APPLICATION OF CT-SCAN IN CORE ANALYSIS

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ABSTRACT

Computerized tomography (CT) is a new radiological imaging technique that measures density and atomic compostion inside object. Since 1980, the CT has been applied in petrophysics and reservoir engineering. This paper discusses several petrophysical application in core analysis such as: quantification of complex mineralogy, characterization drilling fluid invasion, core quality control bedding detection, porosity determination, and fracture analysis.

I. INTRODUCTION

X-Ray CT is a radiological imaging technique first developed in Great Britain in 1972 by Hounsfield. CT revolutionized medical radiology by producing anatomical images of extraordinary accuracy in clinical detail. Hounsfield was awarded the Nobel Prize in medicine in 1979 for his contribution.

The main advantage of CT-Scan is its non-destructive nature apart from its ability to obtain image projections at many different angles in view seconds with resolution of less than 2 mm. The image is displayed in a cathode-ray tube monitor and saved as data storage/retrieval.

The use of CT-Scan in oil and gas industry started in early 1980s. It was used both for visualization and for determining fluid saturation during displacement experiments on cores. In 1981, Saraf and in 1984, Wang performed miscible fluid displacement and used CT-Scan for visualizing the processes. Later, similar works were conducted by Wellington and Vinegar (1985) and Hove et al. (1987). In 1987, Vinegar et al used CT-Scan in rock mechanic study to measure compaction and compressibility.

Pre-scanning of core material is a useful addition to any core analysis program. Inspection on conventional cores by CT-Scan can be performed in rapid and non-destructive manner. Objects such as fractures, minerals, micro-layers, porous area maps, and mud-invaded areas can be observed. The scanning can also be done on frozen cores stored either in boxes or in polyvinyl chloride (PVC) tubes. It is usual that for the purpose of core analysis plugs are cut by drilling the full-diameter core both horizontally and vertically with respect to bedding. Therefore, it is important to determine the direction of bedding as the source of permeability anisotropy (difference in permeability with respect to directions, normally taken as horizontal and vertical), to obtain which scanning prior to slabbing is important. Another purpose of CT-Scan is in form of pre-scanning plug samples in order to control their quality in relation to the tests.

This paper demonstrates information that is potentially contained in CT-Scan results. It is to be seen that core scanning is worth to be integrated in the standard procedure for routine core analysis.

II. SCANNING TESTS

A. *Instruments and Method*

CT scanners have been undergoing considerable developments since 1972. First generation scanners used a single pencil beam source and detector arrangement. Second generation scanners improved image quality by the use of multiple detectors in a translate/rotate configuration. A large improvement in speed characterizes the third generation scanners, which used rotating-only fan beam geometry with source and detectors rotated altogether around the object. Finally, the fourth generation scanners use fan beam geometry with source rotating within a fixed ring of high efficiency detectors. The second- through fourth generation of CT scanners, normally used for medical purposes, are considered satisfactory for petroleum engineering application since they have adequate X-Ray energy and dose for scanning core material.

CT-Scan used in this experiment is the Universal Medical ADVENT HD200 which system design incorporates fourth generation. The machine consists of the following major components: the operator's console, the display console, the gantry, the power box, a high voltage control cabinet, the sample table, the image processor, a line printer (Figure 1). The operator communicates with the system via a typewriter-like keyboard and easy-to use pushbuttons, both located at the operator's console. The controls located at the operator's console allow the operator to effectively initiate scanning routines and also direct a variety of computer functions geared toward image display, image processing, data storage/retrieval, etc. The actual collection of data occurs at the gantry. An array of 720 detectors is located within the gantry. As soon as the data is collected at the gantry, it may be further qualified using a variety of image display and image analysis functions directed by the Image Processor.

For a scanning, the sample is centrally positioned on an adjustable table at the aperture of the gantry. At the operator console, the operator selects parameters and technique factors such as: Voltage and current for the X-Ray source, the number of scans, exposure time, table interscan increment, etc. When the operator starts the scan, a narrow fan beam of X-Ray is generated by collimating the fan of X-Rays emanating from the X-ray source. The beam is collimated, transmitted through the object being scanned, and is detected by a detector that conducts the electrical currents, then converted into digital signals for computer processing (Figure 2). A beam of X-Rays passing through an object of thickness is attenuated by absorption and scattering. The amount of absorption is determined by the atomic composition and density of the sample material.

B. *Principles of X-ray Attenuation*

The basic quantity measured in each pixel of a CT image is the linear attenuation coefficient, m. This is defined from Beer's law:

$$I/Io = \exp(-\mu h) \quad (1)$$

where

Io : the incident X-Ray intensity.

I : the intensity remaining after the X-Ray passes through a sample

h : sample tickness.

The linear attenuation coefficient (m) can be defined as:

$$\mu = \rho(a + bZ^{3.8}/E^{3.2}) \quad (2)$$

where

a : the Klein-Nishina coefficient

b : constant.

The first term in Equation 2 represents Compton scattering, which is predominant at X-Ray energies (above 100 kV). The second term in Equation 2 accounts for photoelectric absorption, which is more important at X-Ray energies well below 100 kV. One image that is proportional only to bulk density and another that is proportional only to atomic number (i.e. the chemical composition of the rock and fluids) can be obtained by scanning at high and low X-ray energies and solving Equation 2 on a pixel-by-pixel basis.

III. RESULTS AND DISCUSSION

Several samples have been scanned and some of information contained in CT-scans of core is demonstrated in the following examples.

Figure 3 shows the CT-reconstruction of laminated whole core sandstone that the bedding plane is very clear. When a bedding plane is visible, its dip angle can be measured directly from the CT-Scan (on monitor console). However, this is only an apparent dip; unless the X-ray

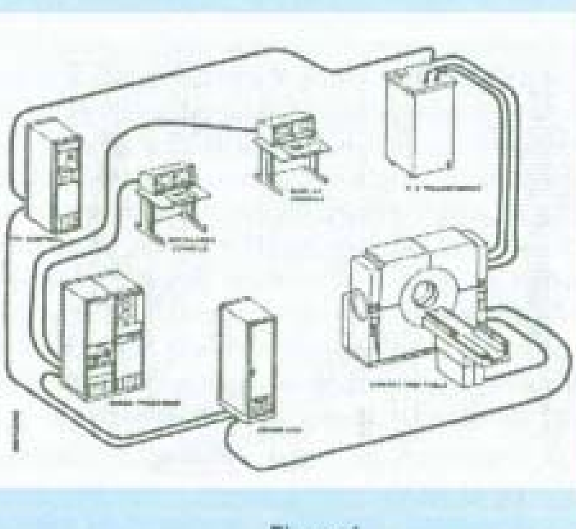

Figure 1
Advent HD200 whole body scanner system

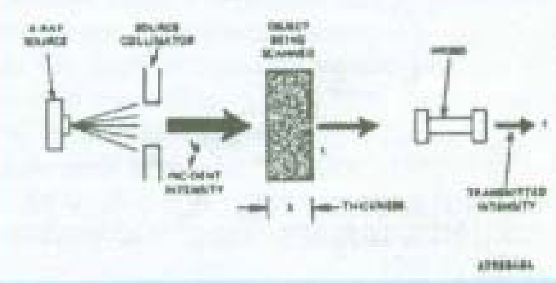

Figure 2
Measurement of X-ray attenuation

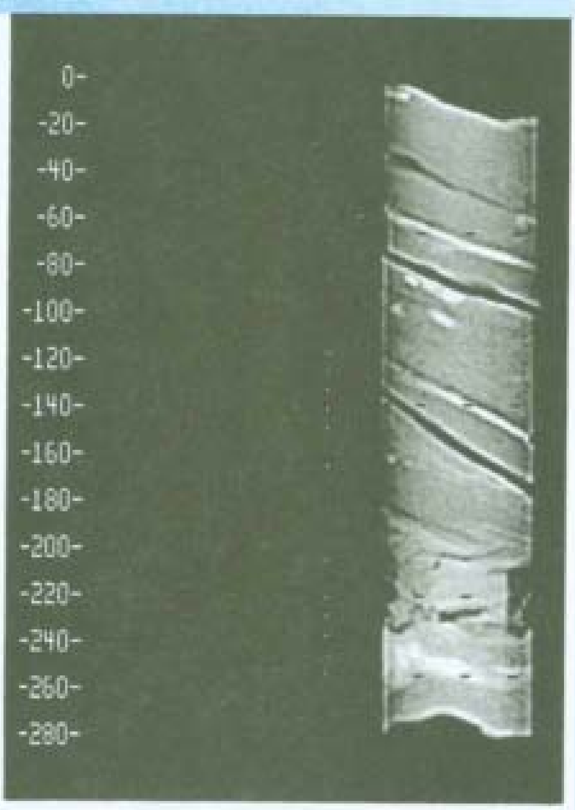

Figure 3
The CT-reconstruction of whole core sandstone shows bedding plane

Figure 4
CT-scan photo of a whole-core carbonate sample. Notice the white spots and a vertical hole left by vertical plug in the interior of the core

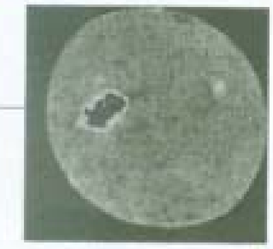

Figure 5
An axial "slice" of the sample in Figure 4 (the line of Figure 4 indicates the sliced area). The white spots prove to be minerals with higher density than the rest of the rock matrix

beam path is precisely parallel to the bedding plane strike, this angle will be less. If both the apparent dip and the angle of divergence between the X-Ray path and bedding plane strike are known, the true dip angle can be calculated. This can provide an increased level of quality assurance when orienting for the purpose of slabbing, and can also be a valuable comparison tool for dipmeter or formation image logs. This data is very useful for sampling, in order to obtain the most representative horizontal and vertical permeability (anisotropy).

Figures 4 and 5 are the CT-Scan reconstruction of 0.5 meters whole carbonate sample. As shown in Figure 4, the white spot area indicates fragments or mineral that is also supported by the axial slices of this sample (notice the red area in Figure 5). In this case, scanning electron microscope (SEM) and X-ray analysis are needed in order to identify these fragments or minerals. Needless to say, the CT-Scan has the capacity to quantify the fragments and minerals in a whole core.

Figures 6 and 7 illustrate the CT-Scan reconstruction of an unconsolidated sand plug. These figures indicate various damages sustained by the pore system. Figure 6 shows mud that is indicated by red areas, an observation on which indicates deep mud invasion. Figure 7 shows the pres-

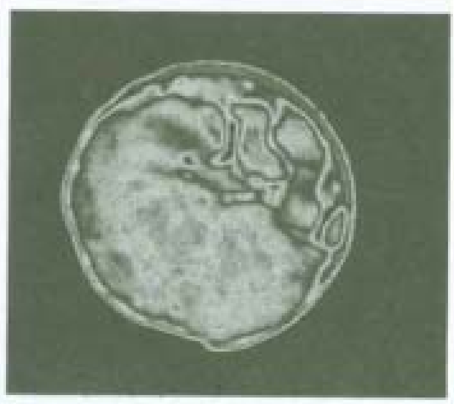

Figure 6
CT reconstruction of a plug sample shows invasion of barite (red area or high-density area)

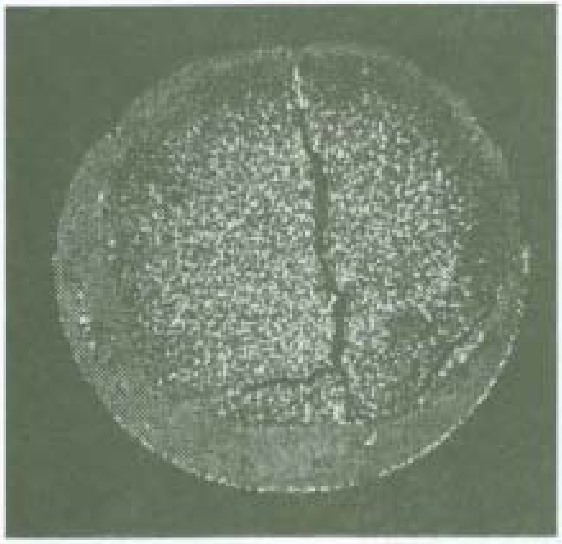

Figure 7
CT cross section of the plug sample indicates presence of fractures (dark area or low density area) and mud invasion (red area or high density area)

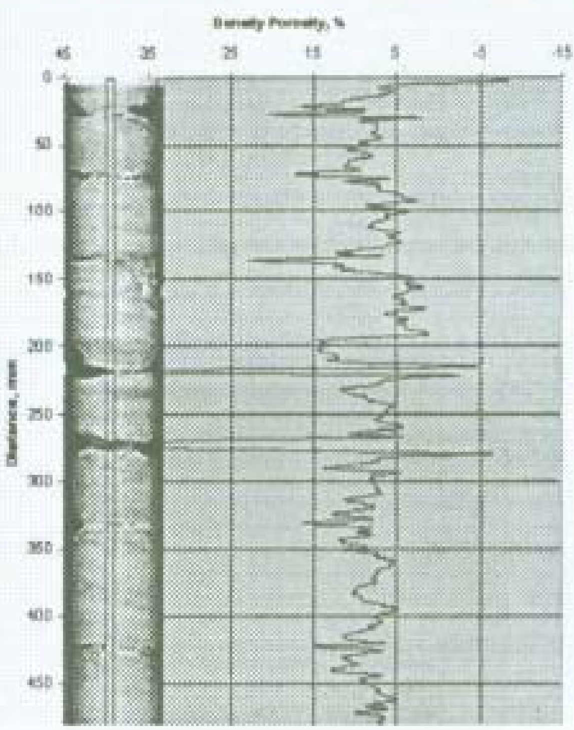

Figure 8
Show the CT-Scan photo and the porosity profile calculated from CT data

Figure 9
CT Reconstruction of outcrop carbonat sample

ence of a fracture in the plug. It can be concluded accordingly that the plug sample is not appropriate for core analysis since it is considered that the sample does not represent the actual reservoir condition. It is heavily contaminated by mud and is fractured. Later porosity measurement indicates an abnormally high porosity (54%), supporting the earlier conclusion that the plug sample is not representative.

As mentioned earlier, the CT-Scan also represents density hence facilitating the determination of porosity. Figure 8 shows the CT-reconstruction of laminated sandstone and the porosity profile. Since some cores are often lost during coring operations (i.e. unfavorable core recovery), it is sometimes difficult to correlate the remaining cores with natural gamma ray logs. In this case, the porosity profile can be correlated with the log data to check the missing intervals.

Figure 9 shows the CT-reconstruction of a carbonate outcrop sample. From this figure, we can see the vugular pores. This suggests that the CT-Scan can be used to determine the pattern of vugular pores in carbonate reservoir rocks.

IV. CONCLUSIONS

A set of conclusions has been drawn from the study:

- The CT-Scan has proved itself as rapid, non-destructive, providing high-resolution images, and having capacity as data storage for core images.
- For petrophysical studies, CT-scan provides images (either density or effective atomic number) that can yield porosity, fracture patterns, drilling fluid invasion on a local scale, quantification of complex mineralogy, as well as rock heterogeneities.
- Since the CT-data correlates directly to density log (both measure the amount of Compton scattering that is proportional to bulk density of the material) the determination of porosity can also be made.
- Scanning whole core before slabbing and cutting plugs is important in order to determine the direction of bedding, from which the most representative horizontal and vertical permeability can be obtained.
- The CT-Scan has the facility to calculate angle of bedding of image that shows the apparent dip of bedding. This information can be used to calculate the true dip of bedding that is a valuable comparison for dipmeter or formation image logs.
- The CT-Scan can be used to control the quality of sample. It is therefore suggested that scanning is carried out on plugs before and after any flow tests in order to check the possible presence of fractures.
- Considering its potential support for rock description, it is appropriate to propose that the CT-Scan analysis to be integrated in the standard procedure for core analysis.
- Its capacity for describing the interior of cores implies that CT-Scan can be useful as a tool for observing fluid displacements, as well as fine tuning EOR tests conducted in laboratory.

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