a weak Van der Waals force in the ice crystal that would make the entire lattice more stable [41]. Thus, the gas hydrates are formed and able to persist and build a large depositional layer, for the clathrates to be more stable than the ice or methane gas alone. Thus, stability of gas hydrate hinges on the delicate balance between the temperature and pressure, which decides whether the gas hydrate be intact or dissociate and gets released into the environment. Even though gas hydrate is said to be clean energy, it is still considered potent when released into the atmosphere without proper aid. It is said to be 20 times more powerful that CO_2, and takes 8 years to disintegrate. Gas hydrates has natural tendency to escape through seeps, but as the temperature in the atmosphere raises, stability of the hydrate is hindered and the methane gas starts to get released from the bed to the atmosphere (Fig. 4)**.**

III. RESULTS AND DISCUSSION

Ocean acts as the major carbon sink. Climate change has drawn increasing attention all around the globe in the past several decades. The raise in the ocean temperature has led to the decline of oxygen concentration which has impacted the marine life in many different ways. This climate change can affect the stability of the methane hydrate. As the temperature increases the methane hydrate loses its stability and it starts to dissociate into methane gas and water. The dissociated methane bubble starts to rise through the water column. The methane bubble undergoes anaerobic and aerobic oxidation process as it travels through the water column and forms respective by products which may be harmful to the marine and the benthic environment and can also cause subsidence. Although when followed the regime of hydrate stability, the methane hydrate still remains a commercially feasible alternative energy source in the near future. Any gas production test from the methane hydrate should be based on the environmental impact assessment [42]. Natural or anthropogenic migration of methane into the marine environment and atmosphere will exert impacts on the marine ecosystem, global climate change and component balance. Thus, the phase diagram becomes an important tool in understanding the stability of the hydrate and the resultant weakening support to the sediments, which may cause seafloor instability, submarine landslide or even tsunami.

Factors of Methane Hydrate Instability: Methane hydrate stability hinges on a delicate balance between low temperature and high pressure, even a few degrees Celsius increase in the hydrate vicinity can cause instability and methane clathrate can dissociate [43]. This dissociate can bring pockmarks or holes in the ocean sediment surface and can even cause mechanical instability of the seafloor, and cause a significant release of the methane gas. The size of the bubble determines whether gas would diminish as it travels through the water column or would is reach the ocean surface and get exposed to the atmosphere. Approximately, 1-5 GtC of methane can get released in a single event, causing an increased radiative force upto $0.2 Wm^{-2}$ to the atmosphere [44]. Besides temperature variation in the deep ocean, the ocean circulation due to oscillatory currents can also promote dynamic release of methane through seepage [45].

Impact on global warming: The methane hydrate is quite abundant on the permafrost and beneath the seabed regions. Nevertheless, this abundant energy when triggered can cause global warming. Methane is considered a greenhouse gas because, methane is 21 time more potent than CO_2 and also take 8 years to disintegrate to from CO_2 [46]. Due to lower concentration of methane in the atmosphere, the infra-red radiation absorption band is less saturated [47]. Therefore, when large amount of methane gas escapes can likely to cause a catastrophe globally. As the climate change is persistent due to the global rise of temperature, the stability phase of methane shifts and causes ablation of the permafrost in Arctic regions. The climate change causes the ice in the Arctic to melt and it acts as a triggering mechanism to dissociate methane and water from the methane hydrate. The deep ocean has a long ventilation time almost 100 – 1000 years therefore, a new equilibrium methane hydrate can only be achieved in 1000- 10,000 years. Besides, the fraction of methane from the deep ocean that reaches the atmosphere is uncertain and totally depends on the transport phenomenon of the methane bubbles [48]. The oxidation lifetime of methane dissolved in seawater is almost 50 years [49]. Therefore, it is like a vicious cycle of global warming with methane released from gas hydrates and rise in temperature. Necessary measures need to be taken in order to control the methane release from the hydrates and its release to the atmosphere.

The release of methane from the hydrate in oceanic regions can cause ocean acidification and oxygen depletion in the surrounding region. If the hydrate release is from a low oxygen environment then the ecosystem can be severely affected. More than 50% of the dissolved methane could be retained inside the seafloor by microbial anaerobic oxidation of methane (AOM) [50, 51]. The AOM converts methane and oxygen into the carbon-di-oxide, causing an imbalance in the pH of the ocean [52]. Ocean acts as a biggest carbon sink and if there is an increase in the formation of carbon-di-oxide in the ocean and also in atmosphere, it can be catastrophic globally.

Gas impact on marine organisms: The gas which dissociates from the bottom of the sea bed gets partly dissolved in the ocean before coming to the surface. Marine animals can get severely affect when it comes in contact with direct gas bubbles and also dissolved in ocean. Gas can rapidly penetrate into the fish through gills and disturb their main functional systems like respiration, nervous system, blood formation, enzyme formation etc. External symptoms include common behavioural changes like fish excitement, increased activity etc. Furthermore, prolonged exposure can lead to chronic poisoning i.e. at this stage the cumulative effects if physiological and biochemical occurs depending on the nature of the toxin and its concentration. Gas emboli can cause rupture of the tissues, enlarging of bladder, abnormalities in circulatory system and other pathological changes. Three main types of intoxication by methane gas has been given by the Medical Toxicology viz.,

(i) **Light:** Reversible and the effect on central nervous and cardiovascular system will disappear quickly

(ii) **Medium:** Can cause a deeper and permanent functional change in the central nervous and cardiovascular systems also can increase the number of leukocytes in the peripheral blood.

(iii) **Heavy:** Permanent damage to the cerebrum, heart tissue and alimentary canals and also acute form of leucocytosis.

The above description gives a general pattern of how a vertebrate would behave when it is exposed to those situations. Correspondingly, the release of methane can also reduce the oxygen content in the surrounding and this will affect the surrounding marine ecology.

Seafloor instability caused by methane hydrate: Methane hydrates form a solid structure when they are containing sediment pore space [53]. Due to the fact that the water can't be expelled in a consolidated sediment, this in fact adds a stress to the sediment. The methane hydrate being fragile can be consequential even when there is a slight deviation of temperature and pressure. The methane clathrate would collapse into water and gas as soon as the hydrate bearing sediments become under-consolidated. Furthermore, the seafloor deforms and could cause a submarine landslide or an earthquake beneath the seabed leading to tsunami. Similar incident of methane hydrate was observed at the off coast of Norway about 7000 years ago. 25m high mega tsunami hit Norway and Scotland, which was thought to be triggered by the Storegga submarine landslide with enormous amount of sediments gliding down up to 800kms down the continental slope. Also, the Russian researchers found that the unstable hydrate slid in 1997 too. The thickness of the tsunami deposited is 20 to 100 cms [54]. Maslin *et al.* stated that the mass failure event of the Amazon Fan was mostly generated by the calamitous failure of the continental slope, which was later correlated with the climate induced changes of sea level. The rapid decrease of the sea level exposed the gas hydrates and de-stabilised the gas hydrate at the continental slope triggering slope failure and causing the massive glacial mass transport of sediment deposits [55, 56]. It is been said that the slope become susceptible to fail with increase in the thermal diffusivity, water depth and gas saturation and decreases in the pressure diffusivity, water depth and gas saturation.

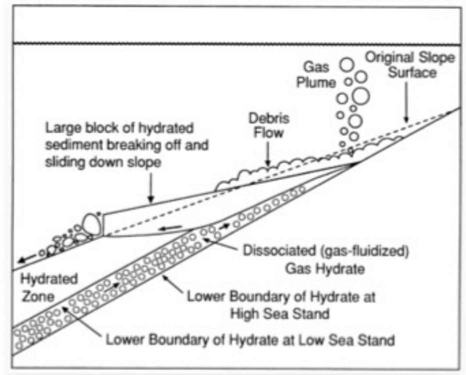

Fig. 5. Dissociation of hydrate continental slope [56].

Reduction of the sea level and varying temperature and pressure combination has said to initiate the dissociation of the hydrate along the base, which would cause a large volume of gas being released into the atmosphere (Fig. 5). The increasing pore fluid volume, reduces the slope stability. It was studied that the disruption of continental slope in Beaufort Sea was induced by the hydrate decomposition within the impermeable clayey sediments [57]

IV. CONCLUSION

Due to the industrial revolution, anthropogenic activities have boomed and its activities are ever increasing in a rapid pace for example, little rise in temperature in the deep sea can trigger methane hydrate dissociation and the outcome may be release of crucial amount of methane in the seawater resulting in the increase of carbon in the ocean and in atmosphere if the CH_4 bubble manages to reach the surface. The daily internal semi-tides creates an eruption of intense current at the bottom creating an inertial motion and linear change in the friction velocity changing the equilibrium [58]. Discovery of crude oil and natural gas was considered more of a blessing in the modern world but the easy oil got diminished soon and researchers are looking for energy in most harsher conditions. Also, the energy requirement keeps increasing due the luxury of human living and it is very difficult for the engineers to meet the demand and therefore, we need to look for alternate energy source, one such source is Gas Hydrates which occurs beneath the seabed and in permafrost conditions. Number of nations are coming forward to study this bundle of energy and making significant efforts in securing and efficient utilization. Countries like USA, Japan, China, India etc are taking a serious interest towards this energy. Even though there are various implications involved proper monitoring system needs to be employed in order to curb the situation and safely exploited. Various opportunities and challenges for commercial gas recovery from gas hydrates are discussed with respect to the environmental impact.

V. FUTURE SCOPE

This paper reckons the implication of catastrophic discharge of methane hydrate in the ocean and in atmosphere leading to unprecedented chain of events. This work presents the severity of the event, if required EIA studies like seafloor subsidence, geo-mechanical study, baseline study to evaluate the risk associated during the production and after the production of methane hydrate which would help in the exploitation of the energy source in the cleaner way possible benefitting the human society and caring the marine animals.

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Conflict of Interest. No Conflict of Interest.

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