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State of the Art: Review of Coring and Core Analysis Technology

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Abstract. The main goal of core analysis is to reduce uncertainty in reservoir evaluation by providing data representative of the reservoir at in- situ conditions. Basic core analysis measurements are unchanged, but advances in core analysis techniques provide the ability to measure the required petrophysical properties at reservoir conditions and to acquire also simultaneous measurements of reservoir dependent parameters. Core analysis has to be integrated with field and production data to minimize reservoir uncertainties that cannot be addressed with other data sources such as well logging, well testing or seismic. These requirements define the coring objectives, core handling and core analysis scheme. These objectives cannot be achieved by coring a single well. Coring program is thus an integral part of the reservoir history cycle. The quality and reliability of core analysis data have become more important with the ever-increasing pressing pressures to optimize field development. the post- eighties economics of the petroleum industry, expressed as a need for ever more cost effective technology combined with the need to evaluate thin bed and non-conventional reservoir by means of vertical and horizontal wells serve as both the controlling factor and driving force respectively, behind the development of new techniques of coring and core analysis.

This paper provides an overview of recent and emerging developments and trends in coring technology and core analysis. This is to enhance the reservoir evaluation processes. The questions of quality control and quality assurance are discussed that aim at an early detection of systematic challenges in data products, particularly those with a danger of causing quality reduction. Finally the main challenges in core analysis and recent trends affecting future tool developments will be discussed.

Key Words: Coring, Core Analysis, Quality Control, Characterization and Recent Techniques

Introduction

The task of the reservoir geologist is to describe the reservoir as completely and accurately as possible using a variety of methods, from seismic and well testing to logging, cuttings analysis and coring. These methods present the engineer with a valuable range of scales from photomicrograph of a single filament of illite, to the log investigating up to several feet around the borehole, to the well test probing hundreds to thousands of feet into the formation. Many of the methods allow the engineer to estimate three key formation descriptors- porosity, fluid saturation, and permeability. But different methods may lead to different values. Porosity, for example, measured on a core which is removed from in situ pressure, temperature and fluid, then cleaned, dried and resaturated may not become close to porosity determined from log measurements [1]. To form a commercial reservoir of hydrocarbons, a formation must exhibit two essential characteristics. These are a capacity for storage and a transmissibility to the fluid concerned, i.e. the reservoir rock must be able to produce and maintain fluids, when development wells are drilled. In general, several objectives must be met when taking core samples. But in the prime place, a careful on-site examination for hydrocarbon traces is desirable (e.g. gas bubbling or oil seeping from the core, core fluorescence on a freshly exposed surface, fluorescence and staining in solvent cuts etc.).

Advances in technology continuously make new improved measurements and experiments available to the industry. Today this process seems to move faster and faster and there is a demand for new standards both for coring and logging. Even with the current possibilities in computer technology, much energy is used in the process of transporting data between different software systems and different formats. A potential for improving acquisition and analysis at reduced cost is obvious.

This review paper starts by the basic concepts of core data analysis and then discusses the quality issues in coring and cores data analysis. The development in coring and core data analysis represents the main goal of the present study, so it is classified into three parts. The first part covers the recent techniques in core data analysis, the second part outlines the factors controlling the feature development in tools and the third part is devoted to discuss the challenges in core data analysis.

Basic Concepts of Core Data Analysis

Coring and core analysis form an integral part of formation evaluation and provide vital information unavailable from either log measurements or productivity tests. Core information includes detailed lithology, microscopic and macroscopic definition of the heterogeneity of the reservoir rock, capillary pressure data defining fluid distribution in the reservoir rock system, and the multiphase fluid flow properties of the reservoir rock, including directional flow properties of the system. Also, selected core data are used to calibrate log responses, such as acoustic, or neutron logs used to determine porosity. As a result, core data becomes an indispensable source in the collection of basic reservoir data directed toward the ultimate evaluation of recoverable hydrocarbons in the reservoir. Figure 1 shows types of data obtained from recovered cores [1; 2, p. 325; 3, pp. 62-72].

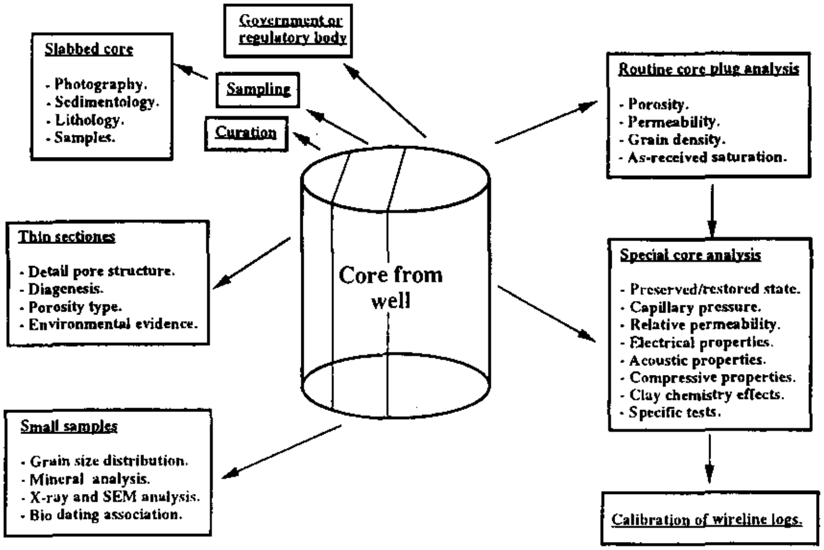

Fig. 1. Data obtained from cored well [1].

The process of obtaining the basic reservoir data required for evaluation is followed by the problem of generating this information at minimum cost. In order to do this, a number of questions need to be resolved: How many wells must be cored in any given reservoir? What types of core data are required?, What types of coring fluids are necessary under the reservoir conditions with regard to the type of core data to be obtained?, How should these cores be handled in preparation for these analyses?, How many core samples should be analyzed? and how can the coring and logging programs be coordinated to minimize the coring requirements and make maximum effective use of the cheaper log information?

Routine core analysis

In general, it may be said that coring operations are subdivided into two types; those conducted on exploration / appraisal wells and those on development wells. As further generality, it is often found that the control of the coring program lies with exploration geologists for exploration / appraisal wells and with reservoir engineers for development wells. The amount of core taken is usually decided on through the basis of a technical argument between data collection, technical difficulty and cost [4-6].

Routine core analysis is primarily concerned with establishing the variation of porosity and permeability as a function of depth in a well. In order to do this, samples of recovered core are subjected to measurements and the results plotted and / or tabulated.

In order to provide valid analysis, different rock systems require various analytical approaches with particular names, i.e. conventional core analysis, whole analysis of the core recovered in rubber sleeve. In addition, some analyses may also be performed on cuttings and sidewall cores. The techniques are reported in API booklet RP40 entitled Recommended Practice for Core Analysis Procedure [7]. Society of Core Analysts SCA has conducted an interlaboratory survey to determine the agreement and the suitability of different methods for measuring electrical property [8]. The end result of this survey was guidelines issued by SCA in four parts [9-12].

State of the art and pressing problems in core analysis

More than 30 years ago, the first edition of the Petroleum Production Handbook had been printed. In the chapter devoted to core analysis, Mr. Koepf, introduced the subject as follows: **"The early-day analysis of cores was largely an art, a qualitative matter of odors and tastes, sucking on the rock, and visual examination".** Obviously, with this picturesque statement he wanted to indicate the tremendous progress made in quantitative core analysis by the year 1962.

Looking at the present state of the struggle with some basic, very simple-looking problems (such as the determination of in-situ porosity) and our inability to reproduce in-situ conditions accurately for the measurement of a host of other crucial parameters, we get the feeling that the day of the truly quantitative and representative core analysis has not arrived yet. So, where do we stand? What is the state of the art? It is undeniable that we already made immense progress in acquiring, handling and analysis cores. Techniques are constantly being improved or new ones introduced. In the area of laboratory core handling we see a more widespread use of CT scanning for quality control and other purposes, and refined core preparation techniques such as the "critical-point drying and wetting" for preserving delicate clay structures. In proper core analysis we are witnessing the automation of the geological core descriptions, a growing use of the minipermeameter and the proliferation of such sophisticated analysis methods as the SEM/EDX, X-ray diffraction analysis, infra-red spectroscopy, X-ray and NMR tomography, NMR spectroscopy, imaging and image analysis. All these Hi-Tech methods provide a wealth of microstructural and macroscopic information previously undreamed of [13]. We have also become much more aware of the importance of working with representative samples and simulating in-situ condition during measurements. Finally, we should mention that advances in computerization and automation have made an immense contribution to more accurate and more efficient data acquisition and interpretation.

The main pressing problems are that: (i) many people don't even realize they have a problem, (ii) others may not know that a solution to their problem has already been found; or several solution to a particular problem may exist, but there is no consensus as to which is the best, and (iii) the clearly superior technique has been identified but it is costly to implement and time-consuming to use, hence it is not attractive as long as the customer is not willing to pay for it.

Quality in coring and core data

Quality always has been and always will be important. In the last few years, however, it has increased in importance. This is due to several factors. First, competition is increasing and, as a result, customers have more choices. Second, more and more companies are implementing their own quality-improvement programs and, consequently, involving suppliers in the process. Third, as a result of both these factors, customers are more likely to be able to define and measure the quality of the products and services they receive. Thus, quality is now more important than it ever has been [14].

Quality in coring/logging industry

A coring or logging is a product and, as such, needs to have quality. Attributes of a product. According to the International Organization of Standards" ISO", product quality has four facets.

- Quality that is due to the definition of needs for a product.
- Quality that is due to product design
- Quality that is due to conformance to product design.
- Quality that is due to product support throughout the product's life cycle.

Each attribute depends on the previous ones; conformance loses its importance if the product at its conception does not match the client's needs. The first attribute, Quality that is due to the definition of needs for a product, is of paramount importance. How are logging companies doing on this first consideration? Does the logging vendor define a match between customer's requirements and the product? Consider the customer's requirements. The customer wants the exact characteristics of the rocks. In addition, he wants these characteristics to be representative of the volume to be produced.

Now consider the product defined by the logging company. The product is the result of a measurement. By the constraints raised by physics, it differs from the true value of the formation. The difference is called "accuracy", Fig. 2. Logs cannot completely match users requirements at the design stage. In addition, the product delivered in the field does not fit strictly with the one designed in research and engineering centers, Fig. 3. This double mismatch represents a challenge and an opportunity to improve the product for the oil companies and the oil data companies. Yesterday's objective of logging was to get a curve, Today's, is to get a curve that looks good, while Tomorrow's, will be to get a curve that the customer can be assured is good. [15,16].

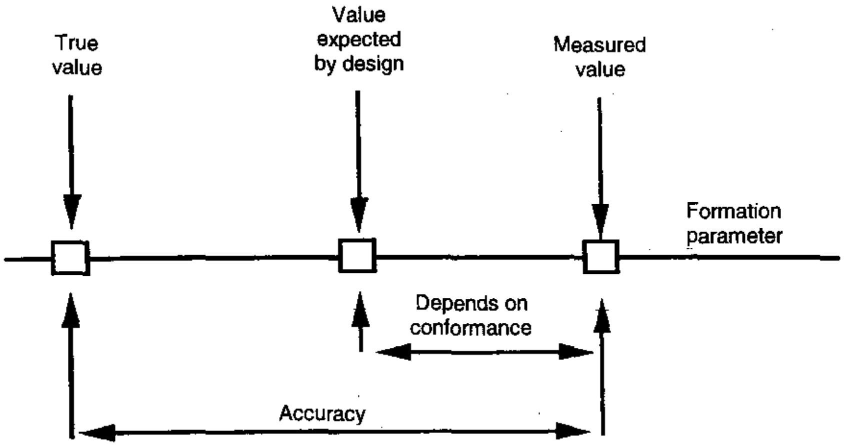

Fig. 2. True value required by oil/gas company and measured value provided by the well logging vendor [16].

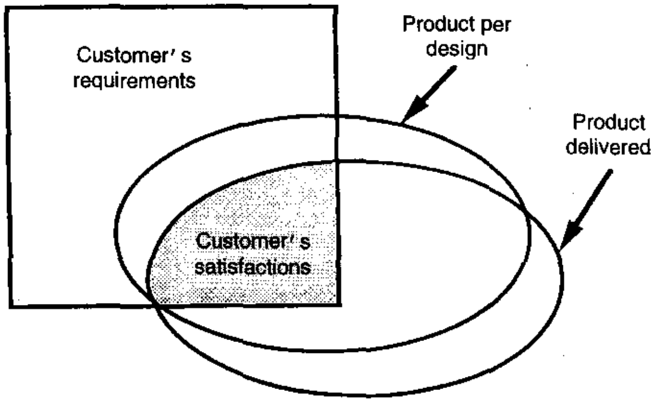

Fig. 3. Client needs and delivered service [17].

Core data quality issues

The key factors in measuring quality of core data are similar to those involved in the quality management of any other product: effective assessment of needs, effective communication, effective planning and effective delivery of a "no-hassle" product. Quality results require quality samples. The planning process starts long before spading the well and must include, among other things, the following multi disciplinary items:

- objectives of the well
- objectives of the core
- detailed planning for mud, bits, barrels, surface handling,
- packaging and transportation costs

The reason for cutting is to optimize the understanding of the reservoir rock and to calibrate the porosity derived from logs such as the density. Why spend money attempting to measure non-reservoir rock? It is far better to use discretion and cut good quality plugs in (potential) reservoir rock. The resulting average properties will not be correct for the gross hydrocarbon column but will be correct for the net column. The choice of core analysis contractor is important because different laboratories give different answers to the same type measurement performed on the same piece of rock. Steps taken by the industry to standardize the results range from recommended practices to test plugs and more recently to the adoption and accreditation of Quality Management [17].

Recent techniques in core analysis

The goal of core analysis is to reduce uncertainty in reservoir evaluation by providing data representative of the reservoir at in situ conditions. These data must be collected quickly and inexpensively. Maximum advantage of this concept is realized only with the full integration of geophysics, petrophysics, geochemistry, and reservoir engineering. Problems of scale, tool resolution, formation anisotropy, reservoir hetrogeneities, and accuracy and precision in laboratory testing must be understood in order to build a realistic reservoir model.

An exhaustive review of the literature would be impractical because of the broad nature of this discipline. The general reviews that follows cites significant contributions and refers the reader to references for further details.

Coring

High quality core material is absolutely crucial to the success of a rock characterization study. The coring program must minimize damage to the rock and maximize recovery. Equally important are core handing and preservation procedures [18]. Mishandling cores can invalidate even the most carefully designed laboratory test. Several recent innovations in coring technology contribute to acquisition of more reservoir- representative rock. A shift towards the coring of unconsolidated sediments, fractured rock, and coal beds has accelerated the use of disposable inner barrels and liners, fiberglass. Aluminum and plastic inner barrels have effectively replaced rubber sleeve methods for coring complex lithologies. Specialized clam shell core catchers permit complete closure of the inner barrel before surfacing the bottom hole coring assembly and are highly effective in recovering unconsolidated rocks [19, 20]. The invasion of drilling fluid into highly permeable rock is damaging and reduces the volume of uncontaminated rock available for analysis. Rathmell et al [21] have developed polycrystalline diamond compact (PDC) core bits and coring techniques to minimize fluid invasion. Side wall coring is an emerging technology that will have a great impact on the way coring is performed in soft sediments. This system allows for the acquisition of a full - diameter continuous sidewalk core where it is difficult for the geologist to predict the formation top of potential pay zone and drilling rates are high. The benefit of such a system `becomes clear when one considers the economics of coring offshore, for example, in the Gulf of Mexico. A developing technology with a high potential is Coiled Tubing Conveyed (CTC) coring. Coiled tubing is a continuous string of pipe spooled onto a reel and mounted on a portable drilling. The main advantages of CTC coring are the savings in trip time since coiled tubing is run continuously with no connections, and circulation can be maintained during tripping to help remove cuttings and cool down hole tools. This technology is now used to drill directional and horizontal wells and be capable of coring vertical wells to depths of 50, 000 ft with down hole mud motors [22].

The pressure-retained coring method, widely used during the early 1980's to recover in situ fluid saturation, is rarely used because of its high cost. Alternatively, many operators have resorted to sponge -coring systems to accurately measure reservoir fluid saturation, Fig. 4. Significant effort has been spent refining sponge-core analytical procedures, Vinegar et al [23] have developed Proton Nuclear-Magnetic Resonance (NMR) spectroscopy methods to determine oil saturation in sponge core. In general, the sponge coring method can provide additional reservoir data at a cost that merely doubles that of a conventional core.

Modern drilling fluids are used during most coring operations. However, if determination of endpoint saturations is one of the objectives, a coring fluid is designed to maintain the immobile-phase saturation. If a core is to be used to define fluid saturation-dependent parameters, such as relative permeability, capillary pressure, the drilling fluid should be formulated to maintain core-wettability characteristics as they were in the reservoir. Core-handling and preservation procedures are designed to maintain the physical integrity and reservoir wettability until planned tests are completed [24].

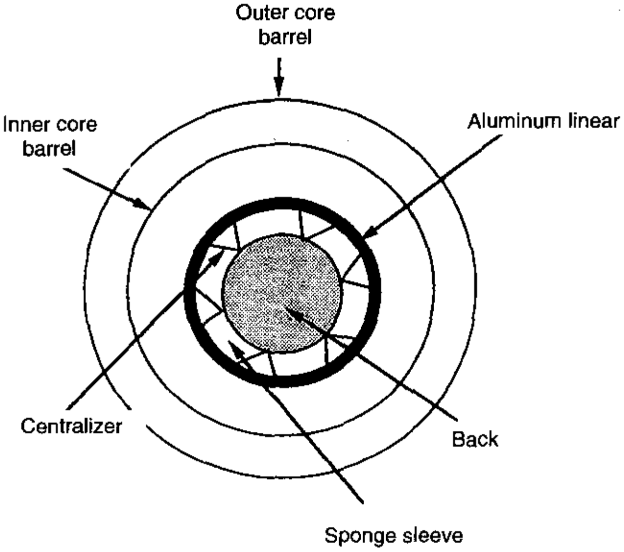

Fig. 4. Cross sectional view through the sponge core barrel [23].

Core analysis

Basic (routine) core analysis involves the measurement of the most fundamental rock properties under near ambient conditions. Porosity, permeability, saturation and gross lithology all provide critical information in deciding whether a wellbore will be economic [25]. A considerable work by the American Petroleum Institute (API) to examine recommended practices for determining permeability of porous media and core analysis procedures was published in the form of API RP40 (1960) [8]. The intent of the API is to provide recommended practices to petroleum technologists through unbiased committee participation. Society of Core Analysts SCA has issued guidelines for core samples preparation and core analysis in four parts [9-12].

Fluid saturation: Basic core analysis begins with the extraction (cleaning) of fluids contained in the pore space of the rock. Cleaning may be accomplished by passive Dean-Stark or Soxhlet extraction, solvent-flushing in a pressurized core holder or centrifuge, or gas-driven solvent-extraction. Research by Tonstad et al. [26] has shown that the Karl Fisher titration technique can be used in many cases to more accurately define water saturation. When the objective of the analysis is to obtain saturation information, X-ray Computerized Tomography (CT), and Magnetic Resonance Imaging (MRI) are alternatives to the time-honored extraction methods. Magnetic resonance techniques have the advantage of being able to distinguish bound from movable fluid as well as to estimate other critical reservoir parameters, e.g., permeability and wettability. A block diagram of MRI and the spectroscopy system is shown in Fig. 5.

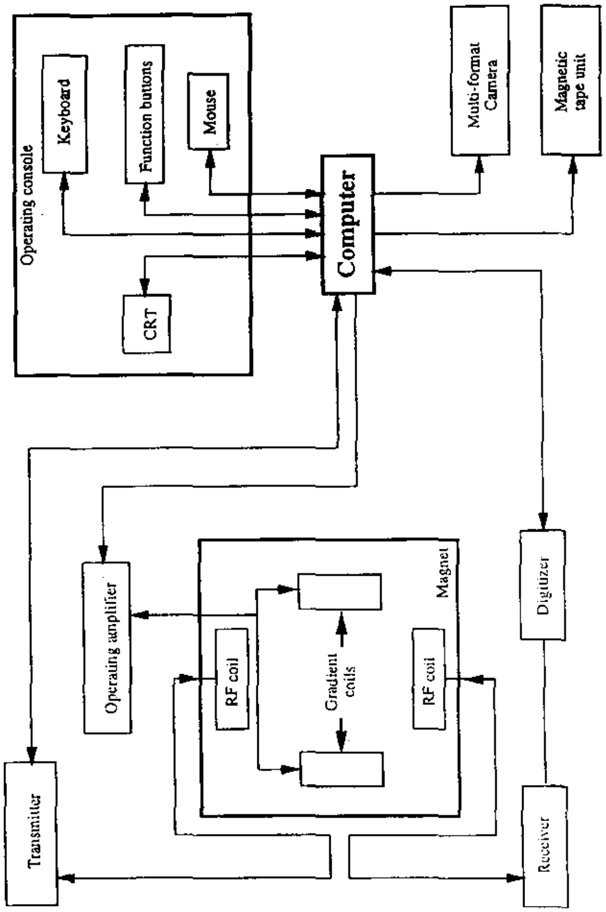

Fig. 5. Block diagram of MRI and spectroscopy system [26].

Porosity: A number of techniques are employed for the measurement of porosity in consolidated rocks. Boyle's-law helium-expansion is a standard method for measuring either pore volume or grain volume. These methods are accurate and reproducible if proper operating procedures are followed. Significant progress has been made in both CT and MRI to measure the porosity of saturated cores; these instruments are not widely available. Few commercial laboratories have CT capabilities and offer MRI services.

Both CT and MRI instruments are expensive and require highly skilled operators. As the costs for these instruments continue to decrease, their availability should increase. Tomographic imaging using thermal neutrons is another emerging technology that takes advantage of directly imaging the hydrogen content of samples and thus measures porosity with high sensitivity. A major limitation of this technique is the availability of neutron sources that are not reactor based. As new, more intense sources are developed, this technique may become practical for basic core analysis [27].

Permeability: Permeability can be estimated indirectly using wireline logging and pressure transient methods, or directly with core-based techniques. Indirect methods often prove to be unreliable; however, integration of methods at all scales yields the best estimate of reservoir permeability. One of the more promising indirect permeability technologies employs spin-echo magnetic resonance technology [28]. Formation testers, acoustic (Stoneley-wave velocity), and nuclear (geochemical) logging tools are also commonly used to estimate permeability.

Injecting compressed nitrogen or air through a small diameter injection tip, which is pressed against a rock surface, Fig. 6, performs probe-perimeter measurements. A rubber seal is used to prevent gas leakage past the probe. If the gas-flow geometry is known, permeability can be calculated from flow-rate and pressure measurements using an appropriate form of Darcy's law. Both steady state and unsteady state versions of the probe permeameter are in use. Halvorson and Hurts [28] have taken this technology one step further with the introduction of an automated laboratory-probe permeameter.

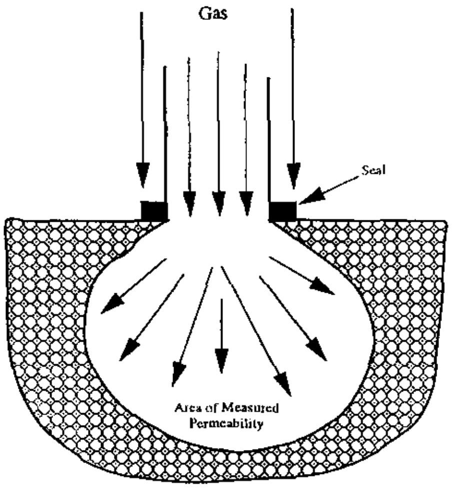

Fig. 6. Schematic diagram of injection probe [28].

Relative permeability is one of the most important reservoir parameters measured in the laboratory. Relative permeability data are used for prediction of reservoir performance and determination of ultimate fluid recoveries. Ebeltoft et al [29] developed a novel experimental apparatus for determination of three phase relative permeability at reservoir conditions, Fig. 7. It allows simultaneous injection of one, two, or three phases into a porous media. Both steady and unsteady experiments can be conducted. Average saturation determinations by the methods of volume balance and the X-ray absorption is in good compliance. Permeability imaging is a new technique that uses closely spaced grids of minipermeameter measurements to generate an image of permeability. These images (i) may be related to nonviable bedding features, (ii) can be correlated to microresistivity borehole images, and (iii) can be used to supplement or verify data form these borehole images where such data are ambiguous [30,31].

Capillary pressure: Several other techniques besides centrifuge have been used for measuring capillary pressure. These include the porous-plate, mercury-injection, and water-vapor adsorption methods. Porous plate is the original technique to which all others are referenced. Baldwin and Yamanashi [32] have demonstrated a new method of generating capillary-pressure curves from centrifuged Samples using magnetic resonance images to obtain fluid saturation distribution in Berea sandstone cores. The development of capillary-pressure instrumentation has far exceeded advancements in theory. Automated mercury injection instruments can now attain pressures in excess of 60, 000 psi. Yuan [33] describes APEX (Apparatus for Pore Examination) porous media technology that resolves pore space into pore bodies (sadirons) and pore throats (rosins) which each one is characterized by entry pressure and volume. Distribution functions are used to express macroscopic rock properties in terms of pore-scale properties. APEX technology can be used to estimate electrical and flow properties. Measure critical gas saturation, improve petrophysical evaluation, evaluate fluid trapping tendency, and predict formation-plugging potential.

Wettability: The wettability has long been recognized as affecting the measurement of special rock properties. Wettability is a major factor controlling the location, flow, and distribution of fluids in rocks. Undoubtedly, in situ wettability is one of the most difficult reservoir parameters to quantify. The most common methods to measure wettability include U.S. Bureau of Mines (USBM), Amott, contact angle (parallel crystal plate) techniques, and variations on these basic methods. Anderson et al [34] reviewed the use of the dynamic Wilhelmy plate for measuring the wetting character of oil, brine, and rock systems. This method is simpler and less dependent than standard contact-angle procedures and can be used to examine the effects of contaminants such as drilling fluid components. Longeron et al [35] have proposed a new wettability index based on the combination spontaneous imbibition and drainage processes in the USBM index. The new index may be able to distinguish fractional and mixed wettability.

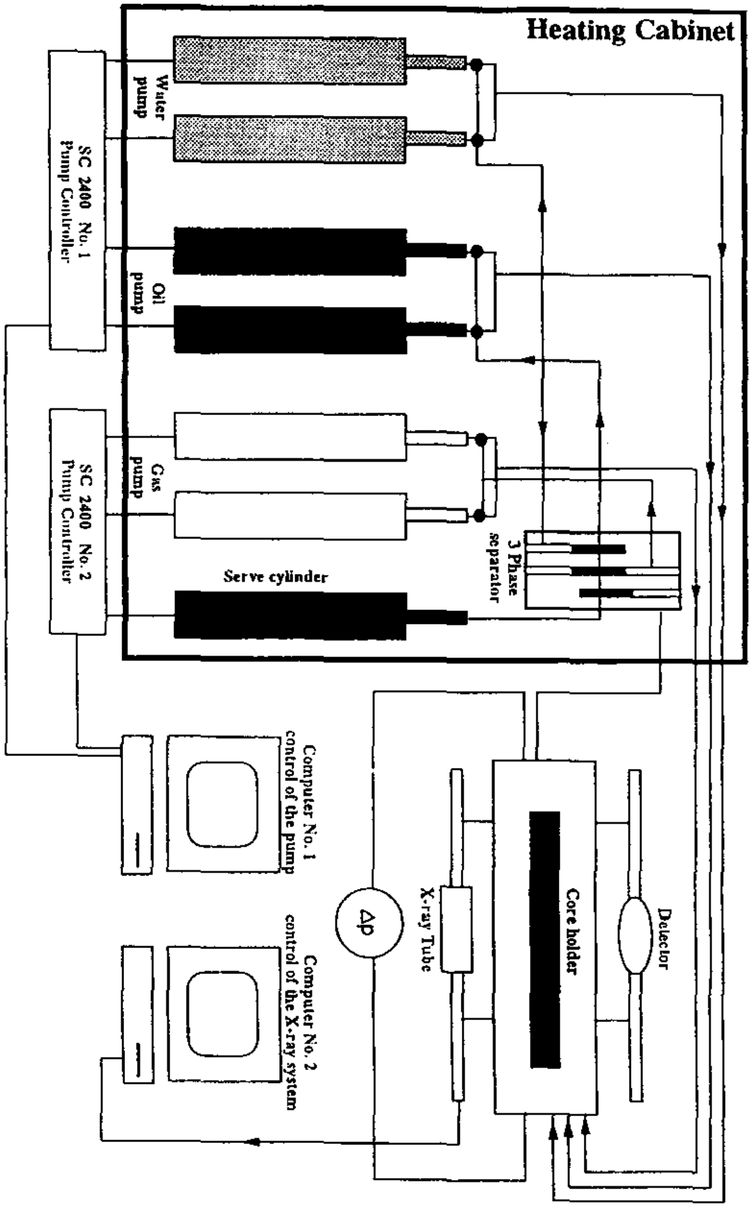

Fig. 7. Three phase apparatus [29].

Core-log correlation. For many years, a great deal of effort has been expended towards comparing, evaluating, and force-fitting core and log data. Formation-evaluation specialists often work on the presumption that core and log data must agree. Unfortunately, this approach is seldom successful. Borehole conditions, tool sampling volumes, rock and fluid properties, and laboratory procedures are some of the reasons why core and log data may not agree. This problem is complicated further if geophysical and pressure transient data are integrated into the interpretation scheme. The solution to the data-integration problem is one of fully understanding the petrophysical attributes of the formation. This can be accomplished through careful evaluation of data acquired from the field and laboratory. An ongoing study by Conoco to evaluate data from a borehole test facility may help explain differences between wireline, measurement while drilling (MWD), and core data [36].

Electrical: Perhaps one of the more elucidating studies in special core analysis in the last decade involved the evaluation of rock electrical properties. Sprunt et al. [8], under the auspices of the Society of Core Analysis, organized a study to assess the electrical-resistivity measurement capabilities of 25 laboratories. Standard plug samples of Berea sandstone, Bedford limestone, and porous Alundum were sent to each of the laboratories. The goals of the study were to (i) determine the reproducibility of different standard methods of measuring electrical resistivity and the extent of agreement between different methods, and (ii) assess the suitability of different methods for obtaining formation factor, cementation exponent; and saturation exponent. Numerous papers have been published on the measurement and analysis of Archie's parameters [37,38,39].

The effects of laboratory procedures on the measurement and analysis of the saturation exponent have shown this variable to be one of the most difficult petrophysical variables to quantify. Both MRI [40] and CT [41] imaging have been used to show fluid saturation and distribution problems during the destruction phase of the resistivity-index measurement.

In the case of shaly formation, more than 50 different models are currently in use to determine shale effect on the electrical properties of shaly formation [42]. Conductivity interpretation in shaly sands is required for clay conductivity. Yuan [33] describes procedures by which conductivity, membrane potential, and induced-polarization measurements are made simultaneously to improve shaly-sand interpretation. Unlike previous methods, the membrane-potential technique is performed with the clays in the rock intact; thus clay conductivity is not dependent upon empirical shaly-sand parameters.

Acoustic: Acoustic (dynamic) testing of rocks in the laboratory at reservoir conditions has been conducted for many years .The data generated are used to estimate impedance and reflectivity of sonic waves in rocks, determine elastic module and Poisson's ratio, and estimate the maximum drawdown pressure of wellbore, etc. Unlike the normal operational environment, where the acquisition of shear-wave data is not always possible, shear-wave velocity can be measured in laboratory rock samples. However, there are several obstacles facing the practical use of laboratory acoustic data in field applications. Major problems associated with using laboratory data to calibrate seismic and logging data are (i) velocity dispersion, (ii) laboratory sample volumes, (iii) rock heterogeneity, and (iv) reconciliation of dynamic and static data. [18,43]

Nuclear: Several laboratory techniques have been developed for measurement of the thermal-neutron absorption cross-section (sigma) of rocks and fluids to aid in the interpretation of pulsed neutron and compensated neutron logs. Another rock property of interest is the photoelectric absorption factor (P_e) measured by spectral litho-density tools. These tools are sensitive to borehole irregularities and drilling fluids with high atomic numbers, e.g. barite. Laboratory measurements of P_e are used to check the reliability of result obtained from downhole logs. Moake [44] reviews formation density and lithology measurement theory and introduces the concept of using a lithology factor (L) to take into account scattering mechanisms. Unlike previous methods, this technique does not rely on rock composition or elemental data.

Cation exchange capacity (CEC): There are numerous models available to account for the non-Archie behavior of rocks, one of the enduring and widely accepted is that after (Waxman and Smits 1968, ref. 45), where clay conductivity is explained in terms of the clays cation exchange capacity (CEC). There are three established methods with which to measure the CEC of a rock. They are (i) membrane potential method. (ii) variable salinity method, and (iii) wet chemistry method.[46,47]

In new wet chemical method for measurement of CEC the number of cation exchange sites existing in a formation sample is determined by an ion exchange process. However, it differs in three important respects from that of the conventional wet chemistry method; (i) a solid core plug is used for the analysis rather than a crushed sample, (ii) the complete analysis is performed using organic solvents (i.e. it is performed under non-aqueous conditions) and (iii) in order to treat the core plug quickly and effectively, the reagent solvents are forced through the core plug under pressure [47].

Petrography: The most dramatic recent advancements in petrography include pattern recognition and pattern classification software for description and quantification of rock-pore geometric characteristics. Elirch and Etris [48] describe Pore Image Analysis (PIA) an emerging technology used to derive the size, shape, and relative proportion of pores of different types through computer-based thin-section porosity analysis. It is possible to define several hundred variables for each field of view using this technique. PIA may be used with mercury- injection data to develop physical models for the determination of capillary pressure characteristics related to pore-type and pore- throat size. Other models have been used to estimate rock permeability and electrical properties.

Rock-mechanics measurement: Rock mechanical properties are frequent concerns in wellbore design, drilling and completion. With deeper wells and horizontal drilling, measurements of both dynamic (seismic) and static mechanical properties of reservoir rocks are made more frequently. Today both static and dynamic measurements can be made at moderate reservoir temperatures and pressures. New experimental equipment has been developed to extend the experimental range of the measurements and to reproduce true triaxial stress conditions, incorporating horizontal-stress anisotropy [49].

Hand-held techniques and outcrop evaluation

Gamma-ray logging of outcrops: The use of truck-mounted wireline tools for obtaining continuous gamma-ray logs of formation outcrops has been an "in-house" technique used by several companies for some time; however, it has only recently been publicized in the technical literature. This technique provides a continuous log that can be used to (I) correlate outcrops with subsurface logs (wireline and measurement while drilling, MWD), (ii) compare wireline log response with the actual rocks (visually and through laboratory analysis) for improved interpretation of these logs [18].

Hand-held velocity probe. This device is used to obtain rapid measurements of ultrasonic velocity on outcrop, core, and hand samples. Smoothed data show good correlation with wireline data [50].

Field minipermeameter: Development of a portable, hand-held mechanical mini-perimeter for rapid, in situ determination of surface permeability at outcrop or on core. This equipment is capable of making 400 to 500 measurements per day [28].

Porosity measurement by gamma-ray attenuation: This experimental method offers a potentially fast, nondestructive and portable means for determining porosity on core or in situ at outcrop. This technique determines porosity on a small part of a sample [51].

Digital core archives and rock catalogs

The advent and ready availability of powerful low-cost desktop computers, inexpensive storage media, and image processing software have made it feasible to work with digital images of core photographs, petrographic microscopy photos and CT images. These factors, combined with the development of CD-ROM media for storage of digitized images have resulted in the development of a new group of digital products that permit easy access to core and petrophysical data. In some cases, these products afford users the opportunity to study the geology of specific reservoirs at their desks, without a trip to a core library [52].

Two types of products are currently available, archives and rock catalogs. Archival products contain digitized images of core (e.g., photographs, photomicrographs, X-ray, or CT images) from public core libraries (e.g., Geological Survey's Core Research Laboratory) and the Canadian Petroleum Image Exchange Library Society (PIXLS). The large costs involved in obtaining measurements of rock properties and images make rock catalogs expensive undertakings. This may result in form in-house corporate efforts (e.g., Shell Oil's rock catalog) or may be the product of a subscription project where participants contribute samples from specific reservoirs, on a regional or worldwide basis; e.g., the worldwide Rock Catalog Digital Core Archives and Rock Catalogs [53,54].

Recent trends affecting future tool development

Partnerships and strategic alliances: Because of large development costs, the length of the development process (5 to 10 yrs.), and the uncertain financial payoff in a continually shifting market, the service companies seek to reduce their risks by combining their technological expertise and field experience with that of the operating companies.

Industry-wide consortiums: Two ideas are currently under consideration. One proposal, the Tool Response Characterization Consortium, would consider proposals forecasting and evaluating new commercial logging tools. Each member organization (Oil Company, Service Company, University and other) would contribute financially to the projects in which it chooses to participate. Participating organizations would share expertise as well as the results of the evaluation process. The other proposal would establish an advisory panel to the Energy Research Clearinghouse.

Acceptance of new technology: At the same time, the cost of the next, logging services works as a counter force that may inhibit the development of future technology. Many, operators are unwilling or unable to accept the high costs of running the latest technology, especially since many remain unconvinced of the costs versus benefits. As a result, service companies find it necessary to offer tiered service to avoid pricing themselves out of the domestic market.

New markets: The development of new markets for well logging technology and core data analysis and down hole geophysics, particularly in environmental assessment and re-mediation, will spur developments of future technology [55-57].

Challenges

Millheim [58] identified the two or three forces that reshaped the oil and gas industry over the last 25 years as : (1) the rise of oil prices in the 1970's with an associated boom growth, (2) the oil price crash of the mid-1980's with the subsequent mergers, takeovers, and corporate down sizing and (3) beginning at the end of the 1980's and into the 1990's organization adjusting that was mainly influenced by management consultants.

Let's now consider the main challenges in core analysis. This brings us to the crucial problem in core acquisition and core analysis: how to obtain data that are really representative of the rock in situ properties? The very process of coring and the ensuing handling changes the material. In spite of all the sophistication we have achieved to date, all that we can do is somehow attempt, during our tests, to maintain, restore or simulate the perceived in-situ conditions. This applies particularly to fluid flow properties, electrical properties and rock mechanical properties [13,59].

Another challenge still plaguing researchers is that of experimental data. Since 1968, when Waxman and Smits published their extensive data set, little experimental work has been published. Some 20 years later theorists continue to test their models against the Waxman-Smits and Thomas data set. Conductivity experiments on partially saturated shaly sands are difficult, slow and expensive, but they will be the key to improving log interpretation in the most common of all hydrocarbon-bearing rocks." Will we ever solve the problem of getting truly in-situ data from cores? The answer to this question should be "yes, almost". Barring a perfect solution, we should be able to come very close to providing representative data with greatly reduced and acceptable error. However, we will be able to meet this challenge only by the combined effort of all those involved in the whole process. The trend of the ever-accelerating technological developments sustained by an impressive R&D effort at many universities, scientific institutes and at the premises of the service industries and the oil companies in the science of coring and core analysis will lead to the believe that the era of truly quantitative and representative core analysis is just around the corner; hopefully we shall reach it by the year 2000 [59-61].

Conclusions

1. Techniques of coring and core data analysis have changed profoundly in the last few years. To a great extent, these changes are attributable to developments in technology conceived for other industries, e.g., medical imaging devices. Clearly, core data analyst must be versed in many scientific and engineering sub-disciplines to effectively use laboratory data.

2. We must continue to develop and refine our understanding of fundamentals of rock properties. As the electrical studies have demonstrated, core data analysis has a long way to go before it can be a quantitative science.

3. Core analysis formulates a basis for the calibration and verification of log analysis in the domain of evaluation of petrophysical parameters for the static and dynamic description of a reservoir. Improved standards are needed both for logging and core measurements.

مراجعة حديثة لتكنولوجيا جمع العينات وتحليلها

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ملخص البحث. الهدف الرئيسي من تحليل العينات الصخرية في تقويم المكامن البترولية وتحديد خواصها البتروفيزيقية بدقة عالية. لذلك، من الضروري، دمج برامج تحليل العينات مع البرامج المتعددة خلال مراحل نمو المكامن البترولية. من الطبيعي أن تعتبر الدقة في جمع العينات الصخرية وفي تقنيات تحليل تلك العينات من المهام الرئيسية للعاملين في حقل تقويم المكامن ذات الطبيعة المعقدة.

يستعرض هذا البحث أحدث التقنيات في مجال تحليل العينات الصخرية وكذلك كيفية التأكد من جودة الطرق المستخدمة في تحليل العينات وكفاءتها. وقدّم البحث الاتجاهات الحديثة التي تحكم التطور التكنولوجي المستقبلي في مجال تحليل العينات.

4. The above conclusions might be achieved by:

- Consolidating our achievements to date (New API guidelines).
- Attacking problems in analyzing difficult formations.
- Making a better use of the opportunities offered by today's Hi-Tech.
- Meeting the challenge of providing truly representative in-situ data, without which no reliable reserve assessment is possible.
- Achieving data integration by a comprehensive data base management and delivery system.
- Exchanging views and ideas and sharing knowledge.

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