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Determination of Moisture Adsorption Isotherm of Shale from Agbada Formation Using GAB Model

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Abstract

Shales are susceptible of different phenomena, including swelling, shrinkage and hydration (shale instability); hence are impacted by moisture content. Moisture adsorption isotherms of shales from Agbada Formation were determined at $27^{\circ}C$ over a water activity (a_w) range of 0.30 to 0.96 using a Static gravimetric technique. Moisture adsorption isotherms of these two shale samples from well A and well B exhibited the sigmoid type II and V shapes respectively. The Guggenhein, Anderson, de-Boer (GAB) model was applied to fit the experimental data satisfactorily. A non-linear regression analysis method was determined to evaluate the parameters of GAB sorption equations. The criteria used to evaluate the goodness of fit to the model were Quadratic estimates, Central derivatives and Conjugate search of Microsoft Excel. The GAB model was used because it fit to the experimental adsorption data for a wide range of water activity (0.10 - 0.96) and the error square value calculated from Microsoft Excel was low. The estimated GAB parameters and constants were in good agreement with what the model dictates and with literature.

Keywords: Shale, adsorption isotherm, GAB model, water activity, monolayer moisture content.

Introduction

Shales are sedimentary rocks that have distinct laminated layers and moderate to high clay content. These distinct characteristics make them vulnerable to phenomena such as swelling, shrinking, hydration, strength reduction and ultimately failure¹. Dzialowski mentions that over 90% of formations drilled worldwide are classified as shale formations. He further explains that about 75% of drilling operations' problems are related to shales. Drilling problems have often been approached on a trial and error basis. Chenevert points out that one of the most important factors that lead to shale failure is that shales contain a significant amount of clay¹. Shales tend to hydrate when they come in contact with water. The transfer of water and ions from and to the shale alter the chemical and physical state of the shale ². Reactive clay minerals such as smectite have a higher number of active interlayers and increased isomorphic substitution than less reactive clays. Shales with higher reactive clays will therefore have more area for monolayer coverage by water molecules before multiple layers begin to form. Chenevert studied the effects of water adsorption on shale samples. He found out that all the shale samples tested were altered as a result of water adsorption, especially Montmorillonitic shales¹. Adsorption isotherms provide information on a material's water content at certain equilibrium conditions. The behavior of a shale sample under these conditions can directly be related to its hydration and swelling potential. The isotherm can also give information on the expandable clay content of the shale. Chenevert studies shale preservation and testing techniques for borehole stability studies and found out that the controlled humidity desiccator technique, that is, the static gravimetric

method, also known as the isopiestic method used to develop the shale adsorption isotherms is a convenient method for hydrating a sample without the risk of material loss; which is commonly associated with direct wetting in the presence of water². Chenevert presented a shale control technique using the concept of "Balanced water activity" in solving drilling problems associated with shales³. He stated that the main reason for shale instability during drilling with water-based fluids is water adsorption and subsequent swelling of the wellbore. In other words, water adsorption could be prevented if the water activity of the drilling fluid is the same as the water activity of the shale pore fluid⁴. The moisture adsorption isotherm of this shale samples could be valuable information on solving the drilling problems encountered when tripping in or out of this shale formations since they give information about the humidity-water activity relation at a given temperature⁵. A number of models to describe moisture sorption isotherm have been proposed but the Guggenheim, Anderson and de Boer (GAB) model is considered to be the most versatile sorption model available in the literature⁶.

The objectives of this study were, hence, to determine experimentally the equilibrium adsorption isotherm of this two Niger-Delta shale samples from Agbada formation and to model the adsorption characteristics using GAB equation.

Material and Methods

Shale samples from two wells in Agbada formation were used for this study. The first sample, Well A from Usan was cored at a depth of 2005 ft - 2006 ft. The second sample, Well B from

Obagi was cored at a depth of 3462.91 ft - 3464 ft and preserved. The Static gravimetric method, also known as the isopiestic method was used to develop the shale adsorption isotherms. In this method, weight measurements were taken of shale samples under varying relative humidity conditions at constant temperature and pressure. The relative humidity environments were created using saturated salt solutions in desiccators. The moisture adsorbed physically is the difference between the water content as expressed in initial weight and the water content at equilibrium known as the final weight of the sample. For this study, tests were carried out at ambient conditions. The adsorption isotherm curve is a plot of the amount of water adsorbed by the shale when placed in various desiccators versus the desiccator's water activity. To prepare these desiccators, various kinds of saturated salt solutions were used to provide and maintain different relative humidity environments. Six saturated salt solutions [KCl, CaCl₂, NaCl, K₂SO₄, KNO₃ and Ca(NO₃)₂.4H₂O] were used to provide constant water activity range from 0.3 to 0.96. These salt solutions were prepared with reagent grade salts and distilled water. The relative humidity data of the salt solutions were obtained from Greenspan. The shale samples were dried by placing them in an oven at 200°F for 24 hours, and then the weight of each dry shale sample was measured. Shale samples are placed in several desiccators with different relative humidity. A vacuum is pulled on the desiccators in order to remove the air and accelerate the test towards equilibrium. As the shale adsorbs water, a weight gain is observed. Each shale sample is weighted daily until there is no further weight gain observed. The shale sample is in equilibrium with the atmosphere inside the desiccators when the shale sample weight becomes constant. The final weight of each sample is taken. The amount of water absorbed by the shale sample is calculated as the difference between the final weight and the dried weight. The shale water activity is determined by matching the native moisture content of the shale with its respective water activity value from the adsorption isotherm curve.

Mineralogy: Mineralogy analysis indicates the relative quantities of compounds present in a rock. Clay and non-clay minerals are usually present in shales. The type of clay present is an indication of the degree of hydration experienced by the shale. It can be used to estimate the severity of wellbore instability issues that may arise. The mineralogy analysis for both Well A and Well B samples are presented in table-1. The Well A (Usan) cored at a depth of 2005 ft – 2006 ft, is made up of 20% quartz and 52% clay. It contains other non-clay minerals such as feldspar and carbonates in minimal amounts. The bulk of the clay content consists of illite and mixed clays with small amount of smectite. The existence of smectite indicates the probability of some swelling and dispersion in aqueous solution. Well B cored at a depth of 3462.91 ft - 3464 ft, is composed of 22% quartz and 51% clay. It also contains negligible amount non-clay minerals such as feldspar and carbonates. Zero smectite levels indicate low swelling tendencies.

Adsorption Isotherm Model: The experimental data obtained corresponding to the water activity, a_w and moisture content was adjusted to GAB (Anderson, 1946; de Boer, 1995; Guggenheim, 1995) equations in order to determine the best fit.

Data Requirements: At least 3 data points of a water activity, a_w / moisture measured at the same temperature, water activity, a_w may be entered as a value or a salt, moisture may be entered as a value (dry or wet basis) or as a set of pan / sample weights.

GAB Equation: This equation has a similar form of BET, but has an extra constant, K. BET is actually a special case of GAB, with K = 1. The GAB equation was used to model water adsorption of these shale samples as follows:

$$m = \frac{CKa_{wM_0}}{(1 - Ka_w)(1 - Ka_w + KCa_w)}$$
(1)

Where m is the amount of sorbate adsorbed by 1g of sorbant at sorbate activity a_w , M_o is the monolayer moisture content. C and K are GAB constants and are related to monolayer and multilayer properties¹². The assumption of the GAB model over the BET (Brunauer, Emmett and Teller)⁶ formulation stating that the sorption state of the sorbate molecules in the layers beyond the first is the same, but different to the pure liquid state, demands the introduction of the additional constant K⁸. C and K are related to the temperature effect being expressed by equation 2 and 3:

$$C = C_o \exp\left(\frac{\Delta h_c}{RT}\right) \tag{2}$$

$$K = K_o \exp\left(\frac{\Delta h_k}{RT}\right) \tag{3}$$

Where Δh_c is the specific bonding enthalpy of water monolayer (J/kg), Δh_k is the mean specific bonding enthalpy of the water multilayer (J/kg), R is the universal gas constant (J/kg/K), T is the absolute temperature (K), $\Delta h_{s,mono}$ is the specific sorption enthalpy of water monolayer (J/kg), Δh_{vap} is the specific vaporization enthalpy of water (J/kg), $\Delta h_{s,multi}$ is the mean specific sorption enthalpy of the water multilayer (J/kg), C_o and K_o are adjustable parameters accounting for temperature effect.

$$\Delta h_k = \Delta h_{s,multi} - \Delta h_{vap}$$

$$\Delta h_c = \Delta h_{s,mono} - \Delta h_{vap}$$

The GAB equation can be rearranged to polynomial expression:

$$\frac{a_{w}}{m} = \frac{K}{M_{o}} \left(\frac{1}{C-1}\right) a_{w}^{2} + \left(\frac{C-2}{C*M_{o}}\right) a_{w} + \frac{1}{C*K*M_{o}}$$
(4)

The modified GAB equation replaces C with C/T, where T is the temperature in °C. This enables isotherms to be estimated for any temperature, based on data measured at one temperature. However, the accuracy of this is approximate only, as it assumes all materials are affected by temperature identically.

Model Validation: In this research, GAB equation was used to model the moisture adsorption isotherms for these shale samples. The experimental data were fitted to the model using a

non-linear regression. All calculations were performed using Microsoft Office Excel 2007 solver and analysis toolpac. The coefficient of determination, R^2 , was calculated to give a measure of the proportion of variability attributed to the model. In addition to R^2 , the criteria used to evaluate the fit of GAB model were quadratic estimates, central derivative, conjugate search and error square (E^2) method of the solverpac. It is calculated as follow:

$$E^{2} = \sum_{i=1}^{N} (m_{exp} - m_{pre})^{2}$$
(5)

Where m_{exp} is the experimental value, m_{pre} is the predicted value, and N is the number of experimental data which is six (6). The lower the value of the error square, E^2 during the non-linear regression; the better the GAB model curve fitting.

Results and Discussion

Experimental characteristic of moisture adsorption isotherm: The experimental moisture adsorption data obtained corresponding to the water activity values of the salt solutions which ranges from 0.30 to 0.96 are presented in figure 1 and 2.

The adsorption isotherm for well A sample exhibited a shape similar to the sigmoid Type II as shown in figure 1. Type II sigmoid do not exhibit saturation limit. This type of isotherm indicates an indefinite multi-layer formation after completion of the monolayer and is found in adsorbents with a wide distribution of pore size. The intermediate flat region in the isotherm corresponds to monolayer formation, following which adsorption occurs in successive layers. Several authors including Chenevert and Osisanya have reported isotherms with similar Type II shape^{9,10}.

The adsorption isotherm for Well B sample exhibited a shape similar to the sigmoid Type V as shown in figure 3. Type V adsorption isotherm shows phenomenon of capillary condensation of gas. The saturation level reaches at pressure below the saturation vapour pressure; this can be explained on the basis of possibility of gases getting condensed in the tiny capillary pores of adsorbent at pressure below the saturation pressure of the gas. It can be deduce from figure 2 and 3 that Well A has higher adsorptive potential than Well B and a conclusion that more adsorption took place in Well A than in Well B can be made; therefore more expandable clays are present.

Modeling of Adsorption Isotherm: The Guggenheim, Anderson and DeBoer (GAB) model being the most commonly accepted model was used to fit the isotherms of Shale A and Shale B. The flexibility of the GAB isotherm has been attested through various literatures⁴. That is, it fits a wide variety of materials. Other shale adsorption isotherms developed by Osisanya for Mancos, Wellington and Pierre shales were also fitted. This was done to investigate any possible trend with shale

type and GAB model parameters. The most important parameter in the model is the monolayer moisture content M_o . Reactive clay minerals such as smectite have a higher number of active interlayers and increased isomorphic substitution than less reactive clays. Shales with higher reactive clays will therefore have more area for monolayer coverage by water molecules before multiple layers begin to form.

The experimental adsorption isotherm of Well A and Well B samples were fitted to the GAB model (equation 1). The most important parameter in the model is the monolayer moisture content M_{o} . Reactive clay minerals such as smectite have a higher number of active interlayers and increased isomorphic substitution than less reactive clays. Shales with higher reactive clays will therefore have more area for monolayer coverage by water molecules before multiple layers begin to form. Thus, the M_{o} of reactive shale should be higher than that of less reactive shale. In our study, Well A and B have M_o values of 6.728 g/g (dry basis) and 2.999 g/g (dry basis). Thus, Well A is more reactive than Well B. Microsoft Office Excel solver was used to fit the curves to the model equation. It was programmed to uses a nonlinear regression-least squares method for curve fittings. The square of the correlation coefficient (R^2) for the fit should range between 0.9 and 1.00 to show a good fit for the model. The coefficients of determination (R^2) for fitting the GAB model was suitable and afforded the best fits to the experimental data because this model gave the best regression coefficient as shown in figure 3 and 4. Experimental data was inputted into the work sheet along with the model equation and the analysis of the nonlinear regression-least squares method for curve fitting carried out (tables 2-5). The square of the correlation coefficient (\mathbf{R}^2) for the fit ranged between 0.95 and 0.98 showing a good fit by the model. Well B fitted more GAB model than Well A shale sample. Another application of adsorption isotherm modeling is the determination of properties at temperatures other than the ambient. Most shale isotherms have been developed under ambient conditions. This is however not representative of in-situ conditions; generally, increased temperature will reduce adsorption to some degree¹⁰. These isotherms can be obtained by placing samples in a constant environment chamber at various temperatures and relative humidities. The temperature dependent parameters, C and K can be evaluated based on their variations with temperature. If a trend is established, predictions can be made for downhole temperatures or desired range of temperatures. Table 2 estimated values of GAB model parameters and regression coefficient, R^2 . It has also been recognized that the fit become better as the determination coefficient approaches 1 and this is evident for the GAB model. Therefore, the GAB equation is optimal to fit the moisture adsorption isotherms of the shale samples. The parameter K is in keeping with sorption on multilayer above the first layer and the heat of vaporization of water. Thermodynamically, K's needs to be smaller than 1.000. The value of K provides a measure of the interactions between the molecules in the multilayer with the adsorbent, and it tends to fall between the energy value of the molecules in the monolayer and that of liquid water. The fitting

of the isotherms with this model was high (R > 0.90) and in all cases the results obtained in the present work for the adjustment of GAB model to the different shale samples are in accordance with the limit values for constants C and K suggested by Lewicki, based on the mathematical analysis of the model (0.24 < K <1)¹¹.

The Monolayer Moisture Content: Modeling of adsorption data of the shale samples using GAB equation allows the determination of monolayer moisture content values, M_o , which are measure of adsorption possibility of the shale samples. The value of the monolayer moisture content indicates the amount of

water that is strongly adsorbed to specific site at the shale sample surface, and this is a value that must be reached in order to assure shale stability. The monolayer moisture content calculated from the GAB model (table 2) were 6.7284 g/g (dry basis) for Well A and 2.9987 g/g (dry basis) for Well B. The low value of M_o reflects a reduction in the number of active sites due to chemical and physical changes. This can also be noticed in the experimental data isotherm where Well B exhibited a shape similar to the sigmoid Type V. Type V adsorption isotherm shows phenomenon of capillary condensation of gas.

Table-1 Shale Sample Mineralogy

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	Data Name File Name Sample Name Comment <entry card<br="">No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0257</entry>	For : W E : SAN : AG : DAE Si Alto K, H3C Pot K-Mg-Z Pot	LL B APLE-B.T BADA S RKISH-SP memical Licon (205 (0H) 4 iminum 2 205 (0H) 4 1-SiO2- cassium (si20)	Aluminu HALE IALE Silicon Silicon Silicate Salolo(o Aluminu H2O Iron Ma	ineral Na , syn) Hydroxia Hy2 m Silicat gnesium /	ame) de Hydra te Hydro Aluminum	5 0.270 : 0.564 : te (Ha 0.567 (xide (0.629 (Silice 0.629 (Dx Dx 1.000(3/11 1.000(5/7 0.1882(15/18) 11 0.909(10/22) 0.909(10/22) 0.909(10/22)	wT%) 0.569) 0.619) 0.757) 0.690	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0	R - 414
	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357</entry>	: W E : SAN : SAN : AG: : DAN Ch Si : II Al22Si2 Al2 (K,H33C (K,H36 (K,H36 (K,H36) (K,	LL B MPLE-B.F BADA S RKISH-SF memical licon (205 (OH) 4 125102 cassium Al-Si02- cassium (Si3AL) (Si3AL)	PKR HALE IALE Silicon 1.2H20 Silicate Saloio(0 Aluminu H20 Iron Ma OS	ineral No , syn) Hydroxid m Silica gnesium 2	ame) de Hydra te Hydro Aluminum	S 0.270 0.564 te (Ha 0.567 (side (Silica 0.629 (Silica 0.632 (Silica	Dx Dx 1.0000(3/11 1.0000(5/7 0.882(15/18 T1 D.909(10/22 ate	WT%) 0.569) 0.619) 0.757) 0.690) 0.716	d I S.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.498 0	R
	Data Name File Name Sample Name Comment (Entry Card) No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595	For : WE : SAN : AG : DAE : DAE Si Al25 : Al2 : (K, H3C Pot (K, H3C Pot (MG, K) Pot	LL B APLE-B. B APLE-B. B BADA S RKISH-SE bemical bemical licon (205 (0H) 4 iminum S 205 (0H) 4 iminum S assium (Si3A1) 5015 (0H)	PKR HALE HALE Silicon 1.2H20 Silicate Salolo (o Aluminu H20 Tron Ma 08 Sodium 2 6420	ineral Na , syn) Hydroxid H)2 m Silica gnesium / Aluminum	ame) de Hydra te Hydro Aluminum Silicat	S 0.270 0.564 te (Ha 0.567 (xide (0.629 (Silica 0.632 (0.632 (0.632 (0.632 (0.634 (5.4))	L Dx L 0000(3/11 0.882(15/18 I1 0.909(10/22 ate 0.941(16/17) 0.941(16/17) 0.941(16/17)	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716</pre>	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0	R .414 .334 .321 .313 .310
	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595</entry>	: W E : SAN : AG : DAN Ch Si Al2Si2 Al2 (K, H3G (K, H3G (K, H3G (Na, K)) (Na, K) Mg4Si4	LL B MPLE-B.F BADA S RKISH-SF Memical Memical 1000 (0H) 4 2005 (0H) 4 125102 125310 1255100 1255100 1255100 1255100 1255100 1255100 10	PKR HALE IALE Formula Name (M Silicon I.2H20 Silicate Salo10(0 Aluminu H20 Iron Ma OS Sodium 2.6H20 Silicate	ineral Na , syn) Hydroxid m Silica gnesium ; Aluminum	ame) de Hydra te Hydro Aluminum Silicot	5 0.270 te (Hd 0.567 (Side (Side (Sidics) 0.629 (Sidics) 0.632 (Sidics) 0.564 (Sidics)	Dx Dx 1.000(3/11 1.000(5/7 11) 0.882(15/18 T1 0.909(10/22 ate 0.941(16/17 ate 0.941(16/17 ate 0.917(33/39	WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.498 0 0.451 0	R - 414
	Data Name File Name Sample Name Comment (Entry Card) No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595	For : WE : SAN : AG : DAE Ch Si Al2 : Al2 : Ch : AG : DAE : AG : A	LL B APLE-B. BADA S RKISH-SE bemical bemical licon (205 (0H) 4 iminum S 205 (0H) 4 iminum (21 Jan 20 cassium (Si3A1) cassi	PKR HALE HALE JALE Silicon 1.2H20 Silicate Salolo (0 Aluminu H20 Tron Ma 08 sodium 2.6H20 Silicate	ineral Na , syn) Hydroxid H)2 m Silicai gnesium / Aluminum e Hydroxa	ame) de Hydra te Hydro Aluminum Silicat ide Hydr	S 0.270 : 0.564 : xide (0.629 (silica 0.632 (c (sa 0.564 (ate (: 200)	L Dx 1.000(3/11 0.882(15/18 11 0.909(10/22 ate 0.941(16/17) 0.941(16/17) 0.941(16/17) 0.941(16/17) 0.941(33/39 0.947(33/39) 0.947(33/39)	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709</pre>	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0 0.451 0	R .414 .334 .321 .313 .310 .293
	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135</entry>	Fee SAN SAN SAN SAN SAN SAN SAN SAN SAN SAN	LL B MPLE-B. B MPLE-B. B RKISH-SF memical licon (205 (0H) 4 cassium (Si3Al) sassium (Si3Al) mesium (Al,Mg)2	PKR HALE HALE Formula Name (M Silicon Silicate Saluolo (O Aluminu H2O Tron Ma O8 Sodium 2.6H2O Silicat Silicat	ineral Na , syn) Hydroxia Mydroxia gnesium / Aluminum e Hydrox: OH) 2.4H23	ame) de Hydra te Hydro Aluminum silicat	5 0.270 0.564 te (Ha 0.567 (0.629 (0.629 (0.632 (0.632 (0.632 (0.564 (0.564 (0.564 (0.289 (0	Dx Dx 1.000(3/11) 0.882(15/18 T1 0.909(10/22 ate 0.941(16/17 atd 0.917(33/39 3ep 0.923(12/17	WT% > 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596	d I 5.G. 0.726 0 0.540 0 0.481 0 0.498 0 0.498 0 0.451 0 0.451 0	R .414 .334 .321 .313 .310 .293 .292
	Data Name File Name Sample Name Comment (Entry Card) No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135	E W E SAN SAN CP SI SI Al2Si2 Al2Si2 Al2 K-Mg-Z Pot (Na, K) Fot (Na, K) Ca0.2 Ca0.2 Ca1.2	LL B MPLE-B.I BADA S RKISH-SF hemical licon (205 (OH) 4 LSIO2- cassium Al-SiO2- cassium (Si3Al) cassium (S	PKR HALE IALE Silicon 1.2H20 Silicote BAL010 (0 Aluminu H20 Iron Ma 08 Bodium 2.6H20 Silicat Silicat Silicot H20 Iron Ma 08 Sodium	ineral Na , syn) Hydroxid m Silicar gnesium 2 Aluminum e Hydrox: Aluminum	ame) de Hydra te Hydro Aluminum Bilicat ide Hydr o Silica	S 0.270 : 0.564 : te (Ha 0.629 (Silde (0.632 (0.632 (0.632 (c (San 0.564 (atte (, San 0.564 (atte)	L.000(3/11 Dx 1.000(5/7 all 0.882(15/18 T1 0.909(10/22 ate 0.941(16/17 ald 0.917(33/39 Sep	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596</pre>	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0 0.451 0 0.451 0	R .414 .334 .321 .313 .310 .293 .292
- 48 	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488</entry>	For : W E : SAU : DAI : DAI : DAI : DAI : DAI : DAI : DAI : Ch : Si : 1 : Si : Si	LL B 1PLE-B BADA S RKISH-SF memical licon (205 (0H) 4 103 (0H) 103 (0H) 103 (0H) 104 (0H) 105	PKR HALE IALE Formula Name (M Silicon Silicate Salolo(0 Aluminu- H20 Iron Ma OS Bodium 2.6H20 Silicat 2514010(0 Caluminu- H20 Iron Ma OS Silicat	ineral Na , syn) Hydroxid M Silica gnesium J Aluminum e Hydrox: OH) 2.4H2(Aluminum	ame) de Hydra te Hydro Aluminum Silicat ide Hydr o Silica	5 0.270 0.564 xide (0.629 (0.629 (0.629 (0.632 (0.632 (0.632 (0.289 (0	L Dx L	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.619</pre>	d I 5.G. 0.728 0. 0.481 0 0.481 0 0.498 0 0.451 0 0.451 0 0.530 0 0.470 0	R -414
	Data Name File Name Sample Name Comment <entry card<br="">1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488</entry>	: WE : SAN : SAN : DAH CH Si : DAH CH Si : DAH CH Si : DAH CH Si : DAH CH Si : CH Si : CH Si : CH Si : SAN CH Si : SAN C : SAN C SAN SAN C SAN SAN C SAN SAN SAN SAN SAN C SAN SAN SAN SAN SAN SAN SAN SAN SAN SAN	LL B MPLE-B.F BADA S RKISH-SF Memical licon (205 (0H) 4 Cassium Al-Si02- cassium (Si3Al) Cassium (Si3Al) Colored (Si3Al) (PKR HALE IALE Formula Name (M Silicon 1.2H2O Silicate Salolo (O Aluminu H2O Iron Ma O8 Bodium 2.6H2O Silicat Silicat Silicat Silicat Silicat Silicat	ineral Na , syn) Hydroxid M Silicat gnesium 2 Aluminum e Hydrox: Aluminum Hydroxid	ame) de Hydra te Hydro Aluminum Silicat ide Hydro m Silica	5 0.270 : 0.564 : 0.567 (0.629 (0.632 (e (8at 0.564 (ate (.8 0.564 (ate (.8) 0.564 (ate (.8) 0.564 (ate (.8) 0.289 (te Hydi) 0.326 : 1inite	L.000 (3/11 Dx 1.000 (3/11 D.941 (16/17) 0.942 (15/18 T1 0.941 (16/17) 0.917 (33/39 Sep 0.912 (12/17) 0.923 (12/17) T0.923 (12/1	<pre>wT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.596</pre>	a I S.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0 0.451 0 0.451 0	R .414 .333 .321 .313 .310 .293 .292 .291
	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 0</entry>	Fee Sales Fee Sales Fee Sales Sales Fee Sales Sales Sales Sales Sales Sales Sales Sales Sales Sales Sales	LL B 1PLE B 1PLE B BADA S RKISH-SP nemical 1cicon (205 (0H) 4 105 (0H) 105 (Aluminu HALE IALE Formula Name (M Silicon Silicate Aluminu H20 Iron Ma O8 Solium 2.6H20 Silicat Silicate	ineral Na , syn) Hydroxid H)2 m Silica gnesium / Aluminum e Hydrox: Aluminum Hydroxid	ame) de Hydra te Hydro Aluminum Bilicat ide Hydr m Silica de (Kao 0	5 0.270 0.564 2.567 2.56	L Dx Dx 1.000 (3/11 	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.619 0.743</pre>	d I 5.G. 0.728 0 0.481 0 0.481 0 0.498 0 0.460 0 0.451 0 0.530 0 0.470 0 0.402 0.2	R - 414 - 334 - 321 - 313 - 310 - 293 - 292 - 291 - 291 - 291 - 291
	Data Name File Name Sample Name Comment (Comment) Earry Card 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 c	: W E : SAN : SAN : DAN CH Si 3125i2 Al225i2 Al25i2 (K,H33C (K,H33C (K,H34C (K,H34C) (K,H35C)	LL B MPLE-B.F BADA S RKISH-SF Memical licon (205 (OH) 4 ISSUE Construction (Si3Al) Costium Sol5 (OH) Sol5 (OH) Costium Ma Sol5 (OH) Sol5 (KR HALE IALE Formula Name (M Silicon 1.2H2O Silicate BALO10 (O Aluminu H2O Iron Ma O8 godium 2.6H2O Silicate Silicate Silicate Silicate Silicate Silicate Silicate	ineral Na , syn) Hydroxia m Silicai gnesium i Aluminum e Hydroxia Aluminu Hydroxia (Calci	ame) de Hydra te Hydro Aluminum Silicat ide Hydr o m Silica de (Kao 0 0 0	S 0.270 : 0.567 (0.567 (0.629 (0.632 (6 (5at 0.564 (ate (5 0.256 (0.256 (0.25	L.000(3/11 Dx 1.000(5/7 all 0.882(15/18 TI 0.941(16/17 ald 0.917(33/39 3ep 0.923(12/17 rox 1.000(14/21 1.000(14/21)	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.619</pre>	d I S.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0 0.451 0 0.530 0 0.470 0 0.402 0.2	R .414 .334 .313 .310 .293 .292 .291
	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 0 10 6-0263 F</entry>	F = W E : SAN : AG: : DAI : Ch Si : Ch Si Al2Si2 Al2C (K, H3C (K, H3C (K	LL B IPLE-B. IPLE-B. BADA S RKISH-SP memical licon (205 (0H) 4 1-SiO2- cassium (Al,Mg) 2 Lcium Ma 205 (0H) 4 iminum Se Lcium Ca Labor Loss Leium Ca Loss (0H) 4 Loss Loss (0H) 4 Loss (Aluminu Formula Name (M Silicon L2H20 Silicate Salol0 (O Aluminu H20 Iron Ma OS Silicat Silicate Silicate Silicate Silicate Silicate Silicate	ineral No , syn) Hydroxio H)2 m Silica Gunesium 2 Aluminum e Hydroxio Aluminum Hydroxio (Calci	ame) de Hydra te Hydro Aluminum Silicat ide Hydr m Silica de (Kao 0 te, syn 0	S 0.270 0.564 xide (3ilde (3	L Dx Dx 1.000(3/11 	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.619 0.743 0.693</pre>	d I 5.G. 0.728 0 0.481 0 0.498 0 0.498 0 0.498 0 0.451 0 0.530 0 0.402 0.2 0.430 0.2	R -414 -334 -321 -313 -293 -292 -291 -291 -249 -248
	Data Name File Name Sample Name Comment <entry cardb<br="">No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 C 10 6-0263 F</entry>	: W E : SAN : AG : DAF Ch Si : Sil Al2Si2 Al2Si2 (K,H3G (K,H3G (K,H3G (K,H3G (K,H3G) (K,H3G) (K,H3G) (K,H3G) (Ca0.2) Ca0.2 Ca0	LL B MPLE-B.F BADA S RKISH-SF memical licon (205 (OH) 4 125102 cassium (Si3Al) 5015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 4 15015 (OH) 15015 (OH)	PKR HALE IALE Formula Name (M Silicon 1.2H20 Aluminu H20 Tron Ma Columinu 2.6H20 Silicat 2.6H20 Silicat 2.6H20 Silicat Silicat Silicat 2.6H20 Silicat	ineral Na , syn) Hydroxia m Silica gnesium / Aluminum e Hydrox: Aluminu Hydroxia (Calci m Silica	ame) de Hydra te Hydro Aluminum Silicat ide Hydro m Silica de (Kao oté, syn 0 té, syn 0	5 0.270 0.564 0.567 0.567 0.629 0.632 0.632 0.632 0.289 0.290 0.289 0.290 0.20	L Dx Dx 1.0000(3/11 1.0000(5/7 0.882(15/18 T1 D.909(10/22 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.917(33/39 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.923(12/17) 0.933(10/42) 833(10/42) Mu	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.709) 0.596) 0.619 0.743 0.693</pre>	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.450 0 0.451 0 0.451 0 0.402 0.2 0.402 0.2	R .414 .334 .321 .313 .293 .292 .291 .291 .249 .248
	Data Name File Name Sample Name Comment <entry card<br="">1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 0 10 6-0263 F 11 10-0495</entry>	For : W E : SAN : AG : DAI : DAI : Si : DAI : Si : DAI : Si : DAI : Si : Si : Ch : Si : Ch : SAS : Ch : Si : SAS : Ch : Si : SAS : Ch : SAS :	LL B IPLE-B.E BADA S RKISH-SF memical licon (205 (0H) 4 1.5321 .3331) .41-SiO2- .2351um .2351um	Aluminu PKR HALE IALE Formula Name (M Silicate Salolo (0 Aluminu H2O Iron Ma OS Silicat Silicate Silicate Silicate Concessium Concession Conces	ineral No , syn) Hydroxid Hy2 m Silican Gunesium 2 Aluminum e Hydroxid Aluminum Hydroxid (Calcin m Silican	ame) de Hydra te Hydra Silicat ide Hydro de (Kao de (Kao de (Kao	S 0.270 0.564 5.567 0.632 0.632 0.632 0.632 0.289 0.564 0.289 0.289 0.289 0.289 0.289 0.289 0.289 0.564 0.564 0.564 0.563 0.564 0.563 0.583 0.583 0.563 0.563	L Dx Dx 1.000 (3/11 	<pre>WT%) 0.569) 0.619) 0.716) 0.709) 0.596) 0.619 0.743 0.693) 0.715</pre>	d I 5.G. 0.728 0. 0.540 0 0.498 0 0.498 0 0.498 0 0.498 0 0.451 0 0.451 0 0.451 0 0.402 0.2 0.430 0.2 0.386 0	R -414
1.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00	Data Name File Name Sample Name Comment <entry card=""> No. Card 1 27-1402 2 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 c 10 6-0263 F 11 10-0495</entry>	: W E : SAN : AG : DAI Ch Si : 12 : AG : Sil Al2Si2 Pot (K,H3G (K,H3G (K,H3G (CAO.2) CAD CAO.2 C	LL B (PLE-B.F BADA S RKISH-SF Memical lemical licon (205 (OH) 4 iminum S 0 (Si3Al) (Al,Mg) 2 Leium Ma (Al,Mg) 2 Leium Ma (Al,Mg) 2 Leium Ma Sol5 (OH) 4 iminum S leium Ca sigal) olo cassium Sassium Sassium	PKR HALE IALE Formula Name (M Silicon Silicate Salolo (O Aluminu H2O Silicate Silicate Silicate Silicat Silicat Silicate Silicate Silicate Silicate Silicate Silicate Magnesium (OH) 2 Magnesi	ineral Na , syn) Hydroxia m Silica gnesium / Aluminum e Hydrox: OH)2.4H20 Aluminum Hydroxia (Calci m Silica	ame) de Hydra te Hydro Aluminum Silicat ide Hydro m Silica de (Kao o te, syn o te Hydro num Sili	S 0.270 0.564 0.567 0.567 0.629 0.629 0.632 0.564 0.289 0.326 1inite 398 0.326 1inite 398 0.326 0.3567 0.356 0.3567 0	Dx Dx 1.000(3/11 1.000(5/7 0.882(15/18 T1 0.982(15/18 T1 0.999(10/22 ate	<pre>WT%) 0.569) 0.619) 0.757) 0.690) 0.716) 0.596) 0.619 0.743 0.693) 0.715</pre>	d I 5.G. 0.7540 0 0.481 0 0.498 0 0.498 0 0.451 0 0.451 0 0.402 0.2 0.402 0.2 0.430 0.2	R .414 .334 .321 .310 .293 .291 .249 .248 .231
	Data Name File Name Sample Name Comment (Entry Card) 2 29-1489 3 29-1489 3 26-0911 4 49-1057 5 10-0357 6 13-0595 7 13-0135 8 29-1488 9 5-0586 c 10 6-0263 F 11 10-0495	Feat Souther the second secon	LL B APLE-B. BADA S RKISH-SP bemical licon (205 (0H) 4 logo (0H) 4 (Si3Al) cassium (Al,Mg) 2 Lcium Ma 205 (0H) 4 lcium	Aluminu Formula Formula Name (M Silicate Silicate Salolo (0 Aluminu 2.6H20 Silicate Silicate Silicate aluno (0H,F)2 Aluminu (0H,F)2 Magnesi	ineral Na , syn) Hydroxia Hy2 m Silican gnesium J Aluminum e Hydroxia Aluminum Hydroxia (Calcin m Silican um Alumin	ame) de Hydra te Hydra Silicat ide Hydro de (Kao te, syn ote Hydro ote Hydro	S 0.270 : 0.564 : 0.564 : 0.567 : xide ((0.629 : 0.632 : 0.632 : 0.289 : 0.326 : 1inite .398 : 0.583 : 0. xide (2. 0.603 : 0.402 :	L Dx Dx 1.000 (3/11 	<pre>WT%) 0.569) 0.619) 0.716) 0.709) 0.596) 0.619 0.743 0.693) 0.715) 0.715</pre>	d I 5.G. 0.728 0 0.540 0 0.481 0 0.498 0 0.460 0 0.451 0 0.451 0 0.451 0 0.402 0.2 0.430 0.2 0.430 0.2 0.386 0	R -414

 12
 19-1184 NaAlsi308
 0.402 0.667 (28/42)
 0.773 0.423 0.218

 Sodium Aluminum Silicate (Albite, ordered --- ----

 13
 9-0432 Ca5 (P04)3 (OH)
 0.500 0.886 (31/42)
 0.619 0.393 0.215

 Calcium Phosphate Hydroxide (Hydroxylapat ---- 0.341 0.829 (34/42)
 0.731 0.355 0.215

 Barium Sulfate (Barite, syn)
 ---- -----

	Table-2				
oefficients for GAB	Isotherms for	Shale A	and S	Shale]	B

Coefficients for GAB Isotherms for Shale A and Shale B							
Model	Estimated Parameter	Well A	Well B				
GAB	Mo	6.7284g/g (dry basis)	2.9987g/g (dry basis)				
	K	0.7486	0.6410				
	С	19.9324	18.7147				
	\mathbb{R}^2	0.95	0.98				
	Standard Error	1.6890	0.3056				

Table-3 Adsorption Isotherm Modeling for Shale A and Shale B

	Well A		Well B			
m _o =	6.7284		m _o =	2.9987		
C =	19.9324		C =	18.7147		
K =	0.7486		K =	0.6410		
Aqueous Activity	Experimental Data	Model Data	Aqueous Activity	Experimental Data	Model Data	
0.3	10.44	7.3962	0.3	2.55	3.0322	
0.51	11.23	10.0663	0.51	5.09	4.0136	
0.76	13.37	15.0383	0.76	5.17	5.5359	
0.86	16.36	18.3807	0.86	6.38	6.4040	
0.94	19.51	22.2396	0.94	6.93	7.2879	
0.96	27.26	23.4574	0.96	7.8	7.5443	

Table-4 Well A Regression Statistics Summary Output

Regression Statistics					
Multiple R	0.972494562				
R Square	0.945745674				
Adjusted R Square	0.932182092				
Standard Error	1.688980572				
Observations	6				
ANOVA					
	df	SS	MS	F	Significance F
Regression	1	198.9066425	198.9066425	69.72683923	0.001124419
Residual	4	11.41062149	2.852655371		
Total	5	210.3172639			

Table-5 Well B Regression Statistics Summary Output

Wen b Regression Statistics Summary Output								
Regression Statistics								
Multiple R	0.98853539							
R Square	0.97720222							
Adjusted R Square	0.97150277							
Standard Error	0.30556391							
Observations	6							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	1	16.00869531	16.00869531	171.45566	0.000196402			
Residual	4	0.373477209	0.093369302					
Total	5	16.38217252						



Figure-1 Adsorption Isotherm for Well A



Figure-2 Adsorption Isotherm for Well B



Adsorption Isotherm of Well A fitted to the GAB model



Figure-4 Adsorption Isotherm of Well B fitted to the GAB model

Conclusion

The adsorption isotherms of Well A and Well B exhibit the sigmoid Type II and V behavior respectively, which is a characteristic of a multilayer. Generally, increased temperature will reduce adsorption to some degree. Most shale adsorption isotherms have been developed under ambient conditions; hence, activity values claimed to correctly balance the aqueous phase of the drilling fluid may in fact be incorrect. The experimental data was modeled using GAB equation and estimated parameters and the correlation coefficients (R^2) indicate good accuracy with literature. Thus, it was demonstrated in this study that the GAB moisture adsorption isotherm model can be successfully applied to moisture adsorption by shale samples in the water activity, a_w range between 0.30 and 0.96.

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