Indicators for the Evaluation of Coalbed Methane (CBM) Potential in Labuan, Sabah

By

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DISSERTATION

Submitted to Petroleum Engineering Programme in Partial Fulfillment of the Requirements for the Degree Bachelor of Engineering (Hons)

(Petroleum Engineering)

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved

....

(AP Dr Chow Weng Sum)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

March 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Foremost, coal is a black or brownish-black sedimentary rock composed primarily of carbon and hydrogen along with small quantities of other elements such as sulphur. The coal used for analysis is collected from Labuan area. Coalbed methane (CBM) is one of the alternatives to extract the natural gas from the coal solid matrix. The petroleum consumed per annum is rapidly increasing now but the global production of petroleum is reducing. If this continues, all petroleum will be exhausted soon. Therefore, alternative energy sources must be found to replace the impending worldwide petroleum exhaustion. Basically, the project is based on core analysis sample which is from the field in Labuan Area. The outcomes of the analysis will be an indicator for the advanced exploration and development of the coalbed methane reservoir in the future. The coal distribution in Malaysia (Labuan Area) is basically in shallow depth. This coal resource within Labuan region is around the Lubuk Temiang Formation. There are several techniques that involve in the coal core sample analysis. Most common technique is a laboratory test. After the laboratory experiments carry out, the relation between physical and chemical properties of coal with gas content in coal is analyze and discuss. Research must be conducted in order to understand the title and procedures of conducting the experiments testing for different characteristic or properties of coal. The methodology of the laboratory experiments will be initiated by preparation of laboratory sample. The entire test will be based on cleat analysis, density of the coal and also type of the coal. There are three types of equipments that required doing the entire test on core sample which are POROPERM Machine, OYO Ultrasonic Wave Test Machine and Point Load Test Machine. The whole test will be conducted throughout one semester of study. The outcomes of the test and experiment will be discussed with the supervisor and marked as an indicator for Coalbed Metane potential. The project planning will be a guiding for the further research in the analyzing the coal sample.

ACKNOWLEDGEMENT

First of all, I would like to place my highest gratitude to my Final Year Project Supervisor, AP Dr Chow Weng Sum, who has been very kind to guide me throughout my entire FYP 1 and FYP 2. The author wishes to express his appreciation to the management of Universiti Technologi PETRONAS for the Reservoir facilities and laboratory equipment. Lastly, the author also wants to thank the lab technologist Mr. Reduan and Mr. Shahrul from Reservoir laboratory for helping throughout conducting the experiment.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Coalbed methane (CBM) or coal-bed gas is a form of natural gas extracted from coal beds. The term refers to methane adsorbed into the solid matrix of the coal. Coal is defined as a readily combustible rock that contains more than 50% by weight and more than 70% by volume of carbonaceous material including inherent moisture formed by compaction and induration (hardening of sediment) of various altered plant remains . Coal is a readily combustible black or brownish-black sedimentary rock composed primarily of carbon and hydrogen along with small quantities of other elements such as sulphur. There is natural gas adsorbed in the solid matrix of the coal which is Coalbed methane (CBM), it has becomes an important energy source in some of the countries. It is found that gas contained in Coalbed methane is mainly methane alone with small quantities of ethane, nitrogen, carbon dioxide and few other gases, it is also called 'sweet gas' because it contains small quantities of hydrogen sulphide only. The methane in coal's solid matrix is in a near-liquid state which lining inside the pores of coal. Coal is a dual porosity rock containing micropores (matrix) and a network of natural fractures knows as cleats. The micropores represents the porosity of the coal where else the cleat provides the permeability of the coal itself. A coal seam is a bed of coal and the natural gas of methane produced from it is referred to as coalbed methane (CBM).

Coalbed Methane Reservoir is not same as conventional gas reservoir. There are two main differences between conventional reservoir and CBM. First of all the gas storage mechanism is different. In conventional gas reservoir, gas is stored in the pore volume where else for CBM; gas is adsorbed on the surface of coal .Second difference is in the fracture system, CBM has two types of cleats. Face Cleats and Butt Cleats. Face cleats are continuous and has large contact area. This is the main conduit for the gas flow. Butt cleats are rather discontinuous and perpendicular to the face cleats. The difference is that in conventional gas reservoir does not have butt cleats in which gas desorbs from the coal surface to the pathway.

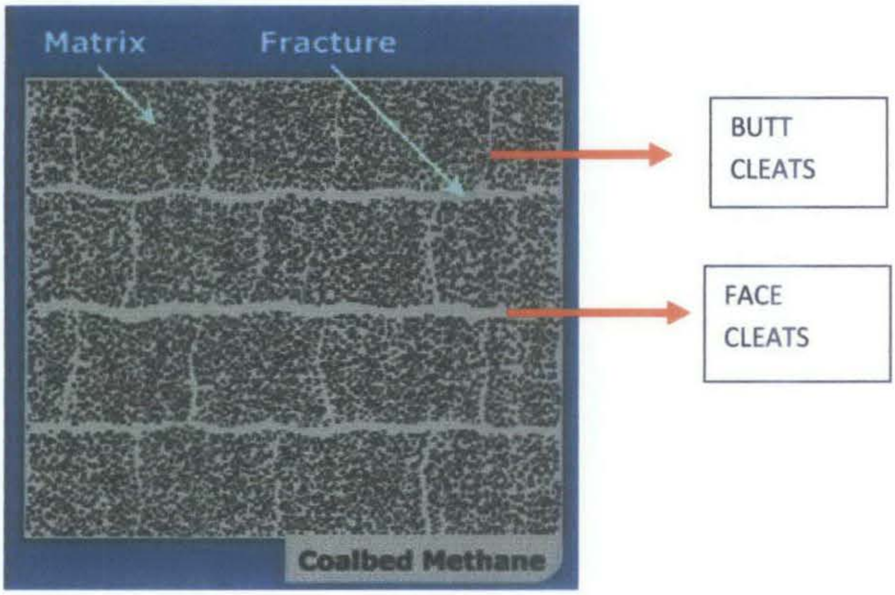

Figure 1: Cleats System in Coalbed Methane Reservoir

Gas desorption from coal can be well understood with the help of Langmuir Isotherm. From the initial pressure, reservoir will constantly be depressurized due to the water production. During this period, process called as "Watering" occurs. Once desorption point has been passed, gas will start to desorbs from the surface of the coal in matrix into the cleats and will be produced from the well in the form of mixture with water. Since two phases of fluid are flowing following initially initial single phase flow, relative permeability will change with time to each of the phase.

The area that has been chosen for the study is Labuan in Lubuk Temiang area. The Labuan Coalfield is on the western limb of northward pitching anticline in Belait Formation. The coal seam occurs in eastern limb of the anticline and corresponds to those main fields. There are four seams in the area between Merinding and Coil Point. An 11-foot seam was started to outcrop at Lubok Temiang, half a mile south of the main mine working. The coal in this seam was so fractured and sheared that it was unsuitable for marketing. Farther south at Segamau, a little coal of poor quality at the outcrop is believed to occur. Near Victioria Harbour, at Batu Arang, two seams 4 feet 6 inches and 2 feed 6inches thick, separated by 30 feet of shale, dip between 55 and 80 towards the east.

When Powell Duffryn Technical Limited [PDTS] examined the Labuan Coalfield in 1947 no sections or sampel of the seams could be obtained from the old workings. The outcrop had been robber to below the present water level. However, three seam outcrop found between Merinding and MacArthur Road were numbered, 1, 2, 3 and 4 in figure 2.The seams of clean coal, 4feet 2 inches, and 7 feet 2 inches thick in outcrop 1 and 4, probably correspond to the Main Seam that was mined and was reported to be 11 feet thick at Coal Point.The coal in other outcrop, 2 and 3, appears to lie at a higher stratigraphical level than the Main Seam and probably corresponds to the thinner seams reported in the old mined.

All the coal in these seams [PDTS, 1948] is clean, bright, and hard, and has a plane fracture but on well-marked cleavages. No evidence of faulting was found in the Merinding area. The inclination of the seams is about 50 near Luke Point, although it decreases towards the northeaset, and is only 30 near Coal Point.

Nine feet of coals is exposed in one of three outcrop found near Lubok Temiang. This coal is bright, but much sheared and very friable. The seam dips eastwards at 45 and is possibly the same as the Main Seam that was worked from Merinding and Nos.3 and 9 mined.

There are four seams were known in the area:

- Main Seam with 7.5 ft thick.
- NO 4 with 4.5 ft thick.
- Eleven Foot with 1.5 ft thick.
- Big Bed with 3.8 ft thick

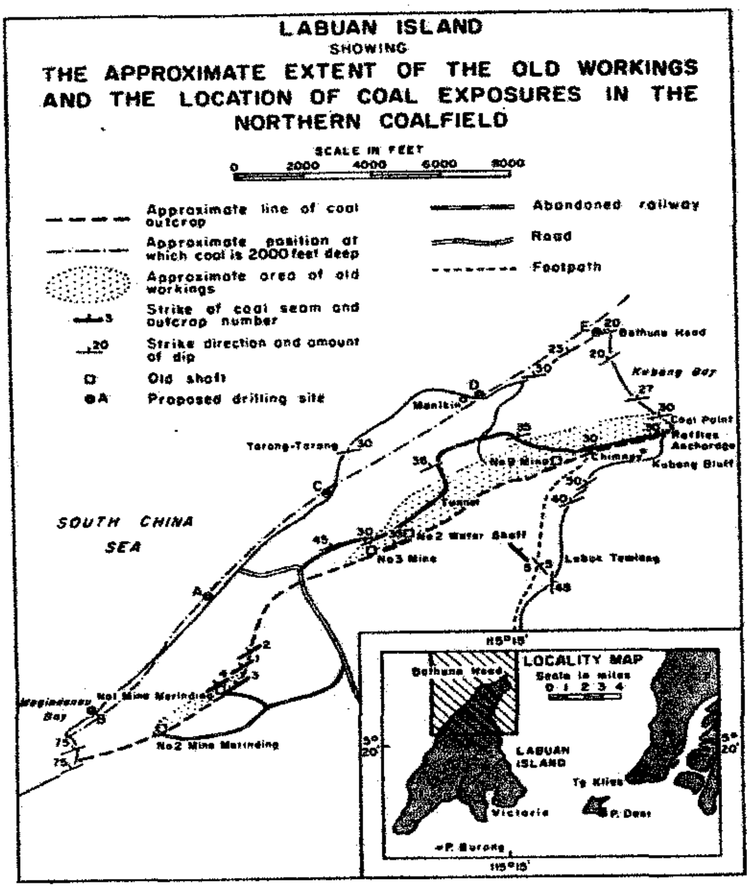

Figure 2: Location Map for coal in Labuan Island

1.2 Problem Statement

The coal distribution in Malaysia (Labuan Area) is basically in shallow depth. This coal resource within Labuan region is around the Lubuk Temiang. The in-situ coal reserves calculated down to 200m below mean sea level of four main seams are around 42.250 x 10^3 tonnes. The opencast reserves are 6.726 x 10^3 tonnes with average stripping ratio of 5.7 BCM/tone. The evaluation of the existence of the coal must be based on the quick assessing as a preliminary assessment.

The coalbed methane indicator is used for evaluation the physical properties of the coal. Physical properties of coal will signify the potential of the coal for coalbed methane study. This assessment consists of the quality of the coal; occurrences of the coal and reserves estimation of the Labuan coal area. The coalbed methane indicator will be the best technique to identify the existence of the coal seams within the proposed area.

This indicator will be based on its parameters and physical properties. The parameters and physical properties are;

- Coal permeability
- Coal porosity
- Geomechanical properties of coal (Young Modulus, Poisson Ratio, Compressibility)
- Coal rank and quality
- Coal strength

1.3 Objectives

Objectives of this project are:

- To evaluate the coal reserve in Lubuk Temiang (Labuan) area.
- To study the physical properties of coal from the Lubuk Temiang (Labuan).
- To model using the physical properties to estimate the potential of Coalbed Methane (CBM).

1.4 Scope of Study

The outcome of this project is for potential enhancement to the oil and gas industry in term of coal development. This project is very useful and significant because it will become the source of natural gas for the future energy supply. The coalbed methane indicator will be one of the tool or technique to predict the existence of high quality of coal based on its parameters. The scope of this project will cover the outcrop study, downhole geophysical logging, geological logging, trigonometrical survey and laboratory test and analysis.

The core sample of the coal will be analyzed in laboratory with specific testing using the equipment available. For this project, there are three types of equipments that available to test the sample in the lab which is POROPERM Machine, OYO Ultrasonic Wave Test Machine and Point Load Test Digital. All these three equipments were ready to use for the laboratory work for coal core sample. The most common work will be on laboratory test in Universiti Teknologi PETRONAS laboratory. The specific location for the laboratory is at Block 14 and Block 15.

CHAPTER 2
LITERATURE REVIEW

2.1 Permeability Rebound by Different Model

2.1.1 Seidle and Huitt

In this method, the following relationship of matrix shrinkage due to gas desorption is used:

$$\left(\frac{k}{k_0}\right) = \left(\frac{\Phi}{\Phi_0}\right)^n$$

where:

k_0 = initial permeability

k = final permeability

ϕ_o = initial porosity

ϕ = final porosity

n = exponent (typically set to 3, although it could be higher (12 or more), according to experimental evidence).

and

$$\frac{\phi}{\phi_o} = 1 + \left(1 + \frac{2}{\phi_o}\right) C_m (10^{-6}) V_L \left(\frac{P_i}{P_L + P_i} - \frac{P}{P_L + P}\right)$$

where:

$$C_m = \frac{\varepsilon_{exp} + c_p P}{V_L \left(\frac{P}{P_L + P}\right)}$$

where:

C_m = matrix swelling coefficient (microstrain*ton/scf).

c_p = mechanical compliance coefficient, represents compressibility of coal matrix (1/psi)

P = reservoir pressure (psia)

P_i = initial reservoir pressure (psia)

P_L = Langmuir pressure constant (psia)

V_L = Langmuir volume constant (scf/ton)

ε_{exp} = net strain between overburden stress effect and matrix shrinkage as measured experimentally (strain, dimensionless)

ϕ = final porosity (dimensionless, fraction)

ϕ_O = initial porosity (dimensionless, fraction)

2.1.2 Shi and Durucan

This model has the following formulation. Note that because it does not calculate intermediate porosity ratios, none will be displayed in F.A.S.T. CBM.

$$k = k_o e^{-3c_\phi(\sigma-\sigma_i)}$$

where:

$$\sigma - \sigma_0 = -\frac{\upsilon}{1-\upsilon}(P - P_0)$$

when above desorption pressure P_c,

and

$$\sigma - \sigma_0 = -\frac{\upsilon}{1-\upsilon}(P - P_c) + \frac{E}{3-3\upsilon}\varepsilon_l\left(\frac{P}{P+P_c} - \frac{P_c}{P_c+P_\varepsilon}\right) + \frac{\upsilon}{1-\upsilon}(P_c - P_0)$$

when below desorption pressure, P_c.

where:

c_ϕ = formation compressibility (1/psi)

E = Young's modulus (psi)

ε_l = maximum strain that can occur as P approaches zero (dimensionless)

k = effective permeability (md)

k_0 = initial permeability at P_0 (md)

ν = Poisson's ratio (dimensionless)

P = reservoir pressure (psia)

P_i = initial reservoir pressure (psia)

P_c = desorption pressure (psia)

$P\varepsilon$ = pressure at 50% of maximum matrix strain (psia)

σ = effective stress (psi)

σ_i = effective stress at P_0 (psi)

2.1.3 Palmer and Mansoori

This model uses elastic moduli to describe the effect of changing pressure on the coal volume. It accounts for narrowing of horizontal cleats (due to overburden net stress increase during reservoir depletion), as well as widening of cleats due to matrix shrinkage. The formulation is as follows:

$$\left(\frac{k}{k_0}\right) = \left(\frac{\Phi}{\Phi_0}\right)^n$$

where:

k_0 = initial permeability

k = final permeability

ϕ_o = initial porosity

ϕ = final porosity

n = exponent (typically set to 3, although it could be higher (12 or more), according to experimental evidence).

and

$$\frac{\phi}{\phi_o} = 1 + \frac{c_m}{\phi_o}(P - P_i) + \frac{\varepsilon_l}{\phi_o}\left(\frac{K}{M} - 1\right)\left(\frac{P}{P_L + P} - \frac{P_i}{P_L + P_i}\right)$$

where:

$$c_m = \frac{1}{M} - \left(\frac{K}{M} + f - 1\right)\gamma$$

where

$$\frac{K}{M} = \frac{1}{3}\left[\frac{1 + \upsilon}{1 - \upsilon}\right]$$

For the above equations:

c_m = matrix compressibility (1/psi) (NOTE: this c_m is not the same as the one used in the Seidle & Huitt formulation)

E = Young's modulus, pertaining to the bulk property of the coal (matrix and cleats), (psi)

f = tuning fraction (0 to 1), (dimensionless)

K = bulk modulus (psi)

M = constrained axial modulus (psi)

P = reservoir pressure (psia)

P_i = initial reservoir pressure (psia)

P_L = Langmuir pressure constant (psia)

ν = Poisson's ratio (dimensionless)

ε_l = maximum strain that can occur as P approaches zero (dimensionless)

γ = grain (coal matrix) compressibility, pertaining to only the coal matrix, not the cleats (1/psi)

ϕ = final porosity (dimensionless)

ϕ_o = initial porosity (dimensionless)

2.2 Coal Properties

2.2.1 Moduli of the Coal

Young's Modulus of Elasticity is defined as the ratio between axial stress and strain. It describes the elastic nature of a given substance and can conveniently describe the amount of deformation of a given object when a given stress is applied. Often this is referred to as the "stiffness" of a material. The greater the value of the modulus, the less deformation occurs at a given pressure. Several examples of different moduli values are: high strength concrete is (4.5E6 psi) and a more ductile material such as polystyrene (0.45E6 psi).

$$E = \frac{\sigma}{\varepsilon}$$

Where:

E = Young's Modulus (psia)

ε = strain (dimensionless)

σ = stress (psia)

Constrained Axial Modulus is defined as the ratio between axial stress and strain, but strain in only one axis is allowed. The compressed material is bounded on the sides, but not in the direction force is applied, as in the following diagram.

Bulk Modulus is the ratio of the change in pressure to the fractional volume compression of the material. For example the bulk modulus for steel is 160E9 Pa while water is at 2.2E9 Pa. Therefore in an environment where the pressure is 2.2E7 Pa, we would expect the fractional change in water to be 1.0%.

Poisson's ratio (ν) relates changes in size of an object along different axes. When compressive force is applied to a particular axis of a material, there will be tensile deformation along a different axis than from which the force was applied. Poisson's ratio is the ratio of contraction strain to extension strain. To give the value a direction, positive is said to be when strain occurs in the direction of a stretching force.

2.2.2 Langmuir Adsorption Isotherm

Coal is able to store a significant amount of gas. The mechanism by which this occurs is called adsorption. In adsorption molecules of one substance become attached to the surface of another. Adsorption can be visualized by imagining a magnet attached to a metal surface, or lint attached to a sweater. This is different from absorption where one substance becomes trapped inside another, such as a sponge soaking up water. Adsorption is a reversible process, because that involves weak attraction forces.

The Langmuir adsorption isotherm assumes that the gas attaches to the surface of the coal and covers the surface as a single layer of gas (a monolayer). Nearly all of the gas stored by adsorption coal exists in a condensed, near liquid state. At low pressures, this dense state allows greater volumes to be stored by sorption than is possible by compression.

The typical formulation of Langmuir isotherm is:

$$V(P) = \frac{V_L P}{P_L + P}$$

where:

P = pressure (psia)

V(P) = amount of gas at P, also known as gas content (scf/ton)

V_L = Langmuir volume parameter (scf/ton)

P_L = Langmuir pressure parameter (psia)

The Langmuir isotherm equation has 2 parameters:

Langmuir Volume (V_L): This is the maximum amount of gas that can be adsorbed on a piece of coal at infinite pressure. This value is asymptotically approached by the isotherm as the pressure increases. The following image is of a typical isotherm and shows its relationship with V_L:

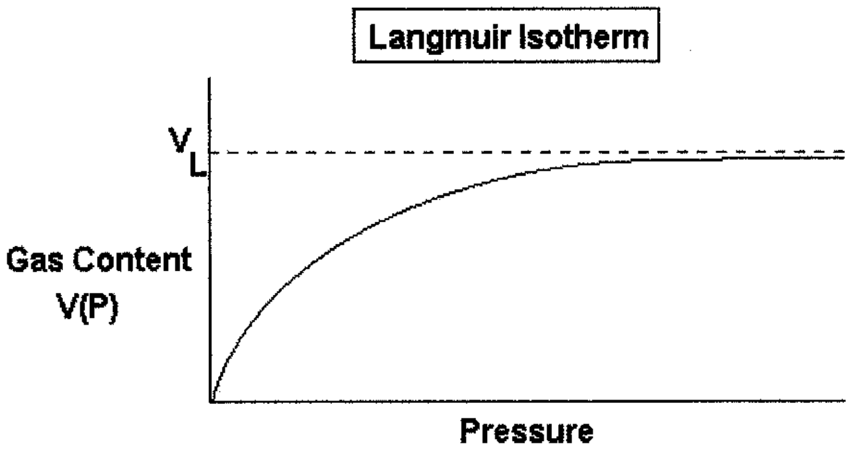

Figure 3: Typical Langmuir Isotherm for V_L

Typically, the units for the Langmuir volume parameter (V_L) are scf/ton (volume gas per mass of unit coal). The volume parameter can be converted to a scf/ft^3 (volume gas per volume unit coal) by multiplying it by the coal bulk density.

Langmuir Pressure (P_L): This parameter affects the shape of the isotherm. The Langmuir pressure is the pressure at which the Langmuir volume can be adsorbed.

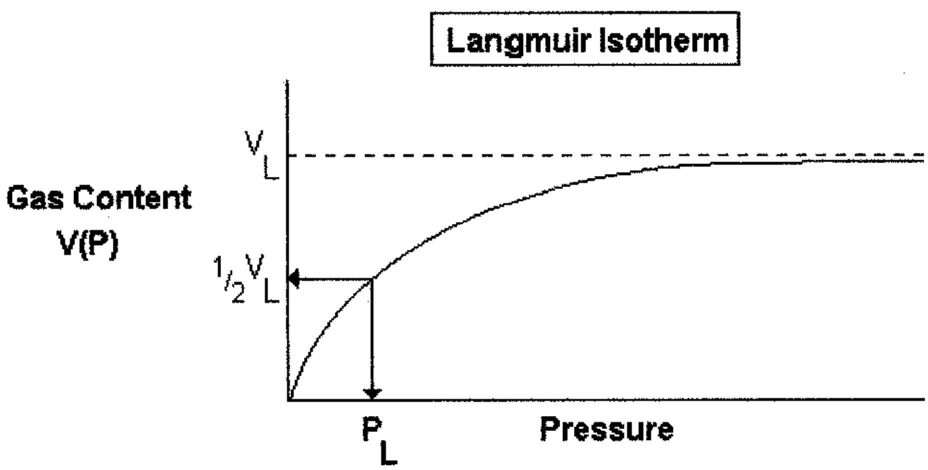

Figure 4: Typical Langmuir Isotherm for P_L

The other notation system that is used in F.A.S.T. CBM™ for representing the Langmuir isotherm is:

$$V(P) = \frac{V_m bP}{1+bP}$$

The variables used in this form of the equation are related in the software as follows:

$$P_L = \frac{1}{b}$$

and

$$V_L = V_m$$

CHAPTER 3
METHODOLOGY

3.1 Project Flow Diagram

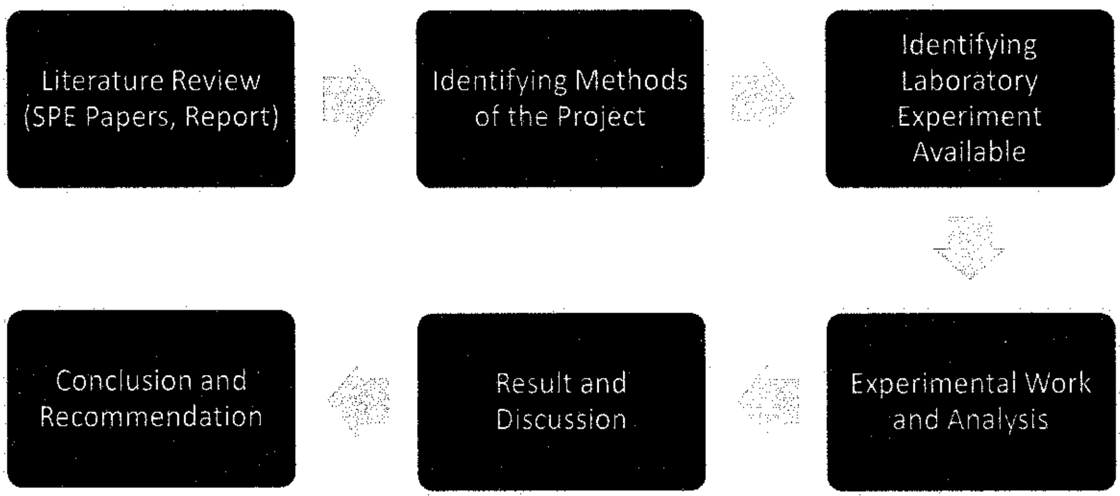

Figure 5: Project Flow Chart

Project timeline and execution plan for experiments are based on Gantt chart for Final Year Project 1 and 2.

3.2 Project Activities and Timelines

Activities	Starting Month	Finishing Month
Literature review preparation(obj. 1 & obj.2)	25 August 2010	11 September 2010
Gathering information and data for the laboratory experiment. (obj. 2)	12 September 2010	24 September 2010
Selection of suitable equipment for laboratory analysis. (obj. 2)	25 September 2010	1 October 2010
Studies on method of modeling the physical properties (obj. 3)	3 October 2010	15 October 2010
Data gathering (obj. 2)	17 October 2010	29 October 2010
Study on the physical properties of the coal (obj. 2)	1 November 2010	29 November 2010
Estimation the potential of CBM (obj. 3)	2 December 2010	20 December 2010
Laboratory analysis / experimental work (obj. 3)	5 January 2011	28 January 2011
Details studies on physical properties of CBM for future potential. (obj. 2)	3 February 2011	25 February 2011
Finalizing the CBM analysis	1 March 2011	31 March 2011
Report Documentation	4 April 2011	7 May 2011

Table 1: Project Activities and Timelines

3.3 Experimental Procedure

Foremost, any particular coal that needs to be tested must be ensured that the core sample is a true representative of the bulk material and does not undergo any chemical or physical changes after completion of the sampling procedure and also during storage prior to analysis.

Before the experiments conducted, a gross sample (a sample that represents the original of coal which neither reduction nor division has been performed) is prepared. Once the gross core sample has been taken, it is reduced in both particle size and quantity to yield a laboratory sample.

There are two types of chemical analysis used to classify coals which is ultimate analysis and the proximate analysis. The ultimate analysis will give the amounts of the principle chemical elements in coal such as carbon, hydrogen, oxygen, nitrogen and sulphur. The proximate analysis classifies coals by giving the relative amounts of moisture, ash content, volatile matter and fixed carbon by difference with caloric value is reckoned.

The first properties of coal to be measured are porosity and permeability which is using POROPERM instrument. The experiment started by measuring the diameter and length of the core plug. Then, the core holder of 1 inch is used in this experiment. The software application which is used to control the POROPERM is started up. Select the 'Standard Tank' for the tank size and '1 inch' core holder size in the window.

Next, choose the measurement that need to be tested in 'Parameters' button which are porosity and permeability. The experiment is continues by loading the sample to measure into the core holder and start measure sequence by clicking on the button 'Start Measure'. The name of the measure file must be stated before the operation enable the readings generated in the POROPERM can be recorded.

The next experiment conducted is to measure the geomechanical properties which are Young's Modulus, Poisson's Ratio and Elastic coefficient. These properties are able to generate by using OYO Ultrasonic Wave Machine. The density and length of the core plug value are required to run this experiment. Then, the value for P-wave and S-wave are set differently to start the experiment. The results of this experiment will be displayed in term of geomechanical properties values and curves for P-wave and S-wave.

The third experiment conducted is to compute the compressive strength of the core plug by using Digital Point Load Tester Machine. The diameter and length of the core plug must be identified before undergo this testing. The value of compressive strength in MPa can be obtained after the testing procedure is done.

The fourth experiment conducted is to quantify the moisture content. Thermal drying method is most commonly used to identify total moisture in the coal sample. For this testing, moisture determination by measuring weight loss of the coal sample of heating in a flow of dry, oxygen-free nitrogen to temperature 110 °C for 1 hour. Most of the low ranks coal with high moisture content is susceptible to oxidation; therefore the heating should be done in an inert atmosphere.

The analysis continues with the determination of the mineral composition of coal. This analysis can be determined by using X-Ray Diffraction (XRD) or X-Ray Fluorescence (XRF). The result from this analysis can be used to obtain the ultimate analysis and proximate analysis.

3.3 Tools Required and Procedures

3.3.1 Core Cutting Machine

Figure 6: Core Cutting Machine

Core cutting machine is used to cut the coal gross sample into laboratory sample size. The cooling water need to be used in order to cool down the core sample when drilling the coal.

3.3.2 Core Trimming Machine

Figure 7: Core Trimming Machine

Core trimming machine is used to trim the unsmooth surface of core plug and trim the core plug into desired length. The cutter for this machine is very hard since it has diamond on the cutting edge which able to cut very hard material. The cooling water need to be used in order to cool down the core when trimming.

3.3.3 POROPERM Machine

Figure 8: POROPERM Instrument

The POROPERM instrument is a permeameter and porosimeter used to determine properties of plug sized core samples at ambient confining pressure. In addition to the direct properties measurement, the instrument offers reporting and calculation facilities thanks to its user-friendly Windows operated software. It will help us to achieve the accuracy of the output value.

The gas permeability is calculated based on the unsteady stated method while the porosity is determined using Boyle's Law equation. The direct measurements using POROPERM are:

i. Gas permeability, pore volume
ii. Core plugs diameter and length.

The calculated parameters are:

i. Core sample bulk volume and porosity
ii. Grain volume and grain density
iii. Klinkenberg slip factor 'b'
iv. Klinkenberg corrected permeability
v. Inertial coefficients.

3.3.3.1 POROPERM (Porosity- Permeability) Measurement Procedures

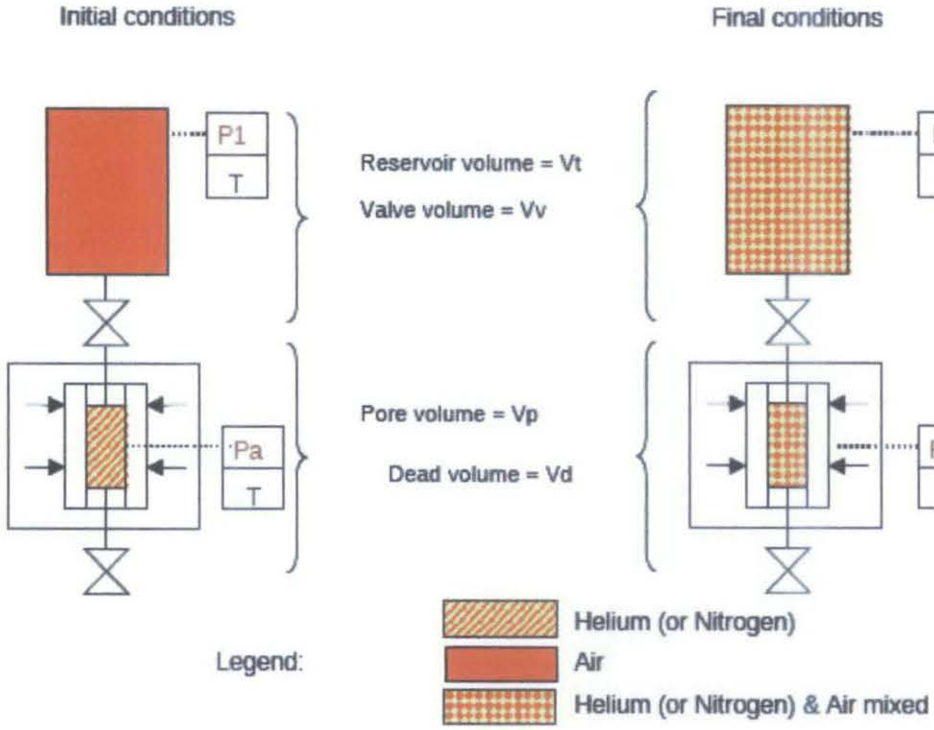

Figure 9: Schematic Diagram of POROPERM Measurement Procedure

From the real gas law PV=nZRT, it comes:

Initial conditions:

Total number of gaseous moles:

$$n_{total} = n_{air} + n_{gas}$$

$$n_{air} = \frac{P_a(V_t + V_v)}{Z_a RT} \quad \text{and} \quad n_{gaz} = \frac{P_1(V_d + V_p)}{Z_{gas1} RT}$$

$$n_{total} = \frac{P_a(V_t + V_v)}{Z_a RT} + \frac{P_1(V_d + V_p)}{Z_{gas1} RT}$$

Final conditions:

Total number of gaseous moles:

$$n_{total} = n_{(gas\ \&\ air\ mixed)}$$

$$n_{total} = \frac{n_{gas}}{n_{total}} \cdot \frac{P_2(V_t + V_v + V_d + V_p)}{Z_{gas2} RT} + \frac{n_{air}}{n_{total}} \cdot \frac{P_2(V_t + V_v + V_d + V_p)}{Z_{a2} RT}$$

The following simplification can be made:

P1 >> Pa, and then: n gas >> n air

Thus it comes:

Hence, the final material balance that gives after simplifications:

$$n_{total} = \frac{P_2(V_r + V_v + V_d + V_p)}{Z_{gas} RT}$$

The pore volume can be easily deduced from this relationship:

$$V_p = \frac{V_r\left(\frac{P_1 \times Z_{gas2}}{P_2 \times Z_{gas1}} - 1\right) - V_v}{1 - \frac{P_a \times Z_{gas2}}{P_2 \times Z_a}} - V_d$$

And the porosity is given by:

Porosity (%) = 100 Vp / BV

With:

Apparent volume of the sample BV = L ∏ (D^2 /4)

Next will be the permeability measurement. The downstream end of the sample is vented to atmospheric pressure. An accurate pressure transducer is connected to the manifold immediately upstream of the sample holder. The reservoir, manifold and sample are filled with gas. After a few seconds for thermal equilibrium, the outlet valve is opened to initiate the pressure transient. Pressures and times are recorded. This technique has a useful permeability range of 0.1 to 5,000 milliDarcys.

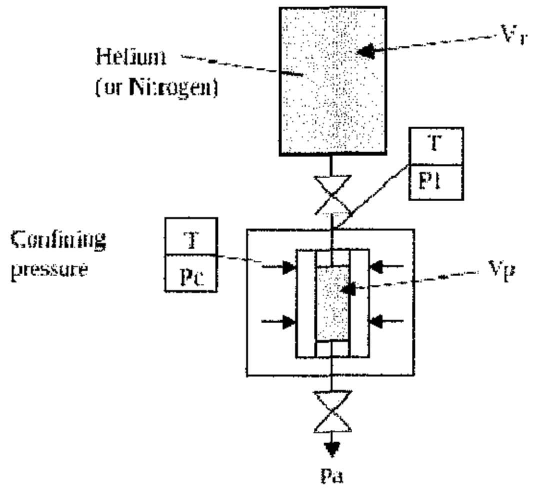

Figure 10: Schematic of pressure-falloff gas permeameter

Sometimes the gas permeability is required rather than the Klinkenberg permeability. The gas permeability is uncorrected for gas slippage. It is obtain from the following relationship:

$$k_g = k_\infty \left(1 + \frac{\dfrac{b_m \mu_c}{\mu_m} \sqrt{\dfrac{T_c M_m}{T_m M_c}}}{1/2 P_g + P_a} \right) \quad (19)$$

subscript m = measured , subscript c = theoretical

b = slip factor (psi)

μ= viscosity of the gas (cp)

M = molecular weight of the gas (g/mol)

T = temperature (°C)

Pg = geometrical mean pressure (psia)

Pa = atmospheric pressure (psi)

kg = gas permeability (md)

This equation is for the gas permeability calculation from the klinkenberg permeability.

3.3.4 OYO Ultrasonic Wave Machine

The SonicViewer-SX is an instrument for the ultrasonic wave velocity measurement of rock samples. It is possible to read the P and S wave propagation with high accuracy, because it contains high voltage (500V) pulser and receiver which consists of 10 bit, 50nsec A to D converter. In addition, input of the parameter of length and density of the rock sample previously, then it can calculate dynamic Poisson's ratio and dynamic shear modulus by built in software.

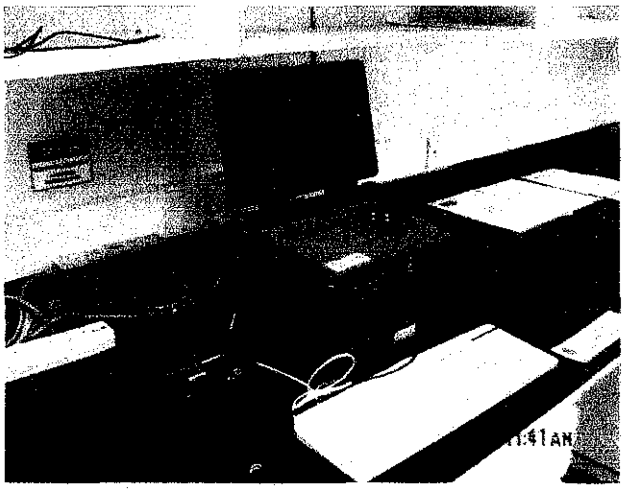

Figure 11: OYO Ultrasonic Wave Machine

3.3.4.1 OYO Ultrasonic Wave Machine Procedures (SonicViewer-SX Model)

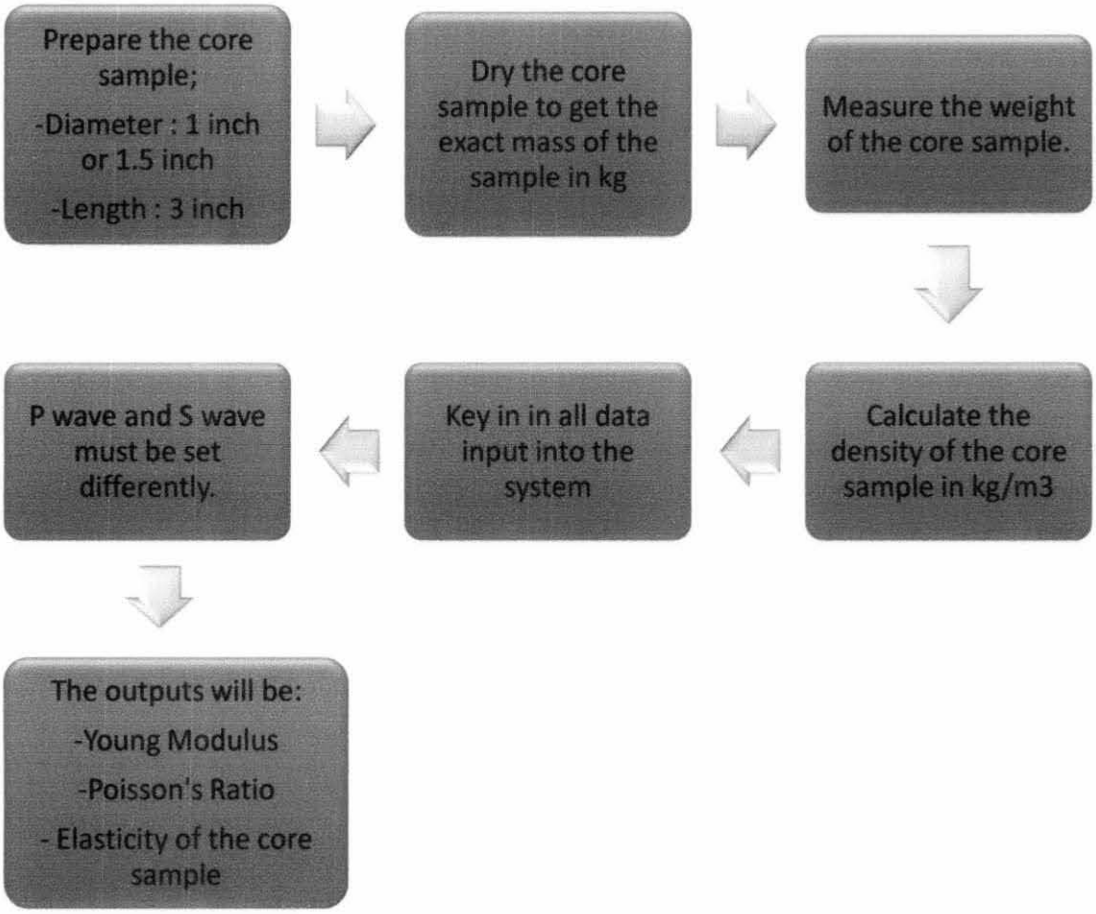

Figure 12: Experimental Flow Chart for OYO Ultrasonic Wave (SonicViewer-SX Model)

3.3.5 Point Load Test Machine

The GCTS Point Load Tester is an apparatus made of high-strength anodized-aluminum that incorporates digital technology to increase precision and ease of use while reducing its size and weight. The introduction of a pressure sensor to measure load provides a better accuracy at any load level eliminating the imprecision of traditional pressure gauges at low load ranges.

The system has a digital display that continuously monitors applied load. An optional second display provides specimen size in mm (or inches). The maximum load is automatically stored and easily obtainable by pressing a button.

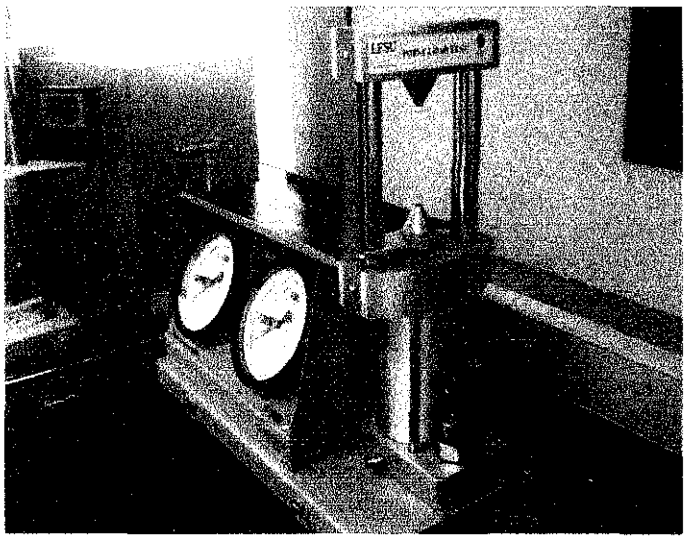

Figure 13: Point Load Test Machine

3.3.5.1 Point Load Test Machine Procedures

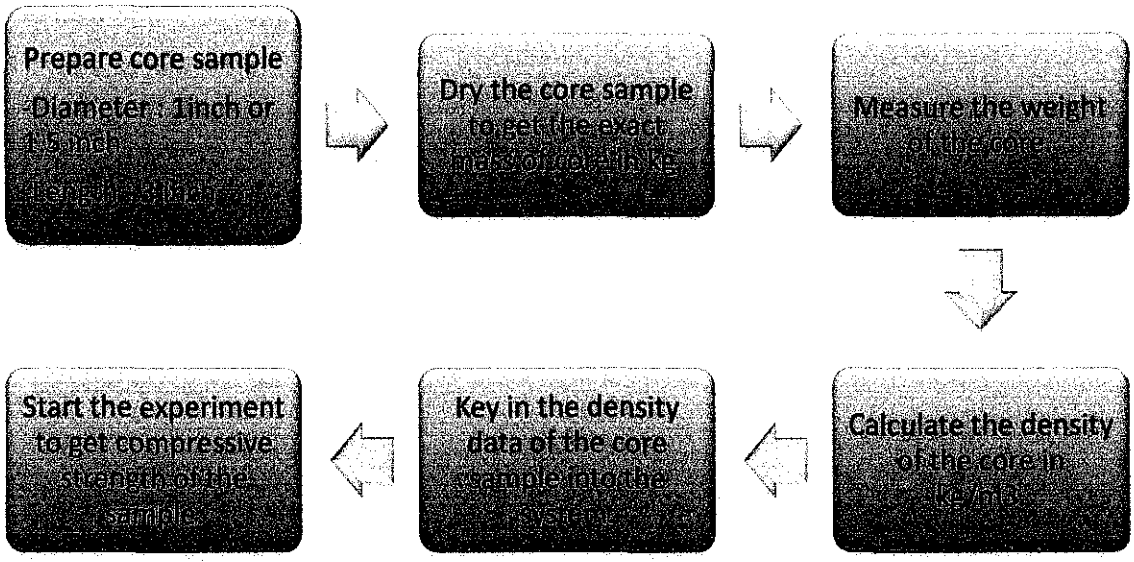

Figure 14: Experimental Flow Chart for Point Load Test Machine

Drying Oven

Figure 15: The Drying Oven

Drying oven is typically used for removal of moisture from water based coatings and adhesives .It is also used for removing water from the surface or interior of certain products or substrates

Energy Dispersive X- ray (EDX)

EDX is used to identify the elemental composition of the specimen at an area of interested or a single point. The specimen must be conductive to enable the electron beam bombarded through specimen. The bombarded electrons collide with the specimen atom own electrons and knocking some of them off in the process. An inner shell electron is ejected and vacated position is occupied by a higher energy of electron from the outer shell. The transferring of the outer electron will give up some of the energy by emitting an X- ray. The atom of every different element release x-ray with different amounts of energy and the identifying of the atom will be identified by measuring the amount of energy present.

The output of an EDX analysis is an EDX spectrum which is normally display peaks corresponding to the energy level for the X-ray received. If the element is concentrated in the specimen, the peak of spectrum will be higher.

X-Ray Fluorescence (XRF) Analysis

Figure 16: X-Ray Fluorescene (XRF) Machine

XRF is the emission of fluorescent X-rays from a material that has been bombarded with high energy gamma ray.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Porosity and Permeability Test

The sample used for the analysis is taken from the coal basin in Labuan area which is within Lubuk Temiang Formation. From the observation of physical view of core plug, the coal is black in colour, soft, easily fractured and glossy.

Before conducting the experiments, measure the diameter and length of the core plug using electronic vernier scale which has 0.01 mm precision and measure the weight using electronic weighting scale which has 0.001 g precision. In order to obtain precise readings, 5 readings of diameter and length of the core plug are measure and average value of the diameter and length are used as a final core plug data.

Core Sample	Diameter 1 (mm)	Diameter 2 (mm)	Diameter 3 (mm)	Diameter 4 (mm)	Diameter 5 (mm)	Avg Diameter (mm)
Lubuk Temiang	25.104	25.210	25.006	25.260	25.152	25.146

Table 2: Diameter readings of the Lubuk Temiang coal sample.

Core Sample	Length 1 (mm)	Length 2 (mm)	Length 3 (mm)	Length 4 (mm)	Length 5 (mm)	Avg Length (mm)
Lubuk Temiang	15.301	15.270	15.245	15.295	15.232	15.269

Table 3: Length readings of the Lubuk Temiang coal sample

The pressure used for core plug measurement is 14.7 psi which is atmospheric pressure and the temperature is in range of 23 °C to 25 °C which is a room temperature. Table 4 shows the results of effective flow area, bulk volume, radial shape factor and axial shape factor from the POROPERM excel sheet.

Core Sample	Weight (g)	Avg Diameter (mm)	Avg Length (mm)	Bulk Volume (cc)	Effective Flow Area (mm2)	Radial Shape Factor	Axial Shape Factor
Lubuk Temiang	9.47	25.146	15.269	7.583	496.624	1.00	1.00

Table 4: Result from POROPERM Excell Sheet

The formula for calculating the bulk volume (cc) and effective flow area (mm2) in POROPERM excel sheet are fixed as below:

i. Effective Flow Area= $\pi r^2 = \pi$ x $(25.146/2)^2$ = 496.624 mm2
ii. Bulk Volume = $\pi r^2 L = \pi$ x $(2.5146cm/2)^2$ x 1.5269cm = 7.583 cm3

The Helium gas is used to pass through the core plug sample to analyze the porosity and permeability value in POROPERM. By using POROPERM, the grain volume and pore volume are known while the effective porosity of core are calculated using the identified value. Tables below show the value for effective porosity and permeability of the core plug sample.

Core Sample	Grain Volume (cc)	Bulk Volume (cc)	Pore Volume (cc)	Effective Core Porosity
Lubuk Temiang	6.7921	7.3631	0.571	7.75 %

Table 5: Effective Porosity for Lubuk Temiang coal sample

Core Sample	Permeability K_{air} (md)	Permeability $K_{klikenberg}$ (md)	Factor Alpha	Factor Beta
Lubuk Temiang	0.1	0.097	2.86E+03	7.65E+13

Table 6: Permeability for Lubuk Temiang coal sample

4.2 Composition of Coal

The composition of Lubuk Temiang's coal sample is analyzing using Energy Dispersive X-Ray (EDX) and the result is shows the Figure 17 and Table 7. From the Table 7, it is found that there are total of seven elements which are Carbon, Oxygen, Aluminium, Silicon, Phosphorus, Potassium and Calcium. The major component is Carbon which having 62.67 wt%. This result shows that there are many impurities in this sample but XRF and XRD testing will be conducted to confirm the composition of the coal.

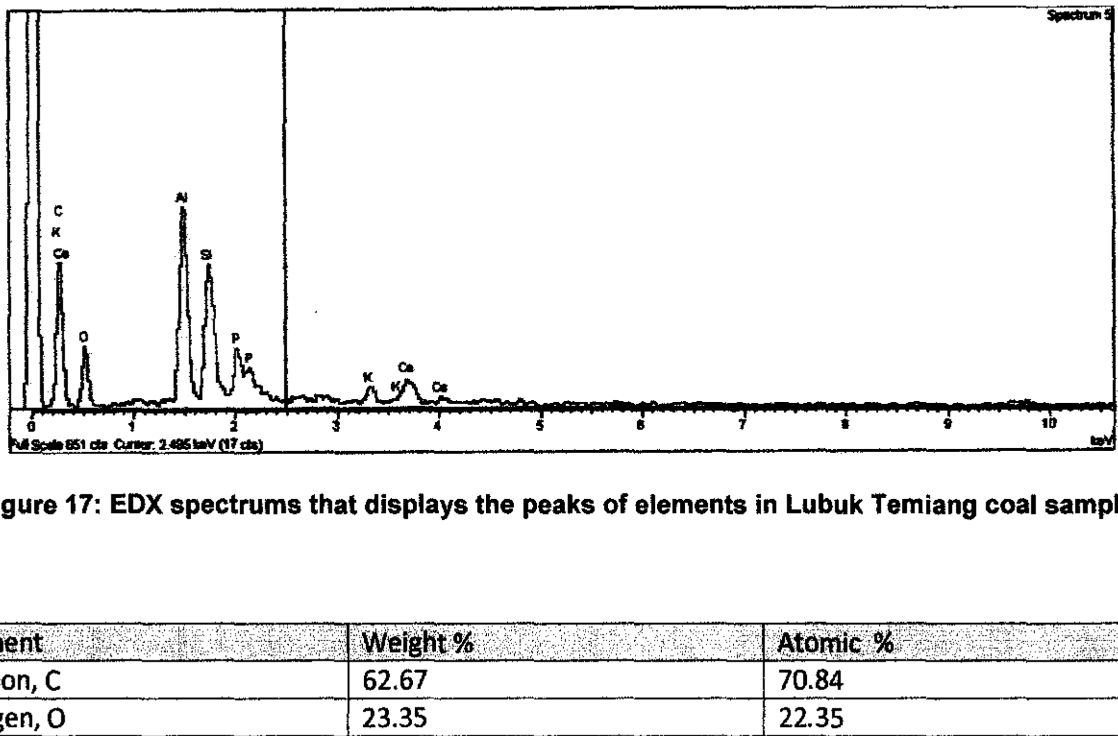

Figure 17: EDX spectrums that displays the peaks of elements in Lubuk Temiang coal sample

Element	Weight %	Atomic %
Carbon, C	62.67	70.84
Oxygen, O	23.35	22.35
Aluminium, Al	6.78	3.47
Silicon, Si	4.54	1.38
Phosphorus, P	1.87	0.63
Potassium, K	0.43	0.26
Calcium, Ca	0.36	0.17
Total	100	100

Table 7: Composition of Lubuk Temiang coal sample in weight percent using EDX

This analysis shows the rank of coal in Lubuk Temiang area is Lignite coal. This is based on the carbon content in the coal sample. The carbon content of the coal at Lubuk Temiang area is 62.67 wt%. This value is within the standard range of Lignite coal which is around 60 wt%.

4.3 Moisture Content of the Coal

Moisture is determined by establishing the loss in weight of the sample when heated under rigidly controlled conditions of temperature, time and atmosphere, sample weight and equipment specifications.

Calculation of the percent moisture in the analysis sample is as follows:

Moisture in analysis sample, % = **[(A-B)/A] x 100**

Where:

A = grams of samples used

B = grams of sample after heating

Core Sample	Weight before heating (g)	Weight after heating (g)	Moisture Content , %
Lubuk Temiang Coal	9.47	7.24	23.55

Table 8: Moisture content for Lubuk Temiang coal sample

Lubuk Temiang coal has a lower porosity and permeability value which leads to lower moisture content. The lower value of moisture is due to water lost during transportation of the coal from the field to the laboratory.

The value of moisture content for Lubuk Temiang coal is 23.55 %. This value falls within the range of the standard Lignite coal which is 20% - 40%. This analysis shows the rank of the Lubuk Temiang coal is Lignite coal rank.

4.4 Moduli of the Coal

The moduli of the coal represent the geomechanical properties which are Shear Modulus, Poisson's Ratio and Elastic coefficient. These properties are able to generate by using OYO Ultrasonic Wave Machine. The density and length of the core plug value are required to run this experiment. Then, the value for P-wave and S-wave are set differently to start the experiment. The results of this experiment will be displayed in term of geomechanical properties values and curves for P-wave and S-wave.

The result of geomechanical properties of the Lubuk Temiang is shown in Table 9 below;

P-wave value: 272 (set)
S-wave value: 271 (set)

P- time (□S)	12.10
S- time (□S)	15.10
P- velocity (m/S)	1240
S- velocity (m/S)	993
Poisson's ratio (□d)	-3.97E-001
Shear Modulus (Gd)	1.27E+006 (kN/m^2)
Elastic coefficient (Ed)	1.53E+006 (kN/m^2)

Table 9: OYO Ultrasonic Wave Machine's result

Below is the figure that represents the curve shape of P-wave and S-wave.

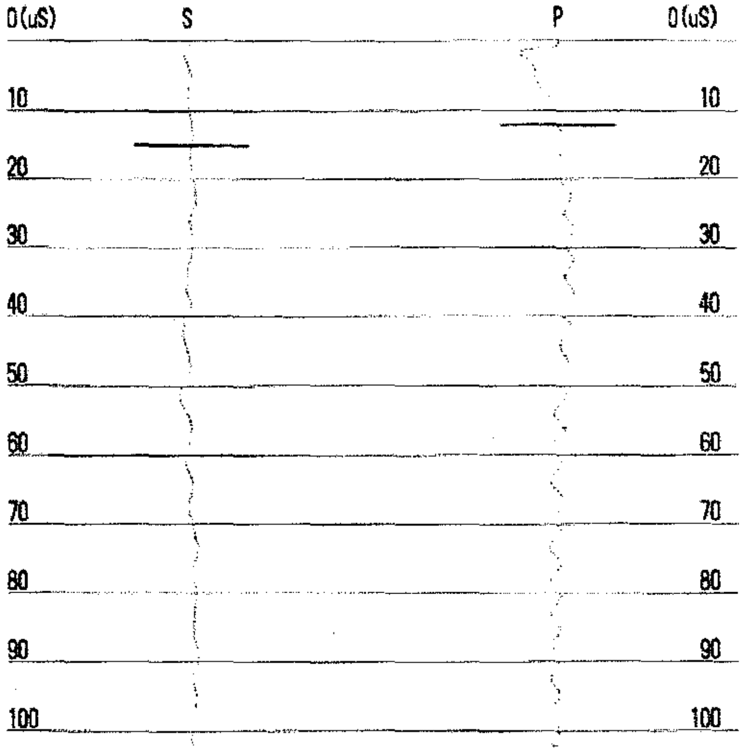

Figure 18: P-wave and S-wave curves shape

4.5 Compressive Strength of the coal

The compressive strength of the coal is determined by using Point Load Tester Machine in laboratory. Below is the table that shows the result of the compressive strength testing as well as standard value for compressive strength of Lignite coal and Bituminous coal.

Parameter	Lubuk Temiang's coal	Standard Lignite Coal	Standard Bituminous Coal
Compressive Strength (psi)	3156.30	2190 - 6560	310 - 2490

Table 10: Review of compressive strength with standard value for Lignite and Bituminous Coal

Based on the Table 10, the value of the compressive strength for Lubuk Temiang coal is 3156.3 psi. This value is fall within the range of standard Lignite coal which is 2190 psi- 6560 psi.

This result shows the Lubuk Temiang coal can be classified as Lignite coal rank.

4.6 Adsorption Isotherm Test

Adsorption isotherm test is performed to determine the gas storage capacity at different pressure steps and generating a Langmuir equation for Lubuk Temiang coal. This test by using modified Boyle's Law which involve several steps which are:

- Sample preparation: sample selection, proximate and ultimate analysis test, and equilibrium moisture restoration.
- Measuring the isotherm adsorption with high purity of methane at six pressure steps.

Gas storage capacity is evaluated at the equilibrium endpoints for each pressure step. The change in gas storage capacity at the endpoints can be calculated using equation below:

$$\Delta G_S = 32.0368 \times \frac{V_r}{m_c}\left(\frac{1}{B_{gr2}} - \frac{1}{B_{gr1}}\right) - \frac{V_{tv}}{m_c}\left(\frac{1}{B_{gtv2}} - \frac{1}{B_{gtv1}}\right)$$

Where,

ΔG_S = Change in gas storage capacity, scf/ton

V_r = Reference cell volume, cm^3

m_c = Mass of coal, gm

B_{gr2} = Gas formation volume factor at the final reference cell pressure

B_{gr1} = Gas formation volume factor at the initial reference cell pressure

V_{tv} = Adsorption cell void volume, cm^3

B_{gtv2} = Gas formation volume factor at the final adsorption cell pressure

B_{gtv1} = Gas formation volume factor at the initial adsorption cell pressure

The gas formation volume factor can be determined using equation below:

$$B_g = \frac{P_{sc}\,z(T + 459.69)}{P z_{sc}(T + 459.69)}$$

Real gas deviation factor is determined from correlation by Piper L.D., et al.

After all 6 pressure steps with gas content values are recorded; a graph of gas content against end pressure is plotted. In order to determine Langmuir pressure and volume, Equation below is used:

$$\frac{P}{V} = \frac{1}{V_L}P + \frac{P_L}{V_L}$$

Where, $1/V_L$ is the slope and P_L/V_L is the intersection of P/V against end pressure graph.

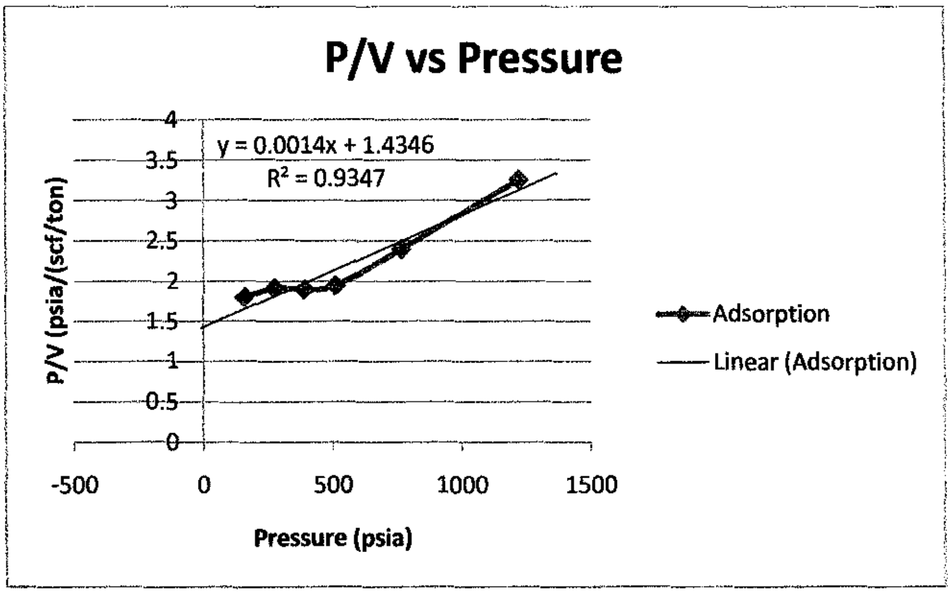

Figure 19: Pressure/gas content against pressure plot

Figure above shows the P/V vs Pressure for the langmuir pressure and Langmuir volume estimation.

4.7 Gas-In-Place Estimation

Gas-in-place volume is the total amount of gas stored within a specific reservoir bulk volume.Yee et al. proposed a mathematical equation 1 linking four properties as shown below:

$$G = 1359.7Ah\,\bar{\rho}_c\bar{G}_C$$

Where,

G = Gas-in-place, standard cubic feet (scf)

A = Drainage area, acres

h = Thickness, feet

$\bar{\rho}_c$ = Average in-situ density, g/cm3

$\bar{G}_C$ = Average in-situ gas content, scf/ton

The first three values can be estimated from log, areal map and core analysis. The fourth value can be obtained from the graph gas content against pressure which is the maximum value of gas content.

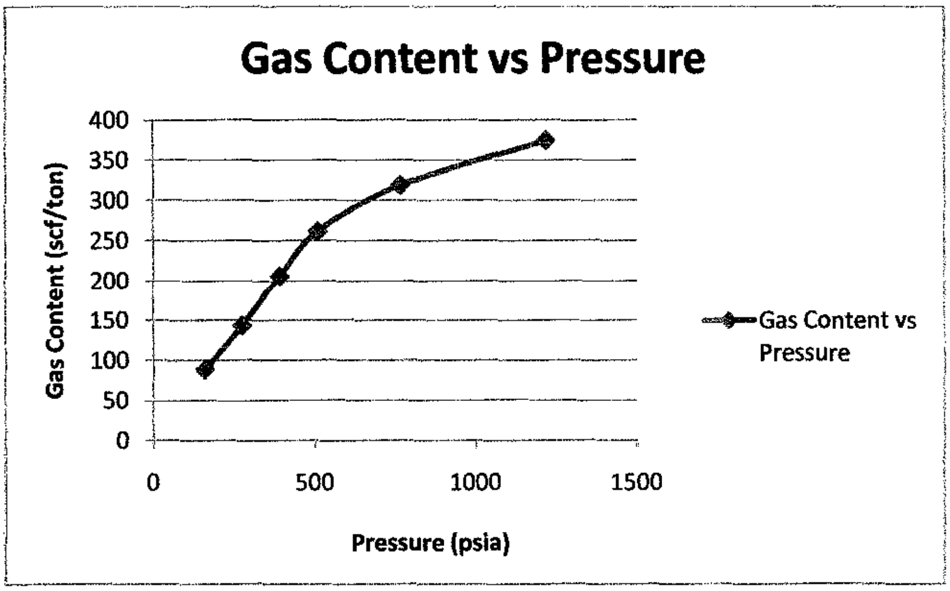

Figure 20: Gas content against pressure plot

The maximum value of gas content is 374.60 scf/ton. This value will represent the value of average in-situ gas content (scf/ton) for gas in place estimation.

Below is the table that represent the langmuir isotherm,gas content and gas-in-place for Lubuk Temiang Coal.

Parameters	Value
Langmuir Pressure, psia	1434.00
Langmuir Volume, scf/ton	1000.00
Estimated Area, acres	1455.40
Thickness, ft	17.30
Average in situ density, g/cm3	1.29
Average in situ gas content, scf/ton	374.60
Gas-in place, Bscf	16.54

Table 11: Gas content and gas-in-place results

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The physical and chemical properties of the coal sample are analyzed which are porosity, permeability, moisture content, composition and compressive strength eventually lead to the modeling of the indicators of the Coalbed Methane Reservoir. The assessment and the evaluation of the coal core sample if from the Lubuk Temiang formation within the Labuan Coalfield area.

Lubuk Temiang coal sample is classified as Lignite coal based on the carbon content, moisture content and compressive strength. All the values are fall within the range of standard Lignite coal measurement. This result will be very good indicators and potential of Coalbed Methane Reservoir in Lubuk Temiang formation.

The objectives of the project are achieved which the physical and chemical properties are identified and lead to the model of Coalbed Methane Reservoir in the Lubuk Temiang formation.

5.2 Recommendation

Since Malaysia has no development in Coalbed Methane Reservoir, this research's result will give a new prospect to Malaysia's Coalbed Methane industry. It also will add a new technology and knowledge in term of Coalbed Methane Reservoir Indicator.

CHAPTER 6
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