SUITABILITY ASSESSMENT AND STORAGE CAPACITY ESTIMATES OF RAMBUTAN COAL SEAMS FOR CO_2 STORAGE

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ABSTRAK

Lapisan batu bara merupakan alternatif pilihan formasi geologi untuk penyimpanan CO_2 selain lapangan migas *depleted* dan *deep saline formations*. Tidak semua lapisan batu bara dapat dimanfaatkan sebagai media penyimpanan CO_2 karena terdapat berbagai faktor intrinsik dan ekstrinsik yang mempengaruhi. Oleh karenanya, potensi penggunaannya perlu dievaluasi kesesuaiannya dan seberapa jumlah CO_2 yang dapat disimpan. Naskah ini menyajikan pertama kalinya evaluasi karakteristik lapisan batu bara di Lapangan Rambutan, Sumatera Selatan, dan potensi kapasitas simpan CO_2. Kriteria semi-kualitatif yang dikembangkan digunakan untuk menilai kesesuaian 4 lapisan batu bara dari aspek permeabilitas, geometri, struktur, homogenitas dan kedalaman. Sementara itu, kapasitas simpan adsorpsi CO_2 diestimasi dengan menggunakan data hasil eksperimen yang dilakukan dengan model *Isothermal Langmuir*. Hasilnya menunjukkan ke-empat lapisan tersebut secara umum sesuai untuk dijadikan tempat penyimpanan CO_2. Kapasitas adsorpsi dari lapisan 2, 3, 5, dan P secara berturut-turut adalah 22.18, 25.09, 24.53, dan 34.12 m^3/t *dry-ash-free* basis. Kapasitas simpan tertinggi dimiliki oleh lapisan P yang mana memungkinkan CO_2 disimpan dalam fasa yang lebih padat (*supercritical*).

Kata Kunci: Lapisan batu bara, Evaluasi kesesuaian, Kapasitas simpan, Lapangan Rambutan

ABSTRACT

Coal seams are an alternative storage options besides depleted oil and gas reservoirs and deep saline formations. They are suitable to different degrees for CO_2 geological storage as a result of various intrinsic and extrinsic. The potential use of this geological media requires suitability assessment and the amount of CO_2 can be stored. This paper presents the first attempt to evaluate the characteristics of coal seams in Rambutan Field, South Sumatera, in terms of their suitability for CO_2 storage and the potential storage capacity. A set of 5 semi-qualitative criteria has been developed for the assessment of 4 seams that includes permeability, coal geometry, structure, homogeneity and depth. CO_2 adsorption capacity estimates were derived from laboratory experiment by employing Isothermal Langmuir. The results show the 4 seams in general are suitable for CO_2 storage. The adsorption capacity from seam 2, 3, 5 and P are 22.18, 25.09, 24.53, and 34.12 m^3/t dry-ash-free basis respectively. The highest CO_2 storage capacity can be stored at seam P enabling the CO_2 in dense phase (supercritical).

Keywords: *Coal seam, Suitability assessment, Storage capacity, Rambutan Field*

I. INTRODUCTION

The Government of Indonesia has committed to reduce greenhouse gas (GHG) by adopting the national action plan addressing climate change through Presidential Decree No. 61/2011. This decree stipulates 26% emissions reduction by 2020 using national efforts from the business as usual and up to 41% by international effort. The current efforts that have been made such as energy mix improvement, the switch to less-carbon intensive fuels and renewable energy deployment are considered still insufficient to achieve the emission abatement target within relatively short period. Therefore, there should be large scale low-carbon technology needed to be entered into the national policy path.

Carbon capture and storage (CCS) is believed can assist the government meeting the target due to its characteristics that can reduce GHG emissions on a large scale and within a short period. However, to deploy this technology a suitability assessment of geological formation and CO_2 storage capacity available have to be undertaken.

Coal seams are an alternative storage options besides depleted oil and gas reservoirs and deep saline formations. They are suitable to different degrees for CO_2 geological storage as a result of various intrinsic and extrinsic. The distribution of this formation is widespread in Indonesia with coal bed methane resources (CBM) potential accounted for around 453 Tcf[1]. The trapping mechanism provided is considered more secure than the other types of geological formations of which trapped in adsorbed phase onto the micropore[2].

This paper provides suitability assessment for CO_2 storage of 4 coal seams in Rambutan Field, South Sumatera. A laboratory experiment is carried out to estimate the CO_2 storage capacity for each seam by employing isothermal Langmuir model. An attempt is made to benchmark the CO_2 adsorbed capacity derived from Langmuir model with Toth model.

II. RESEARCH METHODOLOGY

The scope of work of this study comprises (a) coal seams suitability assessment and (b) CO_2 adsorption storage capacity.

A. Suitability Assessment

A set of 5 semi-qualitative criteria is developed[3,4] that includes permeability, coal geometry, structure, homogeneity and depth. The criteria reflect the key elements of CO_2 storage needed for the coal seams to be applicable for CO_2 storage, containment, capacity and injectivity. Table 1 below lists the semi-qualitative criteriaused to assess the suitability and screen the coal seams. Coal seam characteristics of Allison Unit in New Mexico, USA.are used to benchmark with seams from Rambutan Field. Allison Unit is the first successful CO_2 injection project[5] in the world.

B. CO_2 Storage Capacity Estimates

Capacity estimates are done by calculating the adsorption capacity of coal through Isothermal Langmuir adsorption test. The samples are prepared using combined method of crushing and high temp vacuum outgassing. The objective is to increase the surface area and remove the impurities for the purpose of accuracy. A modified CBM Rig is used to carry out the experiment (Figure 1). The Rig consists of four sample chambers that operated from central control panel. The experiment is conducted corresponds to respective layer temperature with the operating pressure ranges from 123 kPa to 14.000 kPa.

Table 1
Screening criteria of coal seams for CO_2 storage[3,4]

Criteria	
Permeability (mD)	≥ 1
Coal Geometry	Few and thick
Structure	Less fault and fold
Homogeneity	Homogeneous and confined
Depth (m)	800 – 1500

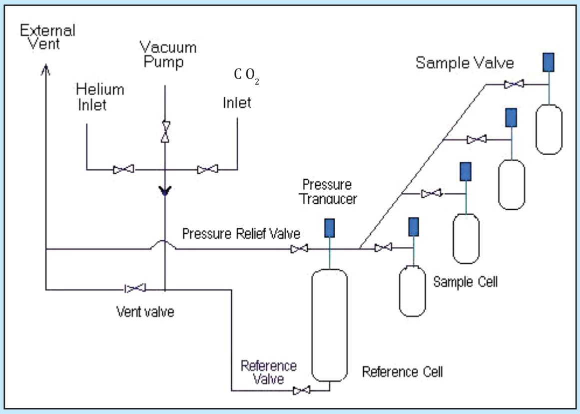

Figure 1
Design scheme of apparatus

The data obtained is then processed using volumetric[6] and modeled by Isothermal Langmuir equation. CO_2 density at supercritical phaseis modeled by Span Wagnerequation of state (EOS)[7].

III. RESULTS AND DISCUSSIONS

A. Suitability Assessment

Suitability and benchmark to Allison Unit are shown in Table 2. Most of coal seams properties in Rambutan Field have favorable criteria for CO_2

storage. The only criterion does not satisfy is the geometry of the coal. It has varied thickness for each seam ranging from 4 to 18 m. The thickest seam can up to 18 m, exceeds the thickness of Allison seam. This variability is a result of terrestrial depositional environment influenced by the marine which occurred in the past.

From permeability point of view, Rambutan seams are fulfilled the criterion required. Although, they are not as high as Allison unit, they are considered sufficient to allow CO_2 flow in the coal matrix. The advantage of having high permeability is easier for CO_2 accessing the cleat systems before it diffused onto the coal surface and stored permanently. Furthermore, with the issue permeability reduction when CO_2 in contact with coal or known as the swelling effect[9,10], having high permeability would provide a buffer for this effect so that can still accommodates high injection rate (high injectivity). The higher injectivity, the higher pressure of formation can handle and the less number of wells needed[11].

The local geological structure Rambutan Field contains with minimum folds and faults which is suitable for CO_2 storage. This would reduce the potential risks imposed due to CO_2 plume migration to these geological features. Rambutan seams are located at Muaraenim Formation. Based on tectonic activity, this formation is defined as low geological group. It is influenced by low level tectonic deformation with characteristics of having wide fault and moderate to flat folds.

Indicator of subsurface heterogeneity is measured by Dykstra Parsons coefficient (DP)[12]. The most heterogeneous reservoir is indicated by coefficient equals to 1.0. Rambutan seams have value 0.24 which is relatively homogenous. Moreover, they have a seal pairs with claystone overlying and carbonaceous mud-stone underlying the formation[13]. They can provide containment to prevent the unintended migration outside the storage complex.

With respect to depth, the four seams have sufficient depth to store CO_2 in dense phase. Depth plays important role to ensure long-term security and utilization of the pore space. The deeper the formation the more secure geological storage is. It is because the more likelihood the CO_2 in denser phase phase (supercritical). Being in the supercritical state means lower buoyancy force which reduce the CO_2 migrating upwards. Furthermore, supercritical phase allows higher efficiency utilization of the pore space. However, if the storage takes place too deep, the permeability will decrease due to compaction and overburden pressure so that can lead to higher injection pressure which can be costly.

B. CO_2 Storage Capacity Estimates

The adsorption capacity from seams 2, 3, 5 and P are 22.18, 25.09, 24.53, and 34.12 m^3/ton dry-ash-free basis, respectively. Seam P has the largest

Table 2
Benchmark of Rambutan seams properties with Allison seam[8]

Criteria		Rambutan	Allison[8]
Permeability (mD)	≥ 1	3.35-10.85	40
Coal Geometry	A few and thick	Vary (4-18 m)	Few, thick (13 m)
Structure	Less fault and fold	Yes	Yes
Homogeneity	homogenous and *confined*	Yes	Yes
Depth (m)	600 – 1500	641-957	950

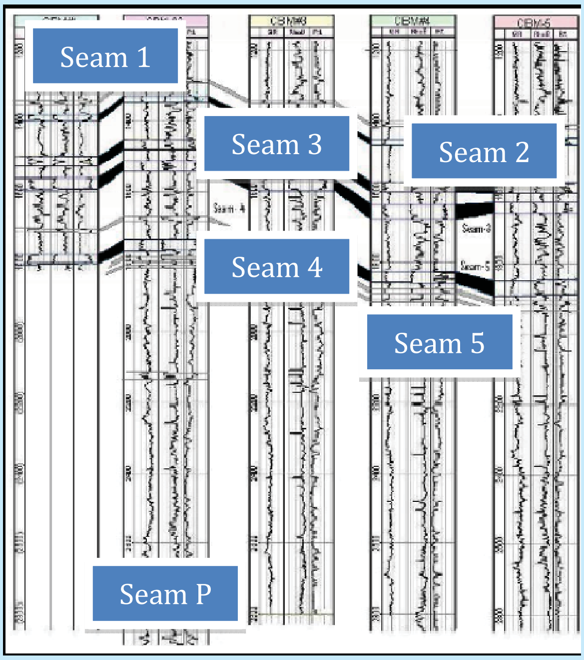

Figure 2
Stratigraphy of coal seam Rambutan Field

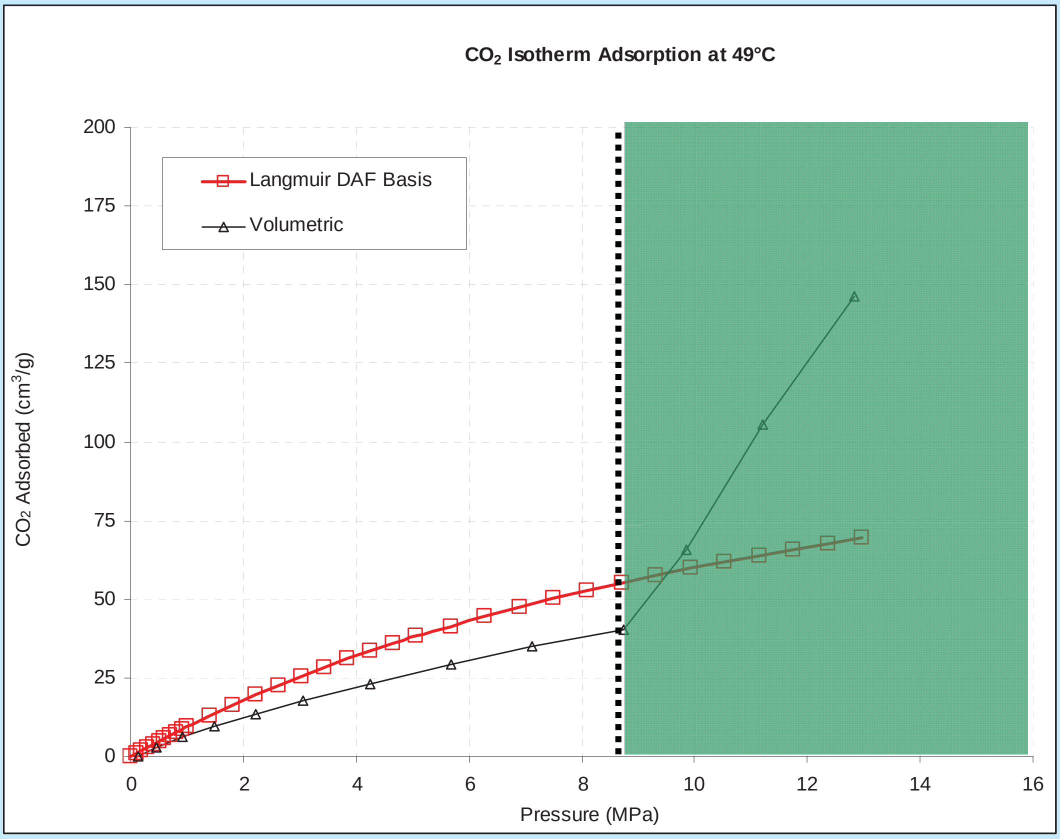

Figure 3
High pressure adsorption and limitation of Isothermal Langmuir Model

capacity, because it is the deepest among the others. As discussed previously, depth is well-correlated with the efficiency of utilization the pore space. The range of adsorption capacity from the four seams is similar to that reported by Cook *et al.*[14] Various factors influence the range of capacity, such as coal rank, moisture content, maceral composition and mineral matter content[9].

Isothermal Langmuir is used to model the adsorption mechanism occurred during the experiment. This model is suitable for describing adsorption mechanism on porous media and can accommodate physics and chemical adsorption mechanisms.

As shown by Figure 3. the high pressure adsorption took place at the operating pressure above 8 Mpa15. This is indicated by sudden increased response showed from volumetric estimation curve. The curve rises monotonically on Langmuir models from 0 up to around 75 cm^3/g. Similar response is also shown by volumetric curve, it increases steadily up to pressure about 8.5 Mpa. Thereafter, the adsorbed capacity has a significant upward trend. Multilayer adsorption is expected starts to occur at this pressure.

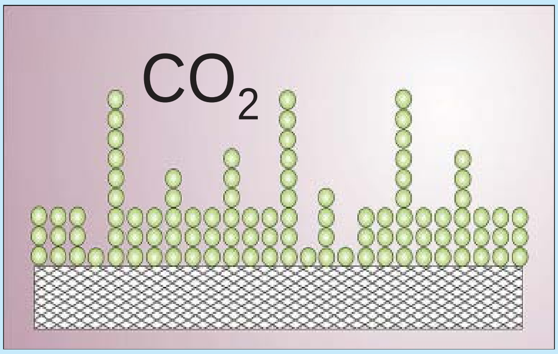

Figure 4
Multilayer Adsorption Phenomenon

At high pressure CO_2 density will rise dramatically hence the considerable amount of CO_2 moleculeswill be compressed and arranged on the coal surface and forms multilayer of adsorbed molecule as depicted in Figure 4.

Low slope response at pressures above 8 MPa (Figure 3.) is the constraint of Langmuir Isothermal to model high pressure adsorption. This is mainly because adsorbate is assumed as a single layer. This limitation is also confirmed by Bae[16]. He reported that Toth model was better to describe high pressure adsorption than Langmuir adsorption isotherm (Figure 5.). High adsorption capacity at high pressure may be contributed to the accessibility of the pore system. At high pressure, CO_2 is more likely to enter the smallest pore system. Structural deformation is suspected can also contribute to the increased storage capacity at high pressure because of larger surface area created.

IV. CONCLUSION

- In general, coal seams in Rambutan field are suitable for storing CO_2 and have favourable criteria that required for CO_2 storage.
- From 4 seams identified inf Rambutan Field, layers 2, 3, 5 and P, have adsorption storage capacity 22.18, 25.09, 24.53, and 34.12 m^3/t on dry-ash-free basis. The largest capacity is found on the deepest layer, seam P. Depth contributes significantly on the storage capacity.
- Langmuir Isothermal is unable to model high pressure adsorption as indicated by low slope response occurred at high pressure whereas multilayer adsorption is expected occurred on this

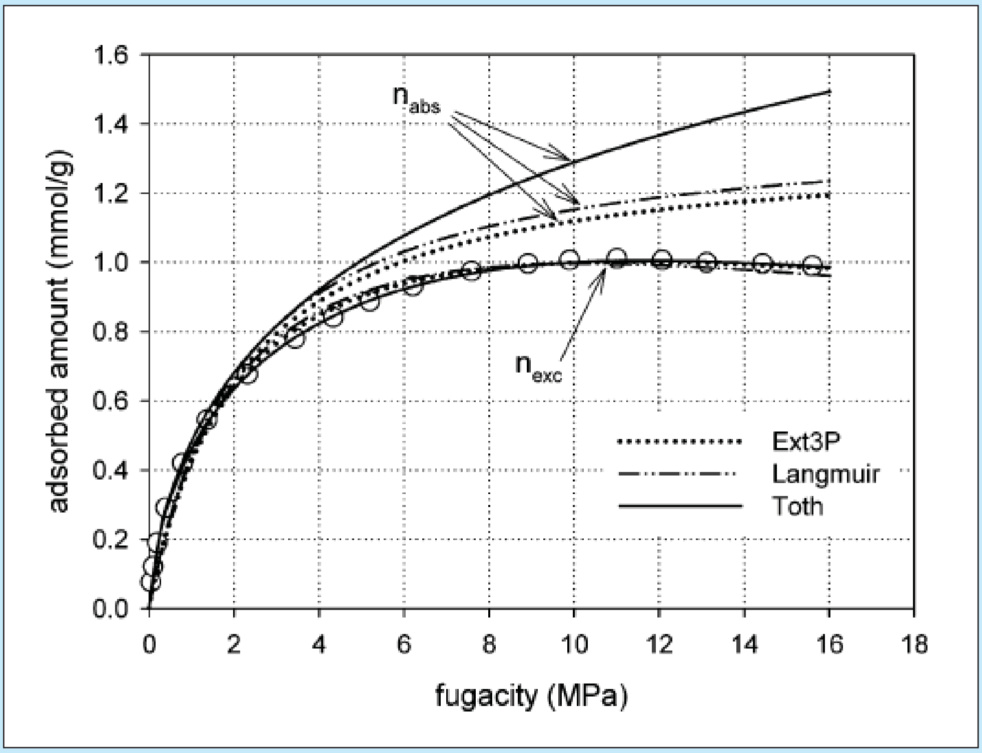

Figure 5
Comparison Toth and Langmuir Model[16]

condition that indicated by a sudden increase of curve or high slope response.

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