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Improved Core recovery using in-situ freezing

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Summary

The importance of obtaining a perfect core of a petroleum reservoir is undisputed. Despite tremendous advances in coring techniques, some basic problems remain as challenging as ever. One of these is the coring of unconsolidated formations. Partially damaged cores, totally damaged cores or zero core recovery are common, especially in unconsolidated formations. This proposed technique promises to greatly improve the recovery, quality and longevity of the core, thereby resulting in a much better interpretation.

Freezing has long been used to preserve cores on the surface, but never before used in-situ. Here in this technique, part of the formation is frozen before being drilled out. Freeze coring promises to be highly beneficial to all forms of coring, as it increases localized formation strength thus increasing shear resistance, impact resistance and consolidation. Hence, the chances of recovering the core intact increase significantly.

This paper discusses the science of the proposed process and explains the mechanism which will help bring back virgin cores to the surface. Changes in the current techniques are proposed which is backed by experimental work.

Overall, this work will help determine petrophysical properties of the reservoir to a much higher accuracy while drilling, thus helping in identifying prolific reservoirs.

Keywords*: Core recovery, Coring, Reservoir Characterization*

Introduction

Formations that are unconsolidated are difficult to core. The core recovery is low and the quality is subject to disturbances and impacts during drilling, tripping, etc. More complicated is side-wall coring, where the impact of the percussion core bullet can damage low strength formations and fail to deliver satisfactory cores.

Liquid nitrogen has long been used to prepare and preserve cores for slabbing and transportation. Especially, unconsolidated cores are cautiously frozen and preserved as they are more vulnerable and may get damaged during transportation (McCollough 1972). We here try to evaluate the possibility of introducing freezing by nitrogen at the preliminary stage of the coring operation, to improve core recovery.

Background

Petroleum reservoirs are complex on both macroscopic and microscopic scales. This complexity stems from a variety of minerals and geologic processes that shape the reservoir. It is imperative that the nature of the reservoir be determined to the highest possible accuracy. And the most accurate method to do this is using cores or physical samples of the reservoir.

Core analysis involves the test procedures and data collected on core samples. A variety of information and data may be obtained via measurements of physical and chemical properties, visual observations, and photographs. However, the most important part is recovering cores that are representative of the reservoir ie undamaged and unaltered.

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Conventional coring techniques involve drilling an axial core out of a formation using a coring bit. This method though comprehensive and most reliable, is time consuming and very expensive thus limiting the number of cores that may be taken from a large field. A comparatively inexpensive alternative is side-wall coring.

In side-wall coring, the coring bit is extended radially from the downhole tool and advanced through the side wall of a previously drilled borehole. A typical side-wall core sample is about 1.5 inches (about 3.8 cm) in diameter and less than 3 inches long (about 7.6 cm), although the sizes may vary with the size of the borehole. The side-wall core is primarily used only to identify prospective formations and for geological and lithological analysis. This is because the sample is taken from a zone that has already been disturbed by drilling. As a result, the sample comes not from the virgin reservoir but the invaded zone where many properties like wettability and relative permeability are affected.

Over the last few years, many techniques and practices have been developed which greatly increase the utility of cores. New tests and empirical calculations can determine the many petrophysical properties to a much higher degree of accuracy and precision. However, few techniques have come, which improve core recovery.

Weak formations present many problems while coring. The probability of damage during drilling and tripping is high. Even is cores are recovered, the grain distribution and arrangement may change due to shocks and vibrations.

Side-wall cores are captured using hollow cylinders also called 'core catchers'. This is done using explosive material to propel the core-catcher into the formation wall at a pre-determined depth. This impact damages the cores by either inducing fractures or by causing compaction, especially in weakly consolidated formations. This may result in low recovery and the impact may also alter the petrophysical properties of the core.

Freezing has long been established as a method of consolidation for rock or formation samples. Cores are frequently and repetitively frozen during handling, transportation and testing on the rig and laboratory facilities. The authors of this paper tried to analyze if this phenomena could be replicated downhole to improve the recovery of the core. The technique will not only increase the strength of the unconsolidated formation but freezing the formation fluids before coring will also reduce the problem of gas expansion & expulsion thus reducing damage to the core. It will also help overcome the problem of coring under low differential pressures.

The primary concern is freezing the formation to sub-zero temperatures in ambient high temperatures which will increase the equivalent amount of coolant required. This is the reason the authors limit the scope of the paper to applying the proposed technology to smaller samples, such as those recovered in side-wall coring. However, the studies and related experimentation conducted can be extrapolated to possible application in even conventional coring.

Technique:

Methodology of Freezing

Our idea aims at improving the formation strength by freezing the fluids situated in the pore space. The fluid, possibly invaded drilling fluid or formation fluid when exposed to an extremely cold medium like liquid nitrogen (−321°F) will freeze immediately. This freezing will extend a few inches into the reservoir with the depth of freezing depending on number of factors including velocity of liquid nitrogen, reservoir temperature, porosity and fluid subjected to freezing. The crystals of these frozen formation fluids will strengthen the bond between grains and form porosity connected lattice structure providing additional strength. This will provide a better candidate for side-wall coring.

Nitrogen remains in the liquid form at −321°F and 14.7 psia. It can be cheaply, stored in and transported in insulated vacuum flasks, thus minimizing loss of heat by conduction, convection and radiation. This ensures that the stored nitrogen remains in liquid state for up to a few weeks. Hence, it can effectively be used as an agent to freeze the formation. When this nitrogen escapes from a nozzle its pressure reduces significantly. This, coupled with the high ambient temperature will cause instantaneous vaporization. At the same time, it will absorb the heat from the environment, in this case the formation and associated fluids. On using a sufficient quantity of nitrogen (as calculated in the appendix), the formation will be successfully frozen.

Design & equipment

The most important modification required is using a separate pathway, by which liquid nitrogen can be circulated downhole. This stream should be isolated from the mud stream to avoid the freezing of mud in the tool or the annulus. The nitrogen should be fired at the bit and formation interface. This is to constantly create a freeze front that penetrates along with the coring bit. This stream will ensure that the formation is frozen before bit shears through it. Part of the nitrogen stream can be diverted through a jacket round the inner barrel to prevent the captured core from thawing and prevent shock and handling damage.

For the design of the side-wall coring tool two aspects need to be considered. The first is the storage of nitrogen and the other is its application on the formation as seen in Fig. 1. A simple design warrants the storage of presurised nitrogen in a thermally insulated cylinder functioning as a vacuum flask. The nitrogen can be initially kept in liquid state to allow for efficient utilization of space and minimum heat-loss. The cylinder requires insulation to control temperature and pressure. It is isolated from the space housing the explosive charges and coring bits. This cylinder is connected by a network of pipes to nozzles fixed adjacent to the various coring bits respectively. The nozzle needs to be designed to spray the nitrogen at the required angle and velocity. A simple tapered nozzle or a circular nozzle, concentric around the core catcher can be initially assumed to be effective. Thus, a few seconds after a nozzle sprays liquid nitrogen, the coring bit will be released into the frozen formation. This process is graphically depicted in Fig. 1.

The process is more viable in side-wall coring due to easier freezing mechanism, smaller nitrogen requirement and intermittent operations.

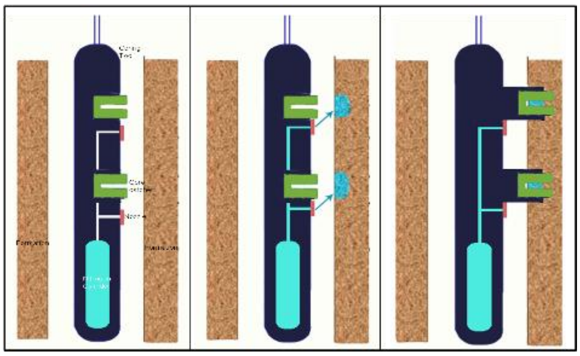

Figure 1: Stages of the technique

Compression experiment

Background: The compressive strength test is a technique used to determine the compressive strength of a given sample. A hollow cylinder, representing a side-wall core catcher, was used to apply the load, so that the recovered cores can be physically compared. Three samples were taken representing different levels of consolidation. This was done to indicate the various types of formations encountered.

Experimental procedure: The formation was tested for compressive strength for frozen and unfrozen samples and the results were compared. The test formations were: a siporex block; a brick; and loose sand. These were immersed in water for 24 hours to achieve maximum level of saturation, similar to a side wall portion in a well that has been drilled, possibly logged and partially or completely invaded with mud filtrate. The siporex blocks and the bricks were immersed without any support, while the loose sand required a metal mould to keep it in place. The brick used was pre-cracked to test the effectiveness of the technique for fractured formations. Each formation was tested for strength under compression and the results were compared.

After the stipulated time of immersion, one specimen of each the three test pieces were subjected to instantaneous freezing by using liquid nitrogen, for e.g.: Fig. 3 shows frozen sand. Care was taken to minimize water loss from the formations. These were then tested for penetration under compression.

A Universal Testing Machine (UTM) was used to measure the strength and adapted to mimic the actual coring process.

To apply the force on the formation a hollow cylinder. This was done to imitate a side-wall coring operation. The internal diameter of the hollow cup was measured to be 2.75". The cup was attached to the upper arm of the UTM and was forced into the test blocks, while the load applied was measured. The machine then exerted increasing amount of load, until the coring tool penetrated the formation. The values of the load applied were displayed directly on the dial. Two readings of importance were duly noted and compared; the load at which the penetration began and the load at which the block cracked. This gave a representation of the formation strength.

Experimental results: The results shown in Table 1 clearly show how freezing increased the compressive formation strength. The brick and siporex blocks showed clear increase in compressive formation strength, of the order of 20%. This is commendable considering the consequent increase in recovery of the core. Also, the recovery of the cracked brick proves the effectiveness of freeze coring to core fractured formations.

The most significant change is seen in unconsolidated sand with a core recovery of 2" length as seen from Fig. 2. In normal conditions, it showed extremely low penetration load of 22.05 lbs and fracture load of 88.18 lbs. On freezing, the penetration load increased to 2821.90 lbs and the fracture load increased to 19841.60 lbs. Moreover, the unfrozen sand sample did not give any recovery in the core catcher. The unfrozen sand-core gave a loose structure which crumpled to pieces when extracted. The unconsolidated sand gave unexpected results in terms of strength measurement under confining stress. This confining stress was provided by the metal mould used to hold the sand. This proves that freezing an unconsolidated formation gives a superior core. Another important result was obtained from coring a brick. Visual observation showed that when a frozen brick was tested, there were significantly less cracks developed inside the core circumference, when compared to the unfrozen brick. Furthermore, frozen water was observed to effectively hold the fractures in the brick together and prevent any further fracturing. Thus, this process can also be utilized in side-wall coring of fractured reservoirs.

Figure 2 : Frozen sand sample after compression test

Investigating change in Petrophysical properties

A study by Kelton (1953) concluded that for all practical purposes, any changes in permeability, porosity and fluid saturations of oil well cores brought about by quick-freezing (dry ice in his case) are negligible. Instead, in almost all the samples studied, the effects produced by commonly used extraction, saturation and drying techniques in the laboratory were found to be of considerable magnitude (five to six times) in causing changes in porosity and permeability compared to quick- freezing. In another study, Ole and Baard (1987) did not find an increasing or decreasing trend in the porosity and permeability on freezing cores obtained from North Sea region and that laboratory procedures are more significant than freezing.

But for independent analysis of change in porosity due to quick-freezing by nitrogen Thin Section Analysis was carried out.

Thin section analysis

Background: Thin section analysis (TSA) is a technique used to estimate the petrography of a given specimen of rock like the grain size, grain shape, cementation, porosity, etc. at microscopic scale. This technique gives better understanding of the parameters listed above. These parameters are difficult to observe in the hand specimen and this process is used widely by geologists around the world.

Procedure: An available sandstone sample was chipped into two chips having 3.5 mm (0.14") thickness, 25 mm (0.98") length and approximately 10 mm (0.39") width using the rock cutting machine. These chips were polished by using a lapping machine and one of them was chosen for the cooling experiment and the other was kept in a non frozen condition. Liquid nitrogen was poured on a specimen used for the cooling experiment.

A dilute solution of 0.1 ml of blue dye and 10 ml acetone was prepared and mixed with synthetic adhesive. This dyed epoxy coat was applied to specimen on one polished side. The epoxy coated specimen was kept in oven at 176o F and 7.5 psi pressure for 20 minutes so as to impregnate the blue dye into the pore spaces of the specimen. It's then kept under press (jig) for 16 hours so as to remove the air bubbles and allow the epoxy paste to set and develop a bond between the specimen and glass slide.

After the curing period, the specimen was removed and polished upto 30 microns. This thin section was then observed under the 4X magnification on the petrological microscope and photographs were taken. The same procedure was repeated for the other sample.

Observation: For the non-frozen specimen, it was observed that the applied blue dye was largely encircling the grain boundaries as seen in Fig. 3. On the other hand, in a few grains of the frozen specimen, the blue dye was observed to be present within the grain structure as well as in the porous region encircling them as seen in Fig. 4.

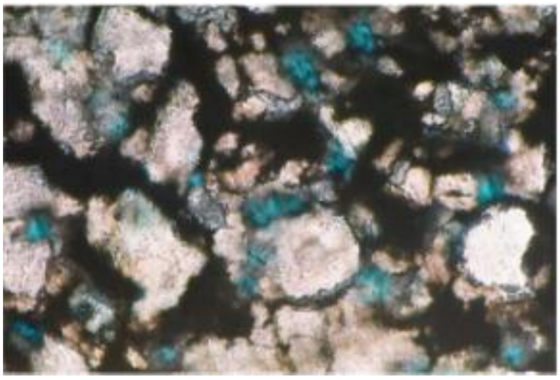

Figure 3: Thin section photo of non-frozen sample

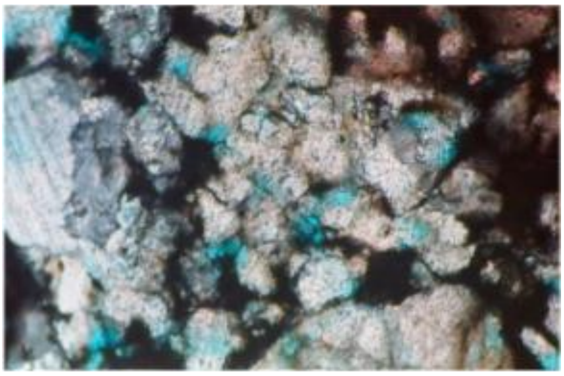

Figure 4: Thin section photo of frozen sample

Result: It can be interpreted from the microscopic pictures that most of the grains remain unpunctured on freezing therefore not reducing the mechanical strength of the specimen. Also, the gain in porosity due to grain fracture was highly insignificant resulting in very less alteration in the petrophysical properties.

Simulating Formation Freezing Process

Background: Due to constraints, a simulation was done to simulate the freezing process of a side-wall coring operation. The process of formation freezing on application of liquid nitrogen was modeled using computational fluid dynamics (CFD) software ANSYS FLUENT. By use of CFD, the various changes occurring in the formation on freezing could be observed i.e. temperature variation with time at different distances from the point of nitrogen impact.

Procedure: A 2-D model was made in GAMBIT and imported into FLUENT. The model dimensions were 300 mm (11.81”) and 100 mm (3.94”) height with a grid size of 1mm (0.0394”).

In FLUENT, the components of the model were given different properties as per requirement. The left vertical wall (well-bore wall) was assumed to be at the initial temperature of liquid nitrogen (-384°F). The other walls were assumed to be initially at reservoir temperature (200°F). The initial pressure throughout the system was assumed to be 2000 psi. The interior was assumed to be sandstone with a porosity of 20% containing liquid water. The permeability was assumed to be 1 Darcy.

This model was simulated for different time periods namely 5, 10 and 20 seconds. A cross-section AB (Fig. 5) was made in the model at time 10 seconds to study temperature propagation with distance.

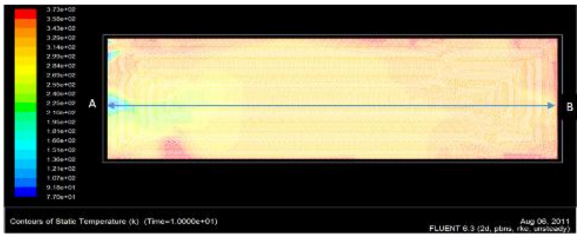

Figure 5: Temperature profle after 10 seconds

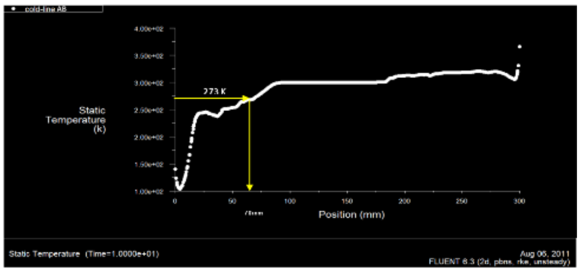

Figure 6: Plot of temperature variation with position

Observations: From the static temperature profiles at various time-periods, the process occurring in the formation can be understood. In the beginning, the region near the left-wall has a very low temperature compared to the rest of the model. However with time, the freeze-front (32°F) progresses away from the cold wall causing the temperature difference between both the regions to reduce. The water in the porosity at the left-side of the freeze-front can be assumed to be frozen since the temperature has dropped down sufficiently. But the simultaneous encroachment of heat from the remaining parts of reservoir (other walls) limits the progress of the freeze-front over time (Fig. 8). Hence there exists a time when the freeze-front is at a sufficient distance away from the well-bore wall but beyond which the temperature will begin to increase again. A graph of temperature versus position has been plotted across cross-section AB at time 10 seconds. From the graph, (Fig. 6) it can be seen that the temperature rises rapidly in the first few centimeters and slows down as we move away. Moreover, the freeze-front (32°F) is at about 70 mm (2.75”) distance from the left-wall which is more than the length of an average side-wall core.

Results: It can be inferred from the CFD simulation conducted that the formation can be frozen for a brief time-period by use of liquid nitrogen. Also the freeze-front will sufficiently propagate inside the reservoir so as to aid in the side-wall coring process.

Conclusion

The aim of this paper was to study and evaluate the hypothesis that freezing the formation in-situ would increase the formation strength and improve the recovery of cores. The experimentation positively proved the effectiveness and feasibility of the idea. Some of these points and the core observations of this paper are listed below.

1. The compressive strength test proves that freezing not only improved the consolidation and strength of the formation but also gives a much better recovery in terms of both quality and size.

2. A significant outcome was the effectiveness of this technique on fractured formations. This means that not only can fractured formations be recovered, but the natural fractures can be analyzed to a higher degree of certainty by reducing secondary fractures that are induced during the coring operation.

3. The This Section Analysis shows that change in petrophysical properties due to freezing process is insignificant.

4. The CFD simulation shows that a sufficient part of this formation near the well bore can be frozen, thus increasing the local strength before impact.

5. Freezing the formation and the saturation fluid will reduce damage to the cores due to expanding fluids, especially high viscosity and low API oils.

6. Problems faced such as bed fluidization may be mitigated by freezing.

Thus, it can be concluded that this technique will significantly improve the analysis of cores, and interpretation of their petrophysical properties. Furthermore, freezing the formation before coring is highly recommended for both unconsolidated and fractured reservoirs.

Table 1: Compressive Strength Using UTM

Compressive Strength using Universal Testing Machine		
	Load (kg)	
	Penetration	**Breaking**
Frozen sand with mould	1280	9000
Frozen sand without mould	135	4600
Normal sand with mould	10	40
Frozen Brick	300	1020
Normal Brick	260	860
Frozen siporex block	640	1160
Normal siporex block	15	960

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