RECENT EXPERIENCE WITH UNCONSOLIDATED CORE ANALYSIS

Richard Rosen, Bill Mickelson, Jason Fry, George Hill,
Bob Knabe - Shell International Exploration and Production and
Munir Sharf-Aldin – Meta Rock Laboratory, Inc, Houston, Texas

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Calgary, Canada, 10-12 September, 2007

ABSTRACT

In recent years there has been a large improvement in technology that has enabled a complete refresh of core analysis equipment. New methods, therefore, have been developed to handle the rigors of unconsolidated core and include protocols for handling, preparation, and analysis of porosity, permeability, electrical properties and capillary pressure. In particular, an apparatus has been developed which extends the range of insitu stress mercury-air stress capillary pressure to 30,000 psi and incorporates internal bulk volume strain and Boyle's law pore volume measurement. Additionally, extension of the standard continuous injection resistivity index includes a hybrid method based on intermediate pressure equilibrium steps which improves measurement of crude-brine capillary pressure under restored state conditions.

INTRODUCTION

Unconsolidated sand is arguably the most difficult material to work with in core analysis. In order to obtain results which accurately reflect reservoir properties, extreme care must be taken during every step of coring, handling, transportation, and preparation. Additionally, laboratory equipment and procedures need to be specially designed to minimize sample disturbance.

What follows below builds on the pioneering work of Ben Swanson and Gene Bowen in the 1960’s (and many other Shell Oil Bellaire Research Center staff, too numerous to list) who first introduced methods to freeze core with dry-ice and drill plugs using liquid nitrogen.

GENERAL COMMENTS ON FREEZING AND STABILIZATION

First, however, we address the issue of damage from excessive grain movement due to expansion of frozen brine. It is asserted for a hydrocarbon bearing, unconsolidated sand that sufficient gas-filled pores either exists or is created during “blow down”. Dry-ice (-80^{o} C) is preferred to standard electrical refrigeration ($–20\ ^{o}$ C) because most oils do not freeze at $–20\ ^{o}$ C. It is the freezing of the liquids at grain-to-grain contacts that cements grains together and increases cohesive strength of the core.

The effect of freezing on water saturated shales is more complicated. While it is certain that fluid expansion occurs, it is not always clear that this causes more damage than mechanical forces exerted upon less cohesive unfrozen cores due to transport and handling. Our bottom line experience is that we have never been able to obtain what we feel is a credible core analysis on anything but dry-ice preserved core.

CORING AND OBM SYSTEMS

Since the introduction synthetic oil based mud systems and improvements to coring systems, the quality of recovered core has dramatically improved. Coring practices, perfected in the Gulf of Mexico, have been successfully implemented globally. Properly designed mud systems also minimizes invasion and reduces the need to include tracers and has improved our ability to match core derived fluid saturation to wire line logs and other field data.

TRIPPING THE CORE OUT OF THE HOLE

While it has been long recognized that rapid transport may induce damage by gas expansion we feel, instead, that the damage mechanism is related to viscous forces exerted on grains by gas-propelled liquids. This notion is more consistent with fluidized bed physics where forces on a particle is dependent on contrast between grain and fluid density and fluid viscosity. Models of this type predict greater movement possible from much larger viscosity liquids than gases. Based upon this, the model we use assumes a cylindrical tank with interior volume related to the porosity with a low permeability mud cake annular exterior. The basic consideration is as the core is pulled up the hole in discrete stages, a sufficient duration wait time is allowed to dissipate the internal pressure buildup across the mud cake. The main difference between this approach and more standard models based on Boyle's law expansion is that more time is required at the end of the journey rather than the beginning.

WELL SITE HANDLING AND TRANSPORTATION

Sufficient capability exists within the major coring companies and analysis vendors to freeze core at the well site. These companies are equipped with specialized equipment to section, lay down, freeze and transport. Insulated freezing troughs, cutoff saws, thermocouples and shipping containers utilizing shock and temperature sensors are examples of essential equipment. Consideration need be given to commercial transport requirements and arrangements should be made to replenish dry-ice within customs holding areas en-route to final destination.

LABORATORY PHILOSOPHY

Shell International Exploration and Production (SIEP) maintains internal resources to support primary and special core analysis which complements commercial capability. Unconsolidated deepwater sand is one example of an important and difficult reservoir where we tend to perform most of the work ourselves under the general philosophy of *you get once chance to get it right*.

LABORATORY PRACTICE

It is our general practice to keep the core in a frozen state from well site to laboratory, throughout all phases of handling and preparation. A plug is allowed to thaw only when safely loaded in stress cell and under pressure. Once a core arrives, it is inventoried, gamma and CT scanned on close spaced intervals in order to document recovery, orientation, and condition. We then remove the core from the aluminum liner and place within card-board tubes, wrapping first with saran and foil and then fill the annulus with resin or foam for stabilization. Foam is preferred as it sets under low temperature and does not warp the tubes. Removal from the aluminum tubes prevents aluminum salt precipitates which, over time, will react with the core and cause deterioration. The cardboard is easier to drill through (less vibration) and enables plug recovery across the full core diameter in any direction.

Plugs are drilled with liquid nitrogen using industrial grade milling machines with large horsepower motors, low vibration and true rotation, Figure 1. A special container is also used (Figure 1) to keep the core frozen with dry-ice during this operation. Plugs are then scanned to determine condition and location for final size and end-trims used for companion measurements such as grain size or thin section.

Selected plugs are sleeved with Teflon (Industry standard metal foil sleeves easily wrinkle and may also allow by-pass during permeability measurement) and screened using sintered metal frits (Figure 2), then loaded in multi-use stress porosity-permeability cells. These cells are designed to load and bring up to confining stress within 30 seconds – fast enough to prevent thaw. These cells are also equipped with internal radial and external gages to measure bulk volume strain during throughout the measurement, Figure 3. The load pistons are designed to compensate for deviatoric stress which enable the cell to perform at true isostatic condition.

Bulk volume strain is a useful indication of sample damage. Figure 4 shows a histogram comparing a benchmark data set against typical results where best practices were not used. In the benchmark set bulk volume strains are within the 1 – 5% and considered to yield meaningful results when compared against independent data such as logs or other field data. Samples with large strains of over 10% tend to yield results that do not appear reasonable. In the case illustrated, the sample with 10% strain had 40% measured porosity but CT scan reveled areas of grain dilation (low density) indicating damage, Figure 4. It is the excessive disturbance or grain to grain contacts with over-compaction of these area which yield the excessive bulk volume strains.

Sample cleaning is accomplished by miscible flow under stress at slightly elevated temperatures using chloroform-methanol until extract colorless and fluorescent free. Salts are removed by flowing methanol. Drying is accomplished by flowing nitrogen. Samples subsequently chosen for relative permeability have additional cyclic cleaning steps using Tetrahydrofuran or Carbon Disulfide.

Porosity, permeability, formation factor and Qv (CoCw method) may be measured during one load cycle. For unconsolidated sands it is important to minimize stress cycling because samples will compact and physical properties change. Following this primary characterization, additional SCAL samples and measurements are selected. Given the concern regarding stress cycling, we do not usually make more than two measurements on a given sample.

OTHER ADVANCES IN LABORATORY EQUIPMENT

Transducers

There are an assortment of 16 bit digital transducers with accuracy +/- .02% commercially available and 0.01% if more accuracy is required. The latter degree of accuracy is considered a secondary calibration standard to NIST certified mechanical Piston Gages.

Pumps

Medical OEM suppliers make syringe type equipment typically used for high precision applications such as for chemotherapy injection that can adapted to low pulse injection systems for high pressure core experiments. In our laboratory tests these high precision systems outperforms other standard industry devices.

Other stock manufactured equipment are typically modified by customizing pistons, gearboxes and motors to achieve computer control to 10 nano-liter per step precision.

Systems such as described above are used for steady or unsteady-state core-floods or high pressure mercury capillary pressure. The device shown in Figure 5, operates to 30,000 psi injection with commensurate confining stress. It operates with a single range to 30,000 psi transducer and has integral Boyle's law for pore volume and internal strain gages to monitor sample deformation or test appropriate effective stress laws.

CONCLUSION

Core measurements on unconsolidated sands made using extreme care during every phase from well site to laboratory using best methods possible can yield useful reservoir property data that both match field history and predict performance.

ACKNOWLEDGEMENTS

We wish to thank SIEP management for supporting and publishing this work and to the many others who contributed ideas and inspiration. These include Mike Myers, Dennis Dria, E. C. Thomas, Joe Robinson, Bas Schipper, Herbert Yuan, Peter Doe, G. R. Pickett, and Peter Christman.

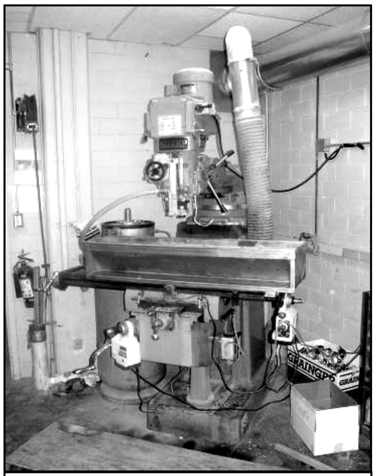


Figure 1. Milling machine used to dill plugs. Note dry-ice trough on table used to keep core frozen with dry-ice.

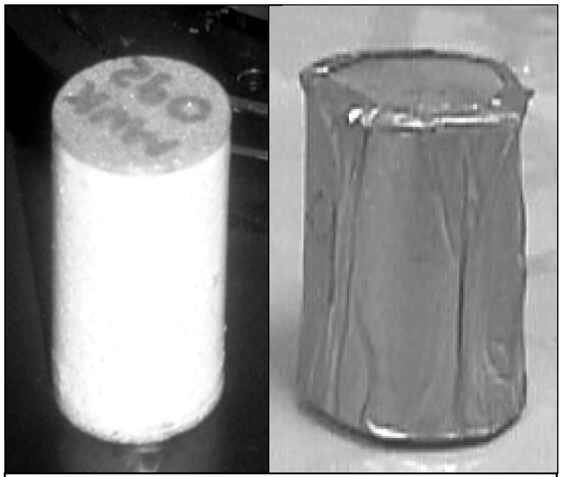


Figure 2. Teflon sleeve with sintered frit, left, compared with typical foil screen arrangement which tends to wrinkle easily and may allow by-pass.

Figure 3. Left, automated porosity permeability isostatic stress cells. Right, flanged viton sleeve with internal radial strain gage and axial LVDT attached to load piston.

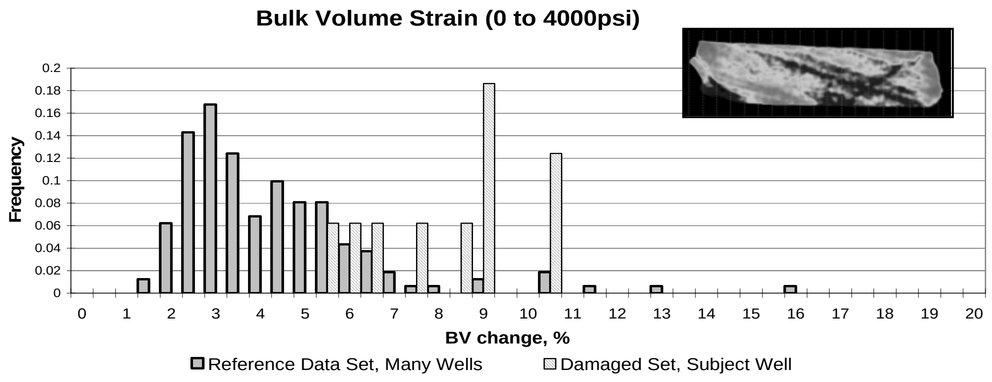


Figure 4. Distribution of sample bulk volume strain measured during porosity and permeability. Reference set of undamaged unconsolidated sands compared to sample set from suspected damage from a subject well. Note low-density dark areas in CT scan of plug shown upper right yielded strain of 10%.

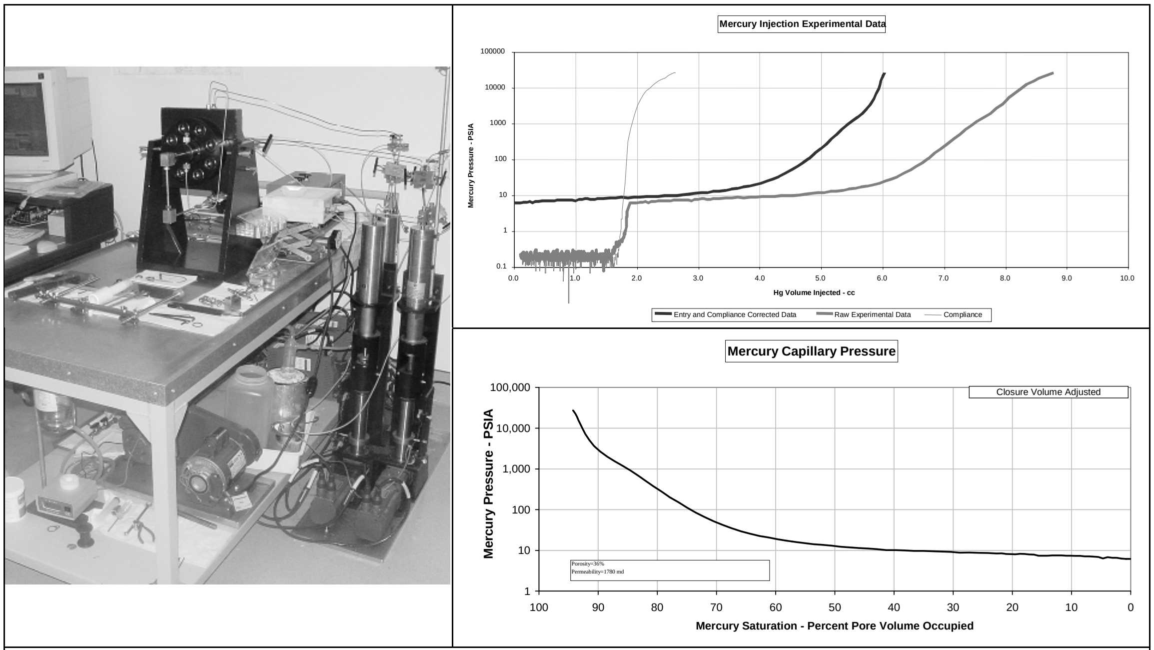
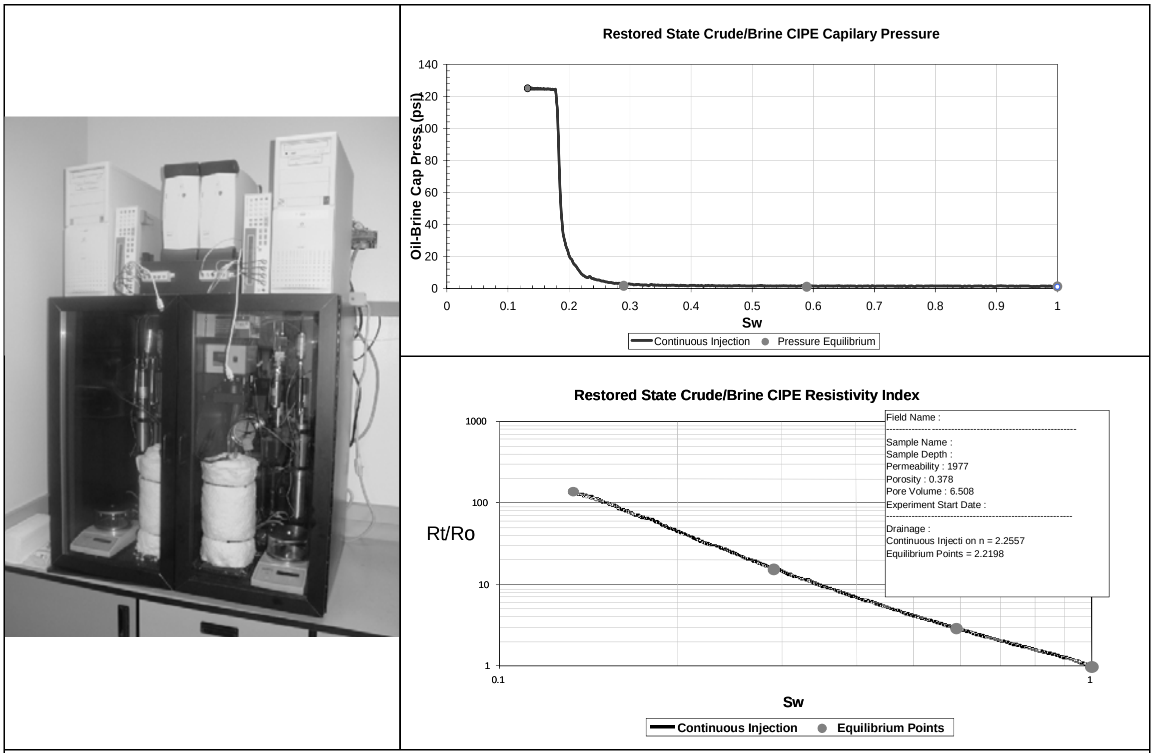


Figure 5. Left, Ultra Stress Capillary Pressure apparatus. Device to measure mercury capillary pressure to 30,000 psi with confining stress. Upper Right, raw experimental data with compliance curve and net capillary pressure. Bottom Right, closure correct result.



Field Name :

Sample Name :
Sample Depth :
Permeability : 1977
Porosity : 0.378
Pore Volume : 6.508
Experiment Start Date :

Drainage :
Continuous Injecti on n = 2.2557
Equilibrium Points = 2.2198

Figure 6. Left, Dual Pump Hybrid Continuous Injection/Pressure Equilibrium Resistivity Index/Capillary Pressure apparatus. Upper Right, example crude-brine capillary pressure curve. Lower Right, resistivity index. In both, points represent equilibrium data and lines continuous injection.