An Image Analysis Technique to Estimate the Porosity of Rock Samples

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Abstract— This paper discusses the possibilities of determining the porosities of different types of rocks using image analysis technique. Before the use of image analysis stereological research for analysis of porosity were conducted by traditional methods which were time consuming and lacked accuracy. The method proposed in this paper determines the porosity by computing the part of the whole sample for which the pores account. The steps involved in the above method are a series of contextual, non-context and morphological operations that are commonly used in image processing and analysis. The procedure was tested on thin sections of sandstone and limestone rock samples. The results were computed in the form of total porosity which includes all types porosities observed in rocks including isolated and connected porosities. The porosity obtained can also be called as visual porosity. Values obtained show that the method proposed can lead to satisfying results. Obtained porosity values can be used further to determine determine other properties like permeability which play a vital role in the study of diffusion in porous rocks.

Key words: Porosity, Image analysis

I. INTRODUCTION

Petrology is the branch of geology that studies the origin, composition, distribution and structure of rocks. Petrography is a branch of petrology that focuses on detailed descriptions of rocks. Rock is a natural porous material. Many engineering problems in rock mechanics and engineering geology are closely related to rock pore structure. For example, the evaluation of rock reservoir productivity in oil and gas exploration, some major disasters such as gas and water inrush in coal mining, and the propagation of stress wave caused by earthquake or explosion in rock and soil medium. Image analysis has played an important role in order to extract relevant information from geological images.

Used in geology, hydrology and many other fields, the porosity ϕ of porous medium (like rock, sediment etc.) defines the fraction of void space in the specific material, where the void may contain air or water. Porosity may range from 0 to 1. Porosity is considered as one of the cardinal property for study of rocks which is a result of complicated, long-term sedimentation processes. Theoretically porosity in reservoir rock is a function of the grain size distribution, the grain shape distribution and of the packing.

Pore space for a particular rock sample is characterized by a specific distribution of size and shape of the pore structure. Fig. 1 which shows the pores of a rock sample, the first rock sample will correspond to a high porosity in comparison to the second one. Well sorted grains, grains of approximately all single sized materials have much higher porosity values than similarly sized poorly sorted materials where small particles fill the gaps between large particles. Fig. 2 gives a more clear, real time porosity illustration for a sandstone rock sample with pores identified by blue colour.

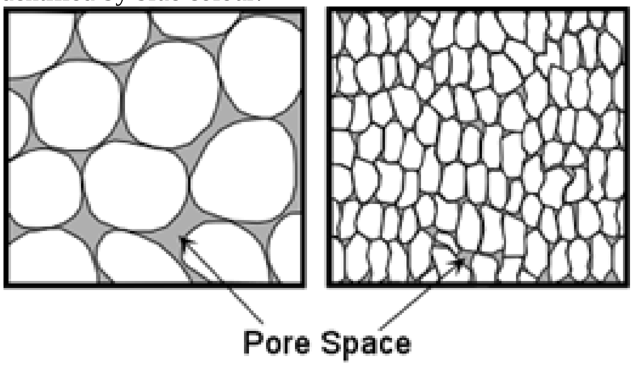

Fig. 1: Illustration of pores.

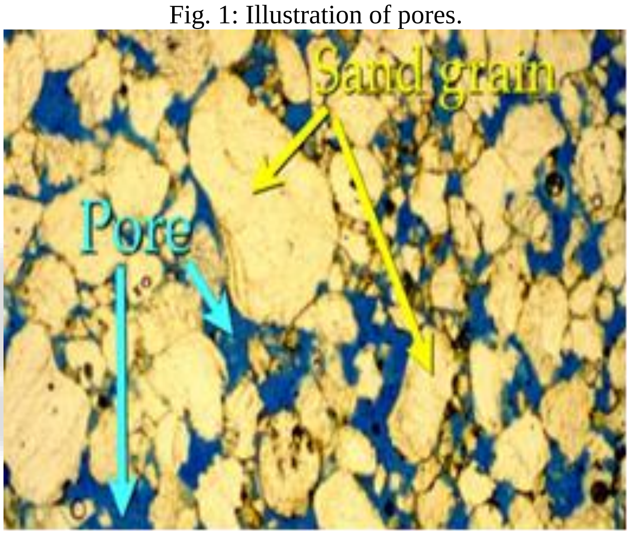

Fig. 2: Illustration of pores for thin section of a sandstone rock.

Blue color for pores is obtained by the use of a blue dye. It is further elaborated in the methodology. Important parameters in this context includes the pore size and its distribution. Pores are classified into four groups depending on the access size: micropores, having size less than 2 nm diameter; mesopores, ranging between 2-50 nm diameter; macropores, which are in the range of 50 nm to 7500 nm diameter and rough pores having size over 7500 nm. In another classification index I (shape factor) was used to differentiate pore size according to Eq.1

$$I=A/P^2 \quad (1)$$

Pores were classified into three groups according to the shape factor as round, intermediate, and elongate shown [9]. Each group was divided into another three groups according to size as small, medium and large [10]. This classification is shown in TABLE 1. Another way to view porosity is in the context of groundwater. Fig. 4. Illustrates the types of porosity based on the location where groundwater can be found. It fills the spaces between sand grains, rock crevices and in solution openings.

Type	**Shape Index**	**Size**	**Area (μm^2)**
Round (R)	I>= 0.04	Small (S)	<15,600
Intermediate (In)	0.04>I>=0.015	Medium (M)	15,600-1,56,000
Elongated (El)	I<0.015	Large (L)	>1,56,000

Table I: Classification of pores.

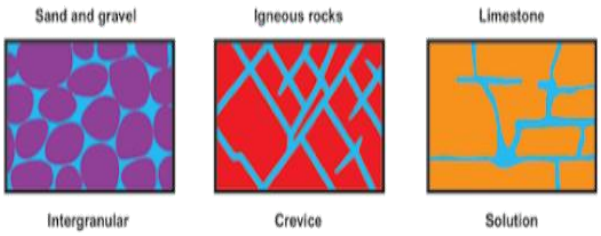

Fig. 3: Main Types of Porosity.

II. LITERATURE SURVEY

Image analysis has been used in the field of geology for nearly a decade now. Researchers from all over the world have been trying to use image analysis actively in study of rocks and its properties. Such expertise in this field has helped us augment our research, which has helped us gain insight into the field. One of those many papers was an article that suggests making use of video sequence analysis to determine the porosity of rock samples. A video of nearly 1 min was recorded for each sample and various operations were performed on each frame of the video. The rock samples used were of carbonate and terrigenous type. This helped us in determining the steps that would be required to perform the analysis on the rocks.

One paper described a laboratory method for investigation of porosity in rock samples found in some parts of Gwagwalada area, Nigeria. This helped in determining the correctness of the values that were obtained by performing Image Analysis.

Another similar research on ten different rock samples of different lithology was performed using mercury intrusion technique. The pore distribution of the samples was demonstrated by frequency distribution diagrams which further helped strengthen our analysis.

Another article summarizes the results of CMT(Computed Microtomography) scanning to estimate total porosity and pore perimeter directly from rock samples. Further permeability estimation is done using Kozeny-Carman equations. This was useful in determining the diffusion coefficient of the rock samples

III. METHODOLOGY

The procedure followed is based on image processing and analysis operations. In order to derive porosity from images we have to define the reservoir rock as a two-phase medium in which the pore system constitutes one phase and the rock minerals, also know as the matrix, the other phase. Various operations involved were implemented in Mathworks Matlab software and Eclipse IDE for java development. The various steps involved are given below.

A. *Image Enhancement*

Each sample should first be treated with a morphological filter (opening followed by closing operation). Square with unity dimension was used as a structuring element. Next although not an image enhancement technique must be done as the next step which is RGB to grey scale conversion. Next contrast enhancement needs to be performed. This can be done with help of histogram equalization. Histogram equalization that is to be performed can be local or global. Adaptive histogram equalization is a type of local histogram equalization. For this paper we have used a contrast enhancement technique known as contrast limited adaptive histogram equalization (CLAHE) which is a variant of adaptive histogram technique. Local histogram equalization is preferred because some specific parts of the image representing pores may have low illumination.

B. *Thresholding (Binarization)*

Next is an important step, thresholding or binariztion of the image with a threshold value. For estimating a threshold value Otsu's thresholding algorithm was used. It is a popular and widely used global thresholding algorithm that uses the image histogram to determine the appropriate threshold value. The algorithm iterates over every threshold value and for each one of them partitions the pixels as background and foreground depending on their grey level. For each threshold value computations are done by calculating within class or between class variance. The standard Otsu's algorithm determines appropriate threshold value by minimizing the within class variance or intra class variance which is simply the sum of the two variances multiplied by their associated weights. This is represented by Eq. 2. W_b and W_f represent the weights of the background and foreground pixels. σ_f and σ_b represent the mean of the foreground and background pixels respectively.

$$W_b*\sigma_b^2 + W_f*\sigma_f^2 \quad (2)$$

Later it was shown by Otsu that minimizing within class variance is equivalent to maximizing between class variance and is represented as a product of weights for background, foreground pixels and square of the difference between the mean of background and foreground pixels. μ_b and μ_f represent the standard deviation of the background and foreground pixels. This is represented by Eq.3.

$$W_b * W_f * (\mu_b - \mu_f)^2 \quad (3)$$

The second expression was used as it provides faster computation as compared to within class variance. Hence the basic idea is to return the threshold value that provides the maximum value for between class variance. A modified implementation was also done by using standard deviation instead of mean in the between class variance expression. Both implementations were used for calculating the threshold value and the one which gave better results was used for thresholding.

The implementation of the algorithm was done in java using the processing library used for dealing with images. A hashmap was used to represent the histogram of the image. Hashmap is a data structure in java implemented as a key-value pair. In our context the keys were the grey levels and values were the number pixels with that grey level. Otsu's algorithm gives good results when image under consideration is bimodal which was apt for the purpose of separating pores from the rest of the areas of rock. At this stage the pores appear to be visible with some clarity. For better results a filter should be used. A morphological filter was used which consists of opening followed by closing with a structuring element of slightly larger dimension. This step helps in removing noise that appears in the black and white regions after thresholding and thereby increases the accuracy of porosity value obtained at the end of the procedure. A median filter could also be used to get better results.

C. Porosity Calculation

After thresholding it was observed that pores were not separated in an acceptable manner. Hence and additional operation was performed. Which involved conversion of the image from RGB to YC_BC_R color space. In YC_BC_R, Y is the luma component which represents the brightness in an image and C_B and C_R are the blue-difference and red-difference chroma components used to convey color information of a picture. Above conversion was done before thresholding in cases where it was observed that thresholding caused the black part or other parts of the rock to become white along with the blue part(pores) and introduced an error in calculation. Fig. 4 shows the above conversion for the limestone rock sample shown in Fig. 7. This method also gave good results in case of other samples.

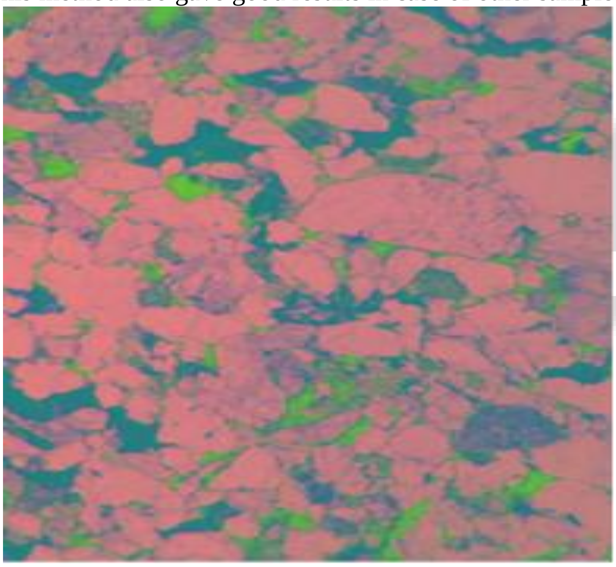

Fig. 4: Representation of Fig. 8 in YC_BC_R color space.

As seen in Fig. 4 the pores in light green are easily distinguishable from other parts of rock and now can be thresholded directly without conversion to grayscale. This conversion fails in some cases where the pores are not colored blue as in Fig. 6. As mentioned earlier porosity is defined as the volume of void space(pores) denoted by V_V divided by the total volume of the bulk rock denoted by V_T which is shown in Eq.4.

$$Ø = V_V / V_T \quad (4)$$

The above ratio is equivalent to the ratio of no pixels occupied by the pores to the total no pixels in the sample. This ratio can be calculated easily by using the built in function's bwarea() or sum(). The obtained value is then multiplied by 100 to get porosity in percentage. Approximate porosity ranges for some types of rock determined by previous researchers are given in Table 1 [3]. The values given vary according to the types of the rock used and locations from where they were taken. For example different types of sandstone may have quite different porosities based on their types, which have different structures.

In this paper we have used thin sections of limestone and sandstone for testing purpose. First one is the sandstone sample from Dobrzyca, Poland [7] and second one is a volcanic and calcareous sandstone from Sandy Bay, St.

Helena [14]. The limestone sample shown is commonly found in northern England [12]. Both the sandstones including limestone are types of sedimentary rocks.

ROCK TYPES	POROSITY (%)
Limestone	7.00-56.00
Shale	0.00-10.00
Dense crystalline rock	0.00-5.00
Fractured Basalt	5.00-50.00
Schist	4.00-49.00
Sandstone	5.00-30.00
Fractured crystalline rock	0.00-10.00
Dolomite	0.00-20.00
Weathered granite	34.00-57.00
Weathered gabbro	35.00-42.00
Karst limestone	5.00-50.00
Quartz	6.00-65.00

Table II: Experimentally determined values of porosity for various rock samples.

The thin section of rocks are shown in Fig. 5, Fig. 6 and Fig. 7. Samples in Fig. 5 and Fig. 6 are different types of sandstone. As seen the pores spaces in the sample appear blue. This is done to distinguish the pores from rest of the rock easily and is done by impregnating the samples in vacuum with a blue-colored glue or dye. The pores in sample shown in Fig. 6 have not been made blue. The binarized samples are shown in Fig. 8, Fig. 9 and Fig. 10.

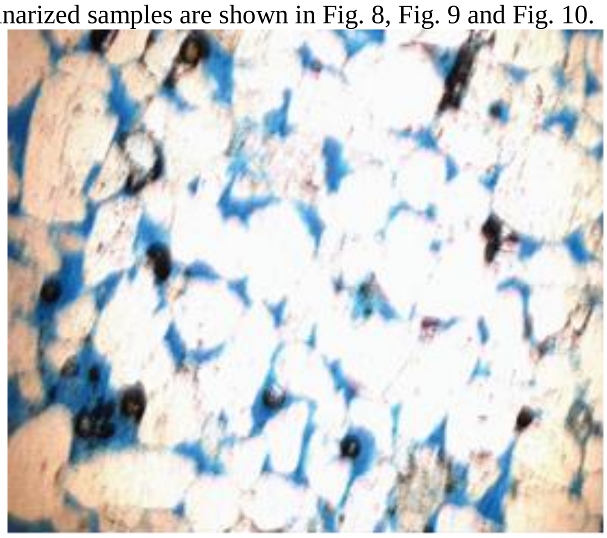

Fig. 5: Sandstone rock sample.

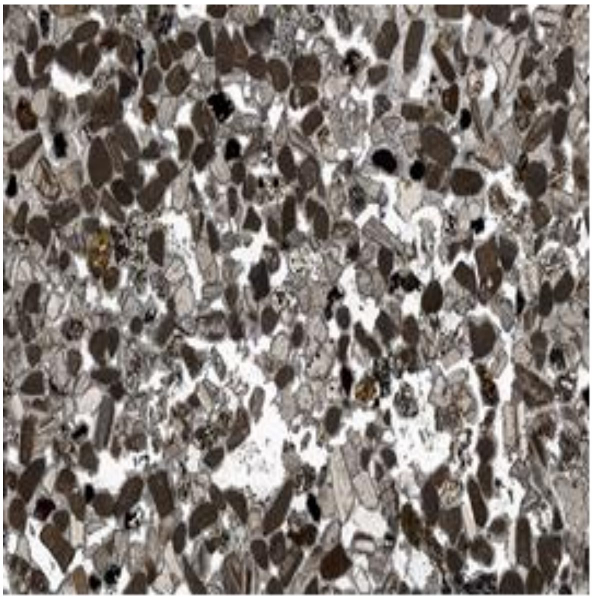

Fig. 6: Sandstone rock sample.

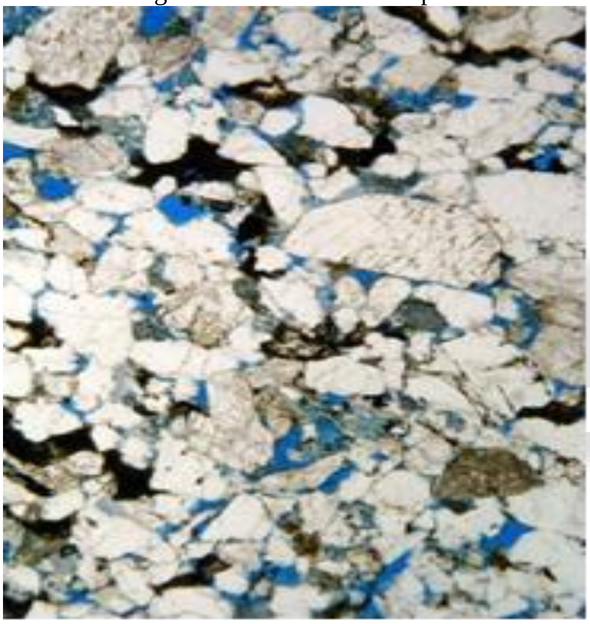

Fig. 7: Limestone rock sample.

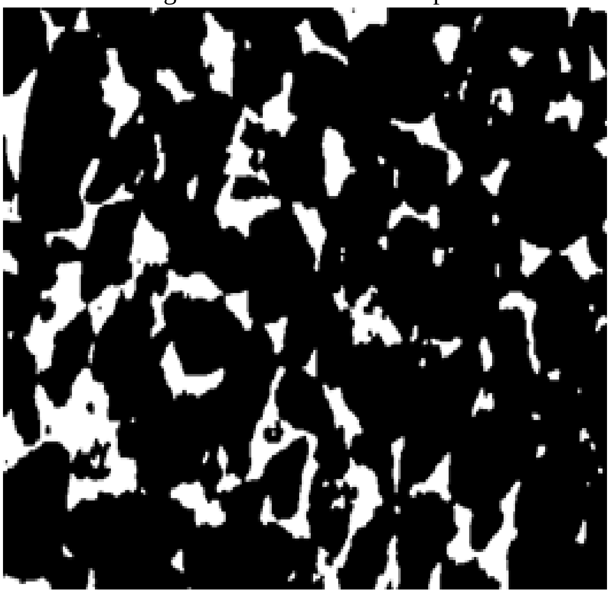

Fig. 8: Binarization of sandstone sample.

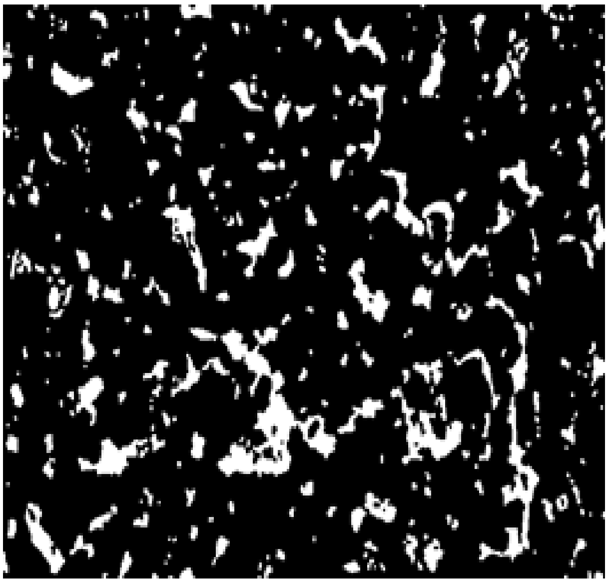

Fig. 9: Binarization of sandstone sample.

Fig. 10: Binarization of limestone sample.

IV. RESULTS

The porosity value obtained for the limestone was 8.32%. It can be seen from the thresholded image that pore space is quite less and hence a low porosity value. For the sandstone samples values obtained were 17.25% and 12.82% respectively. In TABLE II it can be seen that the porosity range is observed to be roughly 5-30% and 7-56% for the sandstone and limestone samples respectively. Thus the results obtained seem to comply with the values available in various sources available. But to examine its accuracy procedures and values from other research papers must be taken into consideration in which different values may be obtained in the same range. For more precise values more samples for a particular rock should be used and average of porosity should be calculated.

V. DISCUSSION

The article presents a simple and easy method of determining rock porosity with the use of image analysis.

Multiple view of the same part of the section is allowed as this does not affect the final result. The presented method can be modified using some variations by using different algorithms from the mentioned above if it gives a more accurate value. To get more accurate values for porosity using image analysis a higher resolution image should be preferably used so that large number of pores of the whole pore system are accounted for in the calculation. Another important point for discussion that should be noted is that image analysis using 2D images will give satisfactorily accurate results if the rock under consideration satisfies the property of homogeneity and isotropy. The rock can be considered isotropic when image features are independent of orientation. This will ensure that 2D area fraction is roughly equivalent to 3D volume fraction for that rock. Correct determination of porosity is of key importance in the oil and gas industry. It's usually conducted with the use traditional methods. Scientists since quite a long time have been trying to use image processing techniques instead of traditional techniques to save time as well as cost.

VI. Conclusion

Rock formation evaluation can be assessed using digital image processing methods for physical properties estimation. This paper proposes a simple and efficient method which determines rock porosity based on image analysis. The main goal of the presented research was to automate the quantitative measurements process, which in the standard, non-automatic form is time consuming and troublesome for the observer. The porosity values combined with some other characteristics of rocks such as permeability can be used to determine diffusion coefficient which is of prime importance in the study of diffusion in porous mediums.

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