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RESERVOIR GAS STORAGE CAPACITY ANALYSIS FOR OILSAND RESERVOIR USING DRYING RATE AND IRREDUCIBLE WATER SATURATIONS METHOD

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Abstract

The maximum pore space available for gas storage in oilsand reservoir was analyzed in this research. This maximum pore space is equal to the maximum volume of water that can be flushed out of the pore space. This corresponds to the difference between the initial water volume and irreducible water volume. Two sets of samples were obtained, the well-mixed and the poorly mixed samples. Three samples were obtained for each of the sets of samples. The ratio of the bitumen to sand was 60:40, 70:20 and 80:20 percent respectively. It was observed that no matter the bitumen content of the oilsand samples used, the irreducible water saturation obtained was 50%. Among the six samples used only two samples followed the expected 2-phases of decline drying curves. These were the well-mixed 60:40% bitumen-sand sample and the poorly mixed 80:20% bitumen sand sample. For the remaining four samples, there were only one phase of decline drying rate which is regarded as the last phase of decline drying curve for the four samples and was therefore taken as the S_{wirr} of the corresponding core sample. It was observed that the obtained porosity values for the samples followed the expected trend for well-mixed samples since porosity is expected to increase with increasing sand content as bitumen is non-porous. The porosity for the well-mixed oilsand samples ranges from 0.0179 and 0.0134 for 60% to 80% bitumen content. For the poorly mixed sample, observed porosity does not follow any reasonable trend. This is expected because the effective porosity for poorly-mixed sample cannot be predicted based on the sand content of the oilsand due to high probability of formation of localized or non-interconnected pore spaces.

Keywords: Irreducible water saturation; CO_2 injection; oilsand; porosity; gas storage.

1. Introduction

This research was carried out to investigate the possibility of using the Agbabu oilsand, Ondo State, Nigeria, as a candidate CO_2 storage reservoir. The irreducible water saturation, S_{wirr}, measurement will indicate the maximum water that can be displaced by the injected CO_2 gas. This will give a rough estimate of the volume of gas that can be stored in the reservoir with special consideration to gas that will be dissolved in the irreducible water.

The Agbabu oilsand samples used in this research was obtained from a well drilled around 1963 from where, presently, the bitumen separates naturally from the oilsand and flows freely during hot day and at about 37^{o}C temperature giving almost pure bitumen. The temperature separates the sand and other metallic impurities from the oilsand due to gravity. Hence, the oilsand out of the well in the hot season is a semi-solid almost pure bitumen.

Due to the softness of the Agbabu oilsand sample that was obtained combined with its over 95% bitumen content, the oilsand was mixed with varying degree of white sands to create possible underground bitumen-sand mixture such as 20 : 80; 30 : 70 and 40 : 60 sand-bitumen contents.

1.1. S_{wirr} Measurement Through Drying Method

The irreducible water is the water that is forced to evaporate from a core due to high temperature. This is indicated by a decrease in the drying rate of the water from the core.

The point of inflection of the drying rate curve signifies a change from the convective drying of the free water in the pore space to the forced drying of irreducible water in the smaller pores of the core sample. This is because the free water is expected to evaporate easily with either increasing drying rate as temperature of the water increases or with constant drying rate at constant drying temperature. The irreducible water tends to stick to the core and must be drained by force.

While the centrifuge method can only eliminate the free water content of the core leaving the core with the irreducible water content after constant core weight is obtained with the method, dryer, or heater, over a long time can eliminate both the free water and the irreducible water content forming a dry-bone core.

A plot of the calculated drying rate from the measured data will give the point when the free water was fully eliminated from the core. This point corresponds with the beginning of evaporation of the irreducible water from the core. This is the point where decline drying rate changed to a more gradual rate.

1.2. Apparent Porosity from the Centrifuge Method

Apparent porosity of the core can be calculated using the total volume of water that is absorbable by the core sample. The core was of 2.5 cm diameter by 2.5cm long with volume 12.2734 cm^3.

Pore volume, V_p = volume of water in the water-filled core at 100% water saturation The core volume above is the volume of an inch diameter and an inch long core.

$$Apparent\ porosity, \emptyset = \frac{V_p}{V_{core}} = \frac{V_{water\ \ at\ Sw=100\%(cm^3)}}{12.2734} * 100\% \quad (1)$$

1.3. Gas Storage Capacity of the Reservoir.

The total reservoir volume can be estimated as follows:

$$Total\ reservoir\ pore\ volume,\ V_p = \emptyset * total\ reservoir\ volume \quad (2)$$

Maximum volume of gas that can be stored in the reservoir is equal to maximum volume of water that can be flushed out of the reservoir by the gas. This volume is equal to the difference of the total reservoir water volume and the irreducible water volume.

The total reservoir water volume, V_{wr}, is the same as fraction of total pore volume occupied by water.

$$V_{wr} = V_p * S_w \quad (3)$$

For 100% water saturated reservoir, the reservoir volume equals the pore volume. In this case Vwr = Vp. Total irreducible water volume,

$$V_{wirr} = V_p * S_{wirr} \quad (4)$$

The reservoir gas storage capacity, RGSC (G_{store}), for the reservoir is estimated as total water volume minus total unmovable (irreducible) water volume,

$$G_{store} = Vwr - Vwirr = Vp\ (Sw - Swirr) \quad (5)$$

This above equation 5 is applicable when there is no solubility of the gas in the reservoir irreducible water and the gas is incompressible. The G_{store} is the reservoir volume available for gas storage. The volume of gas that will be injected at the surface will be far higher than this volume if the gas injection pressure is less than the reservoir pressure. There will be compression of the gas.

Applying the general material balance equation, volume of gas that can be stored in the reservoir will equals

$$G_{inj} = G_{store}\left(B_{CO_2,r} - B_{CO_2.s}\right)$$

$$G_{inj} = V_p(S_w - S_{wirr})(B_{CO_2,r} - B_{CO_2} \quad (6)$$

where, G_{inj} - maximum injected CO_2 gas at surface condition ;$B_{CO2,r}$ - CO_2 gas expansion factor at reservoir condition $B_{CO2,s}$ - CO_2 gas expansion factor at surface condition.

2. Methodology

The following procedure were followed in the course of the research:

- Oilsand was obtained from Agbabu central well with a bitumen content of about 95% due to natural separation process between bitumen and sand content of the Agbabu oilsand at high atmospheric temperature.
- Various samples of the bitumen and sand ratio were artificially created by mixing with white sharp sand to represent the actual subsurface oilsand bitumen-sand ratios at various depths. This was because the Agbabu sample was obtained from a borehole

where the oilsand flows out naturally in the hot afternoons resulting into separation between the bitumen and the sand as the oilsand flows upward.

- Cores of approximately 1cm diameter by 1cm length were prepared from the semi-hardened samples and the cores are then allowed to harden by natural convection followed by long period of drying at about 50°C in oven.
- Cores were saturated with water by soaking for a long time in brine.
- S_{wirr} of the cores were determined using the centrifuge method.
- The gas storage capacity of the cores were then computed with the observed irreducible water saturation.

3. Results and Discussions

The measured data for the drying rate method is as stated below. The centrifuge used for this experiment was operated at a speed of 4000 revolution per minute.

3.1. Well-mixed samples

Sample A1

Table 1 Sw and Drying Rate For Well-mixed 60%:40% Bitumen-Sand Sample

Time (hr)	Mass of core (g)	Water volume in core (g or cm3)	Water saturation Sw (%)	Drying rate kg/hr
0	6.5	0.4	100	
0.1667	6.4	0.3	75	0.600
0.3333	6.4	0.3	75	0.300
0.5	6.35	0.25	62.5	0.300
0.6667	6.3	0.2	50	0.300
0.8333	6.3	0.2	50	0.240
1	6.3	0.2	50	0.200
1.1667	6.3	0.2	50	0.171
1.3333	6.3	0.2	50	0.150
1.5	6.3	0.2	50	0.133
1.6667	6.3	0.2	50	0.120

Volume of the core was 11.4cm^3. From the Table 1, it was discovered that after 40 minutes in the centrifuge, the weight of the Sample A1 became constant from an initial fully saturated weight of 6.5g to a relatively constant weight of 6.3g, therefore at a time of 40 minutes and a mass of 6.3g, it can be said that the core is dry except for the irreducible water content.

Figure 1 shows that the drying rate decreased to a time of 20mins, remain constant for the next 20 minutes and thereafter began to drop. The beginning of the second drop in drying rate corresponds to water saturation of 50% and therefore the S_{wirr} of the core sample is 50%.

Sample B1

The samples B (B1 and B2) are made up of 30% sand and 70% bitumen.

Table 2 Sw and Drying Rate For Well-mixed 70%:30% Bitumen-Sand Sample

Time (Min)	Mass of core (g)	Water volume in core (cm3)	Water Saturation Sw (%)	Drying rate kg/hr
0	7.2	0.4	100	
0.1667	7	0.2	50	1.200
0.3333	7	0.2	50	0.600
0.5	7	0.2	50	0.400
0.6667	7	0.2	50	0.300
0.8333	7	0.2	50	0.240
1	7	0.2	50	0.200
1.1667	7	0.2	50	0.171
1.3333	7	0.2	50	0.150
1.5	7	0.2	50	0.133
1.6667	7	0.2	50	0.120

Volume of core is 12.6cm^3. From the Table 2, it can be inferred that after 10 minutes in the centrifuge, the weight of the core 1 became constant from an initial fully saturated weight of 7.2g to a relatively constant weight of 7.0g. From the graph 3, below it can be inferred that the drying rate reached the peak at time 10 minutes with corresponding water saturation at this point of 50%. There was only one phase of drying rate decrease which is the last phase of decline drying curve and therefore the S_{wirr} of the core sample is also 50%.

Sample C1

These samples are made up of 20:80% sand - bitumen content respectively. Volume of core is 11.6cm^3. Constant weight was achieved within10 minutes of using the centrifuge. From the Table 3 , the weight of the core became constant from an initial fully saturated weight of 6.5g to a relatively constant weight of 6.4g. Therefore, at a time of 10 minutes and a mass of 6.4g, it can be said that the core contain irreducible water.

Table 3 Sw and Drying Rate For Well-mixed 80%:20% Bitumen-Sand Sample

Time (hr)	Mass of core (g)	Water volume in core (g or cm3)	Water saturation Sw (%)	Drying rate kg/hr
0	6.5	0.3	75	
0.1667	6.4	0.2	50	0.600
0.3333	6.4	0.2	50	0.300
0.5	6.4	0.2	50	0.200
0.6667	6.4	0.2	50	0.150
0.8333	6.4	0.2	50	0.120
1	6.4	0.2	50	0.100
1.1667	6.4	0.2	50	0.086
1.3333	6.4	0.2	50	0.075
1.5	6.4	0.2	50	0.067
1.6667	6.4	0.2	50	0.060

As shown in figure 1, the drying rate began to drop uniformly after a time of 10 minutes and this corresponds to water saturation at this point of 50% therefore the S_{wirr} of the core sample is also 50%. Like the sample B1, there was only one phase of decline drying rate curve.

In Figure 1, only the sample A1 shows 2 phases of decline drying rate curve. It is also noted that the sample A1 initially followed the same drying rate pattern as sample C1 and later changed to the drying curve pattern of sample C1. Hence, at low drying time, sample A1 behave exactly as sample C1 and at the S_{wirr}, the drying pattern was exactly as that of sample B1. There is no logical explanation for this behavior as the bitumen content of sample A1 is lower than that of samples B1 and C1.

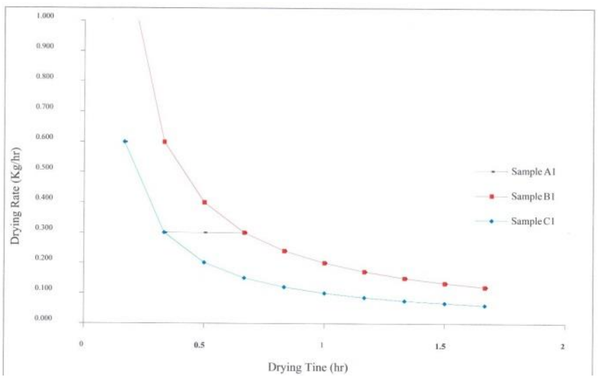

Fig. 1 Drying rate plots for well-mixed samples

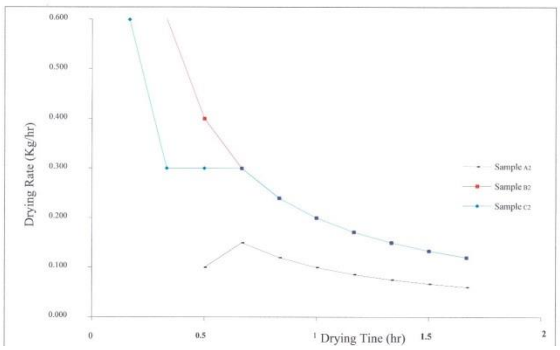

Fig. 2 Drying rate plots for poor-mixed samples

3.1.2. Poorly Mixed Samples

Sample A2

The sample is made from poorly mixed sand and bitumen mixture resulting in poor distribution of pore spaces and, if possible, poorly interconnected poor spaces. Similarly, as in the case of core 1, after 0.67 hr (40 mins) in the centrifuge, the weight of the core became constant from an initial fully saturated weight of 7g to a relatively constant weight of 6.9g (Table 4), therefore at a time of 40 minutes and a mass of 6.9g, it can be said that the core has an irreducible water saturation of 50%.

Table 4 Sw and Drying Rate For Poorly-mixed 60%:40% Bitumen-Sand Sample

Time (hr)	Mass of core (g)	Water volume in core (cm3)	Water Saturation Sw (%)	Drying rate kg/hr
0	7	0.2	100	
0.1667	7	0.2	100	
0.3333	7	0.2	100	
0.5	6.95	0.15	75	0.100
0.6667	6.9	0.1	50	0.150
0.8333	6.9	0.1	50	0.120
1	6.9	0.1	50	0.100
1.1667	6.9	0.1	50	0.086
1.3333	6.9	0.1	50	0.075
1.5	6.9	0.1	50	0.067
1.6667	6.9	0.1	50	0.060

Volume of core is 12.3cm^3. From the figure 2, it can be inferred that the drying rate began to drop uniformly after a time of 40 minutes, from the table, the corresponding water saturation at this point is 50% therefore the irreducible water saturation of the core sample is also 50%.

Sample B2

From the Table 5, it can be inferred that after 10 minutes in the centrifuge, the weight of the sample B2 became constant from an initial fully saturated weight of 7.0g to a relatively constant weight of 6.9g, therefore at a time of 10 minutes and a mass of 6.9g, it can be said that the core has irreducible water content.

Table 5 Sw and Drying Rate For Poorly-mixed 80%:20% Bitumen-Sand Sample

Time (hr)	Mass of core (g)	Water volume in core (g or cm3)	Water saturation Sw (%)	Drying rate kg/hr
0	7.1	0.4	100	
0.1667	6.9	0.2	50	1.200
0.3333	6.9	0.2	50	0.600
0.5	6.9	0.2	50	0.400
0.6667	6.9	0.2	50	0.300
0.8333	6.9	0.2	50	0.240
1	6.9	0.2	50	0.200
1.1667	6.9	0.2	50	0.171
1.3333	6.9	0.2	50	0.150
1.5	6.9	0.2	50	0.133
1.6667	6.9	0.2	50	0.120

Volume of core is 12.3cm^3. From the figure 2 it can be inferred that the drying rate began to drop uniformly after a time of 10 minutes, from the table 4, the corresponding water saturation at this point is 50% therefore the irreducible water saturation of the core sample is also 50%. The drying curve followed exactly the same pattern as that of the equivalent well mixed sample B1.

Sample C2

The core 2 of the sample C weighs same as core 1 and Sample C1 is of better mixing than Sample C2 and hence of better sorted pore spaces. Surprisingly, the drying pattern of the sample, figure 2, is very similar to that of the well mixed sample A1.

Within 40 minutes (table 6), the weight of the sample became constant which implies that all the flushable fluid in the sample has been removed and what remain in the sample was the irreducible fluid.

Table 6 Sw and Drying Rate For Poorly-mixed 80%:20% Bitumen-Sand Sample

Time (hr)	Mass of core (g)	Water volume in core (g or cm3)	Water saturation Sw (%)	Drying rate kg/hr
0	6.4	0.4	100	
0.1667	6.3	0.3	75	0.600
0.3333	6.3	0.3	75	0.300
0.5	6.3	0.25	62.5	0.300
0.6667	6.3	0.2	50	0.300
0.8333	6.3	0.2	50	0.240
1	6.3	0.2	50	0.200
1.1667	6.3	0.2	50	0.171
1.3333	6.3	0.2	50	0.150
1.5	6.3	0.2	50	0.133
1.6667	6.3	0.2	50	0.120

Volume of core is 11.6cm^3. For poorly mixed bitumen-sand samples, the drying rate for the sample with 60% bitumen behaved haphazardly while the sample with 70% bitumen content has constant decline. The sample with 80% bitumen followed the normal expected drying rate curve with two phases of decline rates.

3.1.3 Gas Volume Storability

Table 7 Maximum Injective Gas Volume For Well-mixed Oilsand

Sample	weight, g	Core volume, cc	Water volume, cc	porosity (%)	V_{wirr}, cc	G_{store}. cc	G_{store} (cc/cc reservoir)
A1	6.5	11.2	0.4	3.57	0.2	0.2	0.0179
B1	7.2	12.4	0.4	3.23	0.2	0.2	0.0161
C1	6.5	11.2	0.3	2.69	0.15	0.15	0.0134

For poorly sorted samples:

Table 8 Maximum Injective Gas Volume For Poorly-mixed Oilsand

Sample	weight, g	core volume, cc	water volume, cc	porosity (%)	V_{wirr}, cc	G_{store}. cc	G_{store} (cc/cc reservoir)
A2	7	12.2	0.2	1.64	0.1	0.1	0.0082
B2	7.1	12.3	0.4	3.25	0.2	0.2	0.0163
C1	6.5	11.2	0.3	2.69	0.15	0.15	0.0134

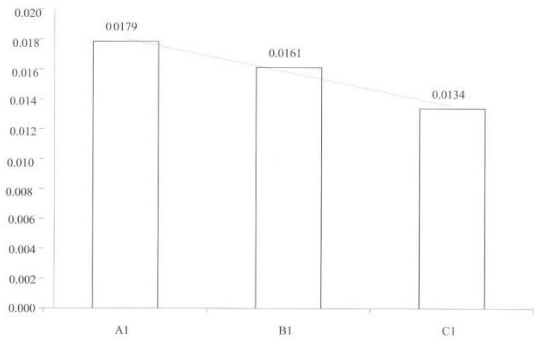

Fig. 3 Gas storage capacity for well-mixed oilsand samples

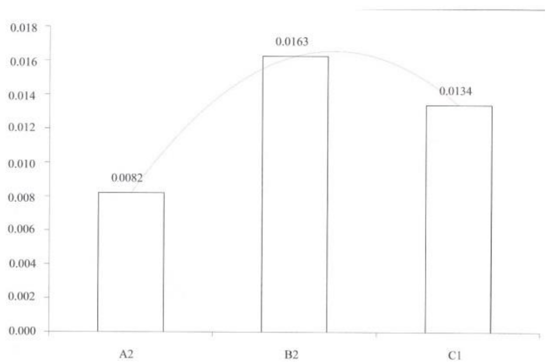

Fig. 4 Gas storage capacity for poorly-mixed oilsand samples

4. Conclusions

The observed maximum possible gas injection G_{inj}, followed the expected pattern as shown in figure 3. This is because, the higher the volume of sand content the higher the expected pore spaces available for gas storage.

For poorly mixed samples, the porosity and hence the space available for gas injection did not follow any reasonable pattern. This is because of the fact of the inter-connectivity of the pore space in the sand zone is unpredictable due to the poor mixing. Estimating gas storage ability of a poorly sorted oilsand zone for gas injection can be erroneous as some of the pore spaces can be localized while the effective poor space is unpredictable.

References

[1] Adebayo Thomas, 2014, “Carbon Dioxide Storage in Unconventional Underground Reservoirs: A Laboratory Study Approach”, Lambert Academic Publications, Germany.

[2] Adebayo Thomas Ayotunde, Nwafor-Orizu Ezejanu N. and Aria Osiwi, 2013, Experimental Study of The Change In Porosity of Imeri Oilsand Rock Contaminated With CO_2, *Chemical & Process Engineering Research*, IISTE, vol.16, pp.1-4

[3] Adebayo Thomas Ayotunde and Olawumi Bukola Funke, 2012, Experimental Study of CO_2 Contamination On The Porosity of Dry Kwale Field Reservoir Rock. *The International Journal of Science & Technology (IJST UK)*, vol.1, no.7, pp.343-345

[4] Hiromi Honda and Kinji Magara, 1982, Estimation Of Irreducible Water Saturation And Effective Pore Size Of Mudstones, *Journal of Petroleum Geology*, Volume 4, Issue 4, pages 407–418, April 1982