A Review of Research on Gas Hydrates in Makran

Muhammad Jahangir Khan, Mubarik Ali
Department of Earth & Environmental Sciences
Bahria University Karachi Campus

Abstract - Makran region has been remained an area of interest for local and foreign geoscientists for many reasons. Gas-hydrates are a naturally formed marine resource of Methane gas and also used as a source of combustible energy. Makran offshore known for the occurrence of gas-hydrates, however, their volume and geometries are not yet clearly developed. This study comprehends recent research developments on gas-hydrates in Makran and serve its academic role to understand the existence of gas-hydrates in Makran region and its exploitation from virgin offshore areas of Makran (Pakistan and Iran) with modern technologies and drilling methods.

Key Words: Makran, Gas-hydrates, Seismic, BSR, Subduction.

I. INTRODUCTION

The energy demands are rising in this modern era. Futurist scientists are eyeing on unconventional hydrocarbons. Globally efforts have been made to explore, exploit and export hydrocarbons. Gas-hydrates are unique aggregates, composed of physically and chemically heterogenous compounds of water (ice) and low-molecular weight gases (mostly methane, ethane, propane, butane and some inorganic origin gases like CO₂ and H₂S). Crystalline structure of natural gas-hydrates has multi-face geometry in which water molecules camouflage the centrally located methane gas. Exploitation of gas accumulation, for the first time, found economically viable in tectonically active areas (which controls the geometry and sub-surface distribution of gas-hydrates) of Alaska and SE Japan in 2012 and in 2013, respectively (Ruppel, 2007; Wallmann, 2013; Collett, 2011; Boswell and Collett, 2011).

The receipe of gas-hydrates consists of several ingredients known today like low formation temperature, high formation pressure, pore water salinity, the gas (either Biogenic or Thermogenic origion), permeability of medium, marine sediments or reservoir (to provide the porosity) and active subduction tectonics. Gas-hydrates are mostly found within upper few hundred meters of ocean floor sediments where the water depth exceeds a few hundred meters to maintain the thermo-barometric stability conditions for gas-hydrates on the continental margins (figure 1), particularly in accretionary prisms at active ocean-continent convergent boundaries (Shipley et al., 1979; Minshull and White, 1989; Hyndman and Spence, 1992; Kvenvolden, 1993; Xu and Ruppel, 1999).

This paper present a review of research conducted on Makran (North Arabian Sea) portrayed in figure 2.

Fig 1. Natural settings for gas-hydrates (after Ergun, 2015)

II. TECTONIC OVERVIEW

Tectonic structure of Makran is complex and is characterized as on-going subduction of the north-eastern part of Arabian plate (possibly one of the oldest parts of the Indian Ocean) which is under thrusting the Afghan block (currently at the southeastern edge of the Eurasian plate) at a rate of ~4 cm/year since Late Cretaceous. Makran subduction zone is similar to other subduction zones of the world such as Southern Lesser Antilles (Caribbean Sea), Hikurangi (New Zealand), Cascadia (North America), and Sumatra/Sunda (Indonesia) where relatively high sediment input dominants in inter-bedded hemi-pelagites facies associations and turbidities (Bourget et al., 2010; Mouchot et al., 2010; Bourget et al., 2011) characterizing the thickest sedimentary cover approximately 7.5 Km (Smith et al., 2013). The sedimentary cover in Makran subduction zone has significant realities, i.e. more thickness even than that of Potwar basin (Khan, 2015), low subduction angle 4-5 degree (Smith et al., 2013) with slow to moderate convergence rates ~3-5 cm/year (White, 1979, White and Louden, 1983; DeMets et al., 1994; Flueh et al., 1989). Makran has remained an active Margin from Cretaceous to Present (McCall and Kidd, 1982).

Geologically, a horizon defines the lower boundary conditions of high-pressure and relatively low-temperature zone in which gas-hydrates are stable in any region (Andreasen et al., 1990; Kvenvolden et al., 1993). A simple geological model for the occurrence of gas-hydrates in offshore areas illustrated in figure 3.

III. METHODOLOGY

The objective of this study is based on reviewed analysis of several collaborative research programs exclusively aimed to study various dimensions of Makran subduction system and gas-hydrates. Analysis of research publications based on interpretation of prior offshore surveys conducted in Makran provide substantial evidences (physical, geological, biological and geophysical attributes) in favour of existence of gas-hydrates in Makran region.

A) Physical Observations

At Makran, physical features of gas-hydrates are directly observed through seafloor sediments and under-water photography. Smell and flame signify the release of gas from trapped gas-hydrates. Potential gas bubbles and escape marks are captured at sea-floor (figure 4A) in Makran. The raised seafloor or appearing/disappearing “islands” in Makran region signify the dynamic plate margin and expose the potential of released gases. An example of physical sample of gas-hydrates collected with seafloor sediments from Oregon offshore region is depicted in figures 4B & 4C.

Methane gas stored in offshore environments controlled by geological and biological elements associated with active tectonics within and beneath gas-hydrates, which may provide a major energy source in Makran subduction zone similar to Alaska and Japan offshore areas bearing gas-hydrates.

Fig 3. Simple geological model of gas hydrates under sea-water

Fig 4 A. Gas leaking from the sea-floor sediments, Makran (after Tabrez and Inam, 2012)

Fig 4 B: Gas-hydrates sample found in Alaskan North Slope. (after Collett, 2011)
B) Geophysical Exploration: (Seismic)

Geophysical exploration have remarkable success and contributed significantly in unearthing the anatomy of complex convergent margin of Makran. Geophysical hunt for gas-hydrates in Makran based on conventional petrophysical models (Flueh and Bialas, 1996; Ellouz-Zimmermann et al., 2007), Multi-channel marine seismic reflection profiles (Ellouz-Zimmermann et al., 2007; Smith et al., 2013), Seismic inversion models (Sain et al. 2000), Amplitude Versus Offset (AVO) modelling (Ojha et al., 2014) and Seismic velocities analysis (Minshull and White, 1989; Holbrook et al., 1996) indicate the presence of a strong and widespread horizon i.e. bottom-simulating-reflector (BSR).

The BSR is an indicative tool in case of gas-hydrates interpretation based on seismic reflection data. The BSR has been clearly identified in various regions of Makran offshore with varying amplitude (Figure 5).

High amplitude dipping reflectors below the BSR are observed on 2D seismic image of Makran offshore (Figure 6a). Moreover, the reflectors dip towards north (landwards) in the Makran accretionary prism. It is also observed from Makran offshore seismic profiles that highly reflective region beneath the BSR may represent alternating gas-rich and gas-poor strata.

Theoretically, P-waves velocity increases with depth due to over burden pressure and compaction of lithified sedimentary layers but while passing through gas-hydrates zone (which acts as speed breaker for P-waves) its velocity decreased notably from 2.2 km/sec to 1.3 km/s at a depth of 2300 m, below the sea floor (figure 6b). This low-velocity-zone (LVZ) marks an anomalous seismic zone (vertically) in subsurface overlying thick sedimentary cover load.
The approach of seismic inversion reveals a thick layer of gas-charged sediments (200–350 m) below the BSR in the Makran accretionary prism (Ojha, et al 2014). The LVZ observed in Makran is much thicker than LVZ found in the abyssal plain close to the toe of the Makran accretionary wedge (White, 1979; Minshull and White, 1989). The difference in thickness may be due to a steady supply of gas as sediments are compacted in the accretionary wedge. Volumetric calculations of the free gas reserve in Makran may be estimated by measuring the thickness of LVZ and related factors (von Rad et al., 2000; Roesser et al., 1997). A continuous high-amplitude reflection event below the BSR corresponds to the bottom of a probable connected gas reservoir whereas below LVZ more discontinues events could been observed in visual interpretation of seismic profiles in Makran (figure 7).

![Fig 7 BSR with undulating topography and discontinuous events at bottom, Makran accretionary prism (after Smith et al., 2013)](image)

Figure 8 presents a case to correlate P-wave velocities from vertical seismic profiles at sites 995 and 997 with single channel section on Blake Ridge (Holbrook et al., 1996). The seismic attributes of BSR in Makran are similar to the BSR in Blake Ridge (Sain et al. 2000).

![Fig 8 BSR with respective velocity model i.e. Low velocity zone (after Holbrook, 1996)](image)

C) Geological evidences:

The Makran accretionary wedge lies in the vicinity of major biological productivity in surface water governed by upwelling of monsoon and sediments transport. It may be a reason for the development of an oxygen-minimum-zone (OMZ) illustrated in figure 9 which controls accumulation rate of the predominantly organic matter in the marine sediments (von Rad et al., 1996; Edwards et al., 2000). OMZ conditions are identified in northeastern Arabian sea (von Rad et al., 1999).

Gas hydrates may be distributed in concentrations that vary both laterally and vertically, and are controlled by heterogeneities in lithology, permeability, and methane transport (Ruppel and Kinoshita, 2000; Trehu, 2006; Riedel et al., 2006; Collett, 2009; Collett, 2011; Malinverno et al., 2008). The layer of gas-hydrates may form a barrier for fluids to flow which inhibits sediment consolidation, leading to the development of excess pore pressures at the BSR and their decomposition can lead to locally reduced shear strength at the BSR so they could play an important role during slope failure (Booth et al., 1994).

Geologically, the mechanism of disassociation of methane gas in appreciable amount from gas-hydrates in Makran offshore could happen due to following reasons alone or in combination.

- Upward movement of the base of gas-hydrates stability field, probably caused by a push during thrusting in Makran subduction zone (White, 1982; Minshull et al., 1992)
- The high sedimentation rate in Makran (Raza et al., 1983; Smith et al., 2013) may also lead to rapid upward movement of the phase boundary relative to the sediment column (Minshull et al., 1992; Korenga et al., 1997; Pecher et al., 1998)
- Tectonic uplift in Makran (Sain et al., 2000) results in buildup of elastic stresses or release of elastic strain energy (tectonic earthquake) in Makran (Khan, 2015)
and under water land-sliding, can put slip-thrust and transfer its momentum to stimulate and accelerate the leaking of aqueous-gas i.e. gas-hydrates (Methane).

Figure 10 depicts the geochemical reaction occur in subsurface (under seawater) associated with gas-hydrates. Theses multiple conditions contribute in separation of fused compounds and isolation of gas that occupied the pore spaces of the marine sediments and sedimentary layer saturated with integrated gas (mostly methane) stationed under the cap of BSR.

Recently, several studies have shown that it may be possible to produce methane from the gas-hydrates by displacing the methane molecule in the hydrate structure with carbon dioxide, thus releasing methane and carbon dioxide (Graue et al., 2006).

In Makran, the production of gas hydrates could be made possible by adopting any one of the above described methods.

A production model (figure 12) of permafrost areas demonstrates how gas is being released from gas-hydrates with depressurization method. Initially a test well is drilled and an electrical submersible pump (ESP) installed above perforations that depressurising the seabed formation by lowering the water level in the well surrounding sand grains are prevented to enter into the well. Hydrates disassociation from gas-hydrates compounds produce water and gas (methane). Then after gas-water filtration process allowed gas to flow to the surface through pipe lines and filtered water re-injected through a separate water disposal well.

Practically, the operation of getting the converted methane gas from a well lithified solid material of geological times is an engineering challenge. It involves pre- and post-operational geological and environmental hazards as well as probable consequential disasters. Any execution plan when adopted in Makran may create a misbalance in subsurface geological settings near and/or far coast of Makran.
Methane gas trapped beneath hydrates may also be a significant drilling hazard in deep waters of Makran: drilling operations affect the ecosystem and sea-floor stability. Too much gas extraction from gas-hydrates may destabilize the seabed, triggering huge under water landslide which may cause tsunamigenic earthquake in Makran region and locally submarine slope failures due to disassociation of gas-hydrates (Nixon and Grozic, 2007). Moreover, on combustion/melting of gas-hydrates release greenhouse gases into the atmosphere which may impact on climate change or global warming in coastal areas of Pakistan and Iran.

The importance of gas-hydrates is also evident from literature such as:

- Gas-hydrates forming an impermeable layer that may act as a cap rock for hydrocarbons in Makran similar to that occurring in southeast U.S (Dillon et al. 1980).
- Gas-hydrates may indicate hydrocarbons in conventional petroleum system.
- The simulating reflector at bottom of gas-hydrates can be used to estimate thermal gradients and hence heat flow in oceanic sediments (Hyndman and Spence, 1992) which contribute in knowing burial thermal history of sedimentary basin in Makran.
- Gas-hydrates could act as a state indicator of thermal maturity and migration of hydrocarbons (gas reserve) in Makran.

VI. CONCLUSIONS

- All necessary elements existing with active tectonics characterises Makran as a host of gas-hydrates. It is evident from sea bed observations and field data of various offshore scientific surveys conducted in past decades by several geoscientists / research institutes of the world, it is apparent that gas-hydrates are present in Makran.
- Analysis of remotely sensed geophysical (seismic) data provide strong evidence of gas-hydrates in Makran offshore.
- Bottom-simulating-reflector (BSR) is the key indicator on seismic data that results from strong impedance contrast at the bottom of gas-hydrate zone. The Makran accretionary complex shows a distinct bottom-simulating-reflector, indicating a thick gas-hydrate bearing horizon between the deformational front and about 1350 m water depth which seals off the upward flow of gas-charged fluids (von Rad et al., 2000).
- The gas-hydrates were initially described by White earlier (in 1982 and 1983) in Makran region, the expanse and abundance of gas-hydrates in offshore Makran was affirmed by later seismic investigations.
- Scientific outcome of the surveys showed a substantial step ahead for long period accumulation and migration process of natural gasses available in huge quantities in ‘gas- hydrate’ in marine sediments in Makran offshore.
- Interpretation of high resolution seismic reflection data when integrated with other geological experiments may increase the existing knowledge about gas-hydrates that will help in quantification and zonation of methane gas-hydrate reserves in Makran.

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REFERENCES


