Mud gas play

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Abstract. The presence of methane gas seepage in the mud volcano proves the existence of gas associated with over pressured zone in the subsurface. The analysis of C isotope on samples of methane gas seepage of mud volcano show the gas is thermogenic methane at the level of thermal maturity that is equivalent to the peak of petroleum formation. The mud of mud volcano extruded from overpressures zone beneath is predicted to have high gas storage capacity. The objectives of this paper are to define capacity of the mud of mud volcano system as a potential reservoir gas and its role in petroleum system. Isothermal absorption test is performed to answer the storage capacity of the mud of Kesongo and Lusi mud volcanoes system. Seismic data and velocity data show over pressured mud zone as chaotic zone with low velocity anomaly distributed crossing the reflector layer as chamber. The gas storage capacity of the mud based on adsorption test at the temperature of 65-degree Celsius ranges from 812 scf/ton up to 3,217 scf/ton shows it has capacity of gas reservoir. The adsorbed gas in over pressured mud shows different mechanism with that of the conventional reservoir. Adsorbed gas in over pressured mud can be proposed as unconventional gas reservoirs with new alternative hydrocarbon play: mud-gas-play (MGP). Mud-gas-play is defined as the accumulated gas trapped in over pressured zone. Gas accumulations tend to be concentrated in the upper part of over pressured zone.

1. Introduction
The mud volcano system has been introduced by many researchers. The terminology of the mud volcano system is used to describe the structures associated with mud volcanoes or the formation of structures and complexes of sediment supply channels that connect mud volcanoes with stratigraphic unit sources in subsurface, a shale diapir or overpressured shale [1-4]. The mud volcano system is controlled by high pressure and fluid sources that may or may not be together with the mud source layer [5]. Another mechanism is the formation of a layer of overpressure because the movement is flanked by shale. Excess fluid has the energy needed and is sufficient to break the cover when the mud-liquid sediment rises to the surface which is then deposited as sediment [4].

The North East Java Basin is known as a producer of oil and gas and many natural phenomena from the mud volcano, often referred to as the mud volcano province. Most of gas and oil fields are located near the mud volcano system. Mud volcano in East Java is associated with an excess layer beneath the surface originating from fine grained rocks, and mud originating from the overpressured zone of Tawun Formation or Kalibeng Formation [2,3]. The mud layer from the Tawun Formation often causes drilling problems from gas kicks, collapse of well walls, drilling pipes pinched, or blow out. These phenomena are more likely to be as geohazard potential or drilling disasters, often overcome by raising the specific gravity of the mud to increase, with potential risk of damaging the formation. Geological and drilling
data in the wells which is located in the mud volcano system area, show high gas potential, but can not be developed for the technical reasons.

The potential of gas can be observed from the methane content of gas seepage in Kesongo and Kradenan mud volcanoes and well data reach 77.9 % and 65% moles respectively, forming thermogenic gases at the beginning to the peak of hydrocarbon maturity [2,6,7]. The total gas is relatively high in either shale, sandstone or limestone, from C1 and sometimes C2-C4 [2,7]. The oil and gas fields in Cepu and its surroundings have been shown have higher cumulative production than proven reserves, which are caused by over pressured shale Tawun Formation or diapir beneath reservoir rock; diapir is directly affect the accumulation of hydrocarbons and the maturity of the source rock [8]; mud volcanoes in East Java which are mostly related to oil and gas fields in East Java [9]. The organic matter content (TOC) in the Kradenan region from well data varies, Tawun Formation TOC ranges from 1.37% to 2.25%; TOC from the Ngimbang Formation 12.17% to 58.86% in CD splinter intervals [10]. The results of the analysis of gas seepage from mud volcanoes are almost all included in thermogenic gas. SEM analysis, XRD of mud volcano material showed mud dominated by smectite and kaolinite dominated clay minerals. Some anomalies occur in Kesongo, consisting of illite and kaolinite. The presence of the Heulandite in Crewek shows a hotter temperature and is equivalent to the peak temperature of the formation of hydrocarbons (peak oil generation) [2,7].

The old paradigm that overpressured shale as a potential drilling hazard needs to be given an alternative perspective that it has large gas storage potential. The aims of the research are to describe the mud of mud volcano system as a potential reservoir gas and propose new unconventional reservoir gas as an alternative petroleum play.

To answer this problem, a storage capacity of mud volcano material in the surface temperature of air pressure and subsurface temperature with high pressure were tested. The seismic, well data and mud samples of mud volcano material are taken from the Kesongo Mud Volcano, Kradenan area (Figure 1), and an additional mud sample from mud volcano Lusi, Sidoarjo area, East Java Province, Indonesia.

![Figure 1. Kradenan mud volcano area in western part of East Java Basin.](image)

2. Methods

Isothermal adsorption testing is intended to determine the maximum capacity of the material to adsorpt certain types of gas where the volume of gas is absorbed as a function of pressure at a fixed temperature. Adsorption is defined as the process of attaching molecules or ions to the surface of solids.

Isothermal adsorption measurements were carried out for two (2) mud samples, from Kesongo mud volcano and Lusi mud volcano. The measurement of isothermal adsorption is carried out in wet and dry conditions with variations in the test temperature of 32 °C and 65 °C. The wet condition sample is the initial condition of the sample from the field in the form of mud, while the dry condition is a wet sample that is heated using an oven at a temperature of 40 °C for ± 48 hours (avoiding damage to the structure of the clay).
The volume-pressure relationship at a certain temperature can be used to determine the gas storage capacity and estimate the volume of gas that can be released from the sample in line with the decrease in reservoir pressure [10]. In general, the relationship between the storage gas capacity and pressure is known as the Langmuir equation:

\[
G_s = \frac{V_L P}{P_L + P}
\]

The above equation is only used with the assumption of pure coal, so this equation is then modified by taking into account the presence of ash content and water content contained in coal, so this equation becomes:

\[
G_s = (1 - f_a - f_m) \frac{V_L P}{P_L P}
\]

with:
- \(G_s\) = gas storage capacity, \(m^3/\text{ton}\)
- \(P\) = Pressure, kPa
- \(V_L\) = Langmuir Volume Constant, \(m^3/\text{ton}\)
- \(P_L\) = Langmuir Pressure Constants, kPa
- \(f_a\) = ash content, fraction
- \(f_m\) = moisture content, fraction

3. Result and discussion

Adsorption tests show that the dry condition tends to have lower adsorption power rather than the wet condition (Figure 2). Based on the Langmuir isothermal graph type delivered by Kiselev et al. B-081 and B-085 samples included type III Langmuir graphs, except for B-085 samples at 65°C and in dry conditions as in Figure 2, including type 1.

![Figure 2. Summary graph of mud adsorption test result on Kesongo (B-081) and Lusi (B-085).](image)

The classification of the Langmuir graph can be seen in Figure 3. Type III isothermal graph has the meaning that the adsorbent has a pore size that is wide enough, or the adsorbent has a micropore to non-porous. Weak interactions cause little absorption of the adsorbate at low pressure. Once the molecule has been adsorbed, the adsorbate-adsorbent interaction will be stronger [10].
Figure 3. Langmuir type [10].

A summary of the results of this test is set out in Tables 1, show the storage capacity for mud is quite high in dry conditions at 32°C (surface) is 0.84-1.27 scf / ton. In wet conditions it increased to 1.35-2.18 scf / ton. For samples tested at 65°C the storage capacity of dry samples was 202 scf / ton (at a pressure of 319 psi) to 1,695 scf / ton (at 4,802 psi), ranging from 812 scf / ton (at a pressure of 5,083 psi) to 321 scf / ton (at a pressure of 3,166 psi).

Table 1. Summary of the results of the isothermal adsorption test at a temperature of 32 ° C and 65°C.

| No | No sample | Langmuir at 32°C (dry) | Langmuir at 32°C (wet) |
|----|-----------|------------------------|------------------------|
|    |           | VL (scf/t) PL (psi)   | Storage capacity at surface (scf/t) | Storage capacity at depth (scf/t) | VL (scf/t) PL (psi) | Storage capacity at surface (scf/t) | Storage capacity at depth (scf/t) |
| 1  | B-081     | 168 2.952 0.84         | 332 3.630 1.35         |
| 2  | B-085     | 866 10.062 1.27        | 518 3.501 2.18         |

| No | No sample | Langmuir at 65°C (dry) | Langmuir at 65°C (wet) |
|----|-----------|------------------------|------------------------|
|    |           | VL (scf/t) PL (psi)   | Storage capacity at surface (scf/t) | Storage capacity at depth (scf/t) | VL (scf/t) PL (psi) | Storage capacity at surface (scf/t) | Storage capacity at depth (scf/t) |
| 1  | B-081     | 190 3.197 0.88         | 1,695 5.083 0.97        | 812 |
| 2  | B-085     | 471 4.802 1.44         | 202 3.166 1.81         | 3.217 |

The absorption test results from mud show the ability to store gas. When compared with shale that has a storage capacity ranging from 50-800 scf/t; coal with a storage capacity of 25-600 scf/ton[11], then the mud storage capacity has a similarity range to shale gas and coal.

Interval seismic velocity is proceeded based on raw data result from re-picking of RMS velocity from 2D seismic data gathered and obtained from previous research by Burhannudinnur. From the previous research that the source of mud volcano material came from the over pressured shale from Tawun Formation. Seismic interpretation on the xx-03(Figure 4A), shows chaotic amplitude forming a continuous channel to the surface as a chaotic channel, exiting as mud volcanoes in Kesongo. The symptoms of this chaotic canal are related to the fold structure at a shallow level (<1.5s) and a large fault at a deeper level with half reaching at the bottom. Minor fault develop outside chaotic channels, in Tawun Formation, as polygonal fault system or valve fault [12]. Polygonal fault has developed well in the muddy mud zone / zone of excessive pressure due to fluid loss, while valve fault relates to fluid migration prior to existing fault. In the seismic cross section, mud volcano system can be seen that material sources show chaotic interference by the channel to the surface [11,12]. Figure 4B, the cross section of the seismic interval velocity shows that over pressured zone has low interval velocity.
anomalies, it has a lower velocity compared to the surrounding [12-15]. Low velocity anomaly geometry is more likely to cut layers or parallel to seal layers.

Figure 4. (a) Seismic section and V Interval section xx-03 lines (b) Velocity section, overpressured zone is shown as low velocity anomaly (white color). Location of wells see figure 1, colour bar refers to figure 5.

Low anomaly seismic interval velocity was confirmed as over pressured zone by tying the over pressured zone to well A (Figure 5). The geometry of the chamber-shaped over pressured zone associated with chaotic zones in seismic reflections, some cutting reflectors. Interval velocity section shows a low velocity anomaly zone spreading laterally under a strong-seal reflector. The over pressured zone spreads over the over pressured zone under the seal. Transfer zone from chamber to upper chamber through a fault which is identified as a valve fault [16]. The geometry of the over pressured zone can be delineated from the low interval velocity anomaly at the seismic velocity cross section. Velocity cross section data, physical cross section and a Hele – Shaw model ensure that the zone overpressure can be defined and delineated using cut-off interval velocity as a chamber [11,12]. The ability of mud storage through the adsorption mechanism shows mud can possibly be a gas reservoir, as unconventional reservoir. The geometry of the chamber that can be determined and made possible to calculate gas resources that will be stored in the over pressured mud [11]. The Mud-gas-play concept was developed from the integration of storage capacity of over pressured mud as a source of mud volcano confirmed by velocity anomaly, adsorption test. Mud-gas-play is defined as a gas that accumulates and is trapped in an over pressured mud, as adsorbed gas, as illustrated in Figure 6.

Figure 5. Well seismic tie of overpressured zone. A. Seismic section and B interval seismic velocity section.
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Figure 6. Illustration of the mud gas play concept. Mud gas play position against other types of gas play in the petroleum system.

4. Conclusion

The presence of overpressured zone containing mud of mud volcano system is as low velocity anomalies at the Tawun Formation level. The mud has storage capacity of 812 scf/t to 3,217 scf/t, shown as an unconventional gas reservoir, with an adsorption mechanism. The reservoir geometry is a chamber crossing the layer and follows geometry of overpressured zone. Mud-gas-play is defined as an accumulated gas trapped in over pressured mud chamber, as adsorbed gas with a tendency to be concentrated in the upper part of the over pressured zone.

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