Determination of Porosity for Core Samples and Interconnected Void Space of Marbles Through: Bulk Volume, Barnes Method, and Helium Porosimeter

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Abstract

Geological formations often hold fluids such as gas and oil within void space known as pores. Conventional oil and gas migrates between porous mediums until it is capped by impermeable rocks. The Marcellus shale located in northeastern Pennsylvania provides a source of unconventional gas. Natural gas trapped within the pores of the shale is unable to be extracted by conventional means. Techniques such as hydraulic fracturing and horizontal drilling have been developed to extract this gas. Porosity is an important rock property that describes a porous medium's ability to hold fluids such as oil and gas. This property is also useful in carbon capture and storage methods which require the sequestration of CO_2 within porous formations such as sandstone. Three methods were used to determine the porosity of a marble pack and core samples. The methods incorporated Barnes method, helium porosity, and additional methods. Helium porosity was utilized to measure microscopic pores contained within core samples usually impenetrable by normal fluids. The effective porosity of the marble pack was expected to be relatively high because of the uniform shape and size of the marbles. The effective porosity was measured to be 56.2% which corresponded with expectations. The porosity of four core samples of different composition was found to range from 0.61-38.01%. Sample 1 contained the highest density at 2.78 g/cm^3 and lowest porosity at 0.61%. Sample 5 had the lowest density at 0.67 g/cm^3 and the highest porosity at 38.01%. This demonstrated the inversely proportional relationship of porosity and density. The helium porosity of two core samples were found to be 24.39% and 39.40%. Porosity, density, and permeability are all important parameters and properties to consider with regards to oil and gas industry. At deep depths, porosity of geological formations can be evaluated based on well logged data. As the need for energy demands increase, deeper and newer extractions methods must be utilized to obtain fuel. Physical rock properties will determine whether unconventional fuel can be extracted.

Introduction

The depletion of abundant fossil fuels has caused need for alternative source locations and fuel extraction methods. Oil and gas production techniques have advanced to the point of extracting fuel sources from unconventional sources such as the Marcellus shale located in the northeast of the United States.[1] Physical properties of geological formations such as porosity, density and permeability are important parameters to be considered during oil and gas mining.[2] When the rock samples are not available, such as oil and gas drilling and mining at deep depth, the well log data and geophysical data can be used to analyze and interpret rock physical and mechanical parameters.[2] Porosity, an important parameter, is the volume of open space or space between the solid mineral components or unconsolidated sediments that make up rock.[2] Permeability is another key parameter that defines the ability of a rock to transmit fluid.[2] Although closely related, porosity and permeability are different. Petroleum and natural gas conventional sources are often found in permeable, porous rocks such as sandstone, where natural gas or oil migrates toward an area of lower pressure and eventually can consolidate the resource in "pools" or "pockets."[2] Recovery of oil and gas begins with primary recovery, which relies on natural pressure in reservoirs to force oil to the surface.[1] Secondary recovery is than utilized by injecting water into the reservoir to push oil to the surface.[1] These methods may only account for the accumulation of 20 to 40% of fuel within the reservoir.[1] A tertiary recovery method known as enhanced oil recovery uses methods of gas injection, heating, chemical additives, and microbes to boost the amount of oil recovery by 30 to 60%.[1] This method can have a double benefit of carbon dioxide sequestration by using CO_2 as the fluid injection source.[1] Injecting CO_2 deep within geological formations pushes oil out due to pressure expansion.[1] The gaseous carbon dioxide is also unable to penetrate fine pores and fissures in the reservoir rocks causing it to be sequestered.[1]

Thermal cracking methods are used to break down hydrocarbon molecules to optimize gasoline yield.[1] This method relies on the important parameter of porosity; zeolites, an enormous family of aluminosilicates, are used in cracking processes as catalysts and are highly porous.[1] Synthetic zeolites contain properties that can be modified such as the diameter of pore size.[1] About 95% of catalytic cracking units in the United States use zeolite catalysts.[1] Hydrocarbon molecules in cracking access the cage or pore of zeolites which only permits molecules of certain sizes and shape to enter and crack.[1] Large alkanes cannot pass through the cage and react on the surface of the catalyst.[1] The breakdown of smaller hydrocarbon molecules leads to the formation of gasoline.[1]

The objective of this study was to quantify and evaluate density and porosity characteristics of core samples and a consolidation of marbles. Effective porosity represents the ratio of the interconnected pore space to the total bulk volume of the rock.[2] The effective porosity of the marble consolidation was quantified by dividing the volume of water in the pores by the total water and marble volume. Barne's method was used to determine the effective porosity of six sample cores. Helium gas is used to measure the "true density" and "true porosity" with the assumption that helium being the smallest atom should be able to penetrate the smallest of pores whereas other fluids may not.[1] A helium porosimeter was utilized to calculate and evaluate the density and helium porosity of two core samples.

Theory

Porosity is an important property to analyze in regards to oil and gas reservoir and aquifer storage.[2] Porous geological mediums contain natural gas and oil deposits within their pores.[2] Porosity is defined to be the ratio of a volume of void spaces within a rock to the total bulk volume of the rock.[2] There are several engineering descriptions that classify porosity, but the two most common are absolute and effective porosity.[2] Equation 1 shows the calculation for absolute porosity (Φ), where V_{pores}, the pore volume, is divided by V_{bulk}, the bulk volume.[2] The porosity is calculated as a percentage of the total medium.[2]

$$\Phi = (V_{pores}/V_{bulk}) \qquad (1)$$

Effective porosity is another method in classifying porosity and represents the ratio of the interconnected pore space to the total bulk volume of the rock.[2] Therefore, effective porosity is also referred to as interconnected porosity.[2] Effective porosity is the preferred measure in petroleum engineering fields as it relates to fluid flow.[3] The fluids in interconnected void spaces contribute to fluid flow within the porous medium.[3] Equation 2 shows the calculation of porosity where V_{inter} represents the interconnected pore volume, and V_{bulk} represents the bulk volume of the rock.[3]

$$\Phi = (V_{inter}/V_{bulk}) \qquad (2)$$

Porosity is primarily controlled by the shape, size and arrangement of the rock grains.[4] It also depends on rock mechanical processes such as compaction, deformation, fracture evaluation and geochemical processes such as dissolution, precipitation, mineralogical changes.[4] The diagram shown in figure 1 demonstrates the properties of shape, size, and arrangement of rock gains which contributes to the porosity and fluid flow.[4]

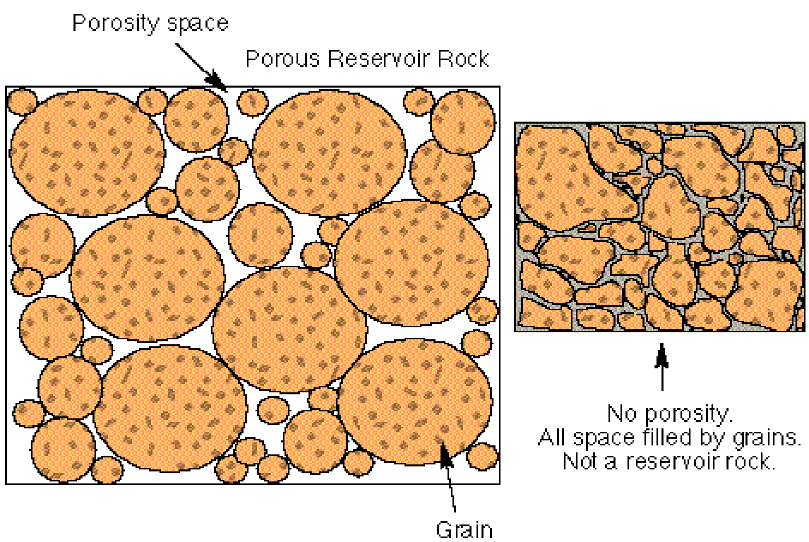

Figure 1. Shape, size, arrangement diagram of rock grains.

Barne's method is utilized in porosity determination to directly measure the porosity of macrosoporous rocks.[3] Barne's method involves adsorption techniques which rely on liquids being adsorbed into the pores of a solid component.[1] Complete saturation of pore spaces in the sample by the fluid adsorbed into the pores determines the pore volume.[1] The weight of the adsorbed liquid, divided by the density of the liquid yields pore volume which can is further compared to the bulk volume of the sample.[1] Barne's method is an important technique often used in petroleum industry to understand oil and gas flow of geological formations.[3]

Helium gas is used to measure the "true density" and "true porosity" with the assumption that helium being the smallest atom should be able to penetrate the smallest of pores whereas other fluids may not.[1] A helium porosimeter was utilized to calculate and evaluate the density and helium porosity of two core samples. Small helium atoms are able to penetrate the microscopic pores of cores samples and adsorb to the porous medium.[1] This determination measures the porosity of core samples most effectively.[5] The helium porosimeter uses Boyle's Law for the calculation of grain volume by the equalization of pressures.[5] The calibration equation utilized by the helium porosimeter is shown in equation 3 where P_1 and P_2 are the pressures, and V_{disc} is the volume of the discs that seal the sample chamber.[5]

$$\text{Grain Volume} = -6.306835 \times (P_1/P_2) + 53.746269 - V_{disc} \qquad (3)$$

Discs are used to seal the sample chamber while helium fills the core sample.[5] The addition of these discs prevents the volume above the sample from being measured.[5] Therefore, the subtraction of the disc volume is necessary in the calculation of grain volume as indicated.[5] If the core rock sample is a perfect cylinder with smooth surfaces, then caliper measurements of length and diameter can give accurate bulk volume.[5] Accurate porosity must depend mainly upon surface texture of the core sample.[5] Helium expansion determinations of porosity on samples with smooth surface textures where the caliper bulk volume is used should fall within ±0.3 porosity percent regardless of actual porosity.[5] High permeability sandstone samples have large grain and pore sizes, and do not produce smooth surfaced right cylinders when plugs are drilled which makes accurate bulk volume determination becomes difficult.[5]

Methods

Porosity of a porous medium is often influenced by geological location and formation which has effects on properties such as size, shape, and arrangement of particle grains. Through this study, quantification and exploration of porosity was conducted by three concise methods. The packing efficiency of marbles was examined as 30 marbles were consolidated together. The addition of fluid (water) to the marble pack demonstrated the pore interconnectivity. The fluid migrated to the void space between the marbles and further occupied it. Using known marble volumes and fluid addition, the effective porosity was determined and examined.

Barne's method was utilized in determining the absolute porosity of four core samples. Air pockets contained within the pore spaces were evacuated by vacuum suction. The removal or evacuation of these air pockets is necessary when determining absolute porosity of a porous medium. The addition of fluid (water) to the samples incorporated adsorption methods to be further utilized. The submerged samples in the liquid caused the fluid to be pushed and adsorbed into the pores on the surface of the core sample due to pressure differences. The fluid occupied within the pore spaces could be further quantified.

A helium porosimeter was utilized to equilibrate and quantify the total or helium porosity of two core samples. The calibration of the helium porosimeter was already performed. The addition of a core sample to the matrix cup was sealed off by discs which prevented any unwanted volume to be measured by the helium atoms. Helium was pumped into the sample chamber causing helium atoms to be diffused and adsorbed to the pores contained on the surface of the core samples. Helium atoms being the smallest atom penetrated any microscopic pores contained within the sample, accurately measuring the entire porosity.

Results and Discussion

The marble packing method was utilized to determine and visualize the effective porosity of marble (grain) packing. The shape, size, and arrangement of these marbles affects the interconnectivity pore space between the marbles. Due to high sphericity and uniform shape, effective porosity within the packing of marbles was expected to be relatively high. It would be expected that fluid would flow relatively easily and migrate to these interconnected pores. Table 1 shows the effective data calculated.

Table 1. Marbles calculated data and effective porosity

Marbles	**Mean Diameter(cm)**	**Mean Volume(cm^3)**	**Pore Volume(cm^3)**	**Bulk Volume(cm^3)**	**Effective Porosity(%)**
30	1.55 ± .005	1.94 (.154)	76.0	135.23	56.20

The pore volume was equal to the amount of water distributed over the marbles. The pore volume was determined to be 76.0 cm^3 and the grain volume was determined to be 59.23 cm^3. These volumes made up the bulk volume of the marble pack at 135.23 cm^3. The overall effective porosity was then calculated as 56.20% which corresponded to the high valued expectations.

Barne's method was utilized to determine the porosity of four core samples based on their porous structure. This method employed adsorption processes; fluid (water) was diffused and absorbed in the pores of the surface on the cylindrical core samples. Each sample has a corresponding number based on its composition, and the calculated data is shown in table 2.

Table 2. Barne's method data of four core samples of different composition.

Sample	**Dry Density(g/cm^3)**	**Pore Volume(cm^3)**	**Bulk Volume(cm^3)**	**Porosity(%)**
1	2.78	0.23	38.01	0.61
2	2.25	3.39	27.20	12.46
4	2.26	3.13	24.73	12.65
5	0.67	20.81	64.9	32.06

The core sample (5) was found to have the highest porosity of the samples at 32.06% and core sample (1) was found to have to have the lowest porosity at 0.61%. It was shown that the sample with the lowest dry density corresponded to the highest porosity and the sample with the highest dry density corresponded to the lowest porosity. This concept illustrates the general inversely proportional relationship between density and porosity.

Two additional core samples were analyzed by helium porosity. A helium porosimeter was used to pump helium into the sample chamber and diffuse helium atoms into the pores. The porosity measured here corresponded to an accurate total porosity. Table 3 shows the data calculated from helium porosity methods. The helium porosity of sample (5) was found to be 24.39% and the helium porosity of sample (7) was found to be 39.40%. The helium porosity indicated the microscopic pores that were able to be penetrated by the small helium atoms. This method gives a more accurate indication as to the porosity of the samples.

Table 3. Helium Porosity of two core samples

Sample	Grain Volume(cm^3)	Bulk volume(cm^3)	Helium Porosity(%)
5	4.11	16.85	24.39%
7	7.45	18.88	39.40%

There may have been numerous errors in this study, ranging from improper Vernier caliper readings, non-flush disc sample chambers, or the inaccurate use of a vacuum which encountered problems. There may have been substantial error regarding this study. Table 4 lists a propagation of error table for sample 1 of the Barnes Method. The error may include not waiting long enough for samples to be evacuated, incorrect method of drying, and incorrect reading of the vernier calipers.

Table 4. Propagation of errors for sample 1 of Barne's Method

	Sample 1	Absolute Error (%)	Relative Error (%)
Length (mm)	79.0	±0.05	0.06
Diameter (mm)	25.0	±0.05	0.20
Dry Weight (g)	105.0	±0.005	0.0048
Wet Weight (g)	105.23	±0.005	0.0048
Pore Volume (cm^3)	0.23	±0.01	4.35
Bulk Volume (cm^3)	38.01	±0.1	0.26
Porosity (%)	0.61	±0.05	8.2

Conclusions

Porosity is an important parameter that may be classified in multiple ways such as effective porosity and absolute porosity. The methods in measuring porosity may vary as did in this study. The use of Barnes method, helium porosity, and additional methods provided the data of this study. The packing of marbles were used to simulate the effects of grain particle void interconnectivity based on shape, size, and arrangement. The marbles were all of uniform shape and size which led to an expectation of a relatively high porosity. The fluid flow would migrate to the interconnected pores easily as it does in geological samples of uniform gravel. The effective porosity of the marble pack was indeed high at 56.2%. Barnes method was utilized for four different core samples with different compositions. The porosity of these four samples ranged anywhere from 0.61 to 32.06%. Sample five had the highest porosity (32.06%) and the lowest dry density (0.67 g/cm^3). Sample 1 had the highest density and the lowest porosity (0.61%). to the interconnected pores easily as it does in geological samples of uniform gravel. The effective porosity of the marble pack was indeed high at 56.2%. Barnes method was utilized for four different core samples with different compositions. The porosity of these four samples ranged anywhere from 0.61 to 32.06%. Sample five had the highest porosity (32.06%) and the lowest dry density (0.67 g/cm^3). Sample 1 had the highest density and the lowest porosity (0.61%). This demonstrated the inversely proportional relationship of density and porosity. Helium porosity measurements were carried out in order to quantify microscopic pores. Two samples were examined by a helium porosimeter and the respected porosity values were found to be 24.39% and 39.40%. Porosity is an important parameter in quantifying a rock's ability to hold oil or gas. This quantification and data log of this property becomes important as further requirements for new oil extraction locations become necessary. This property is of further use in carbon dioxide sequestration. The slowing of climate change requires carbon dioxide to be sequestered into geological formations. The CO_2 is contained within porous mediums such as rocks. Therefore, well log data of porosity is needed for future energy needs.

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