"Enhanced Wellbore Stabilization and Reservoir Productivity with Aphron Drilling Fluid Technology"

Topical Report: Task 1.2 "*Fluid Density*"

by

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Objectives

Investigate the effects of pressure on the density of aphron-based drilling fluids.

Project Description

Determine survivability of aphrons by measuring the effect of pressure on fluid volume and hysteresis during pressurization/depressurization cycles, from which the concentration of undissolved air can be determined.

Conclusions

With increasing pressure, less and less volume is recovered when the system is depressurized, which we interpret as air which is lost from the aphrons and has gone into solution. However, the fraction of aphrons that do survive appears to be quite high, up to at least 1000 psig. From analysis of the recovered volumes, the fraction of the aphrons that survives after each pressurization step was calculated. Study of the Super Enhanced APHRON ICS system indicates that essentially all of the aphrons (> 95 %) survive repeated pressurization and depressurization at room temperature up to 1000 psig, though survivability may also be expected to depend on the rate of pressurization and depressurization, bubble size distribution and presence of other materials in the mud, e.g. contaminants.

Experimental Approach

Originally an Isco pump, used to generate pressure and monitor volume changes of the fluid, drove a piston in a 500-mL cylinder to which a pistonless 500-mL cylinder was connected. The mud sample subject to the pressure ramp was almost 1000 mL in volume. Later, the apparatus was modified to reduce the error introduced by air in the plumbing system. The new system was constructed and calibrated, and a few tests were performed. The system at best still showed 1 to 2 % undissolved air.

The original intent of this project was to determine if aphrons can survive pressurization to 1000+ psia. For a mud sample of 1000 mL which contains 15% air (aphrons), or 150 mL air, pressurization itself (with no loss of air to the surrounding mud) would reduce the volume of air to 2.25 mL (0.225%). The air that is "lost" is assumed to leak through the aphron shell and dissolve in the mud matrix. Thus, the experimental apparatus must be able to generate distinguishable results between the case where no air is lost vs all air is lost, i.e. ΔV_0 = 147.8 mL (no loss of air) vs ΔV_{100} = 150 mL (all air is lost). That should be feasible. However, the air trapped in the plumbing at the beginning of a test would generate a ΔV of 10 to 20 mL. Thus, ΔV_0^{Corr} = 157.8 to 167.8 mL and ΔV_{100}^{Corr} = 160 to 170 mL. Since the uncertainty in the trapped air volume (~ 10 mL) was more than four times the volume difference that we hoped to measure (ΔV_{100} - ΔV_0 = 2.25 mL), these tests needed to be modified again.

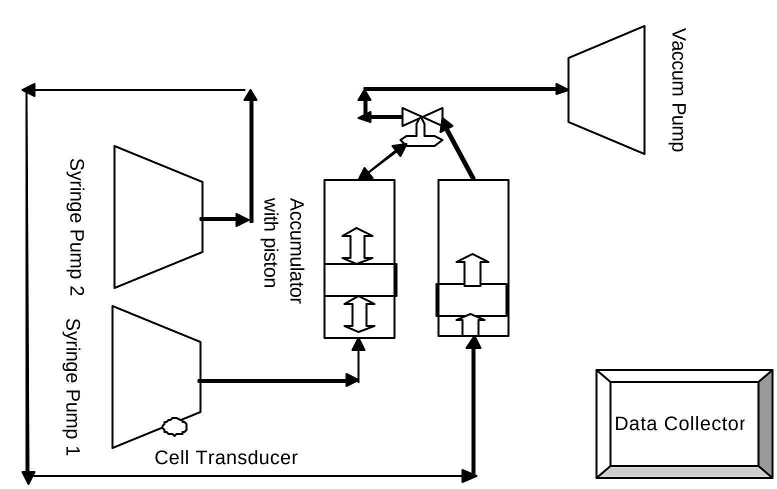
A change in experimental approach was indicated. We decided to investigate the hysteresis in volume readings during pressurization and depressurization. The system was modified again. This time a new vacuum pump was added, along with the required tubing and fittings.

The pressure was varied cyclically, first increasing for 1.5 minute to the desired pressure (100 psig, 200 psig and so on up to 1000 psig, in increments of 100 psi) and then depressurized for another 1.5 minutes down to 10 psig. We noticed that during the depressurization step of each cycle the air that was first compressed during the pressurization step did not all return. We thought that this effect was probably due to the short time between the steps, so the interval between the steps was increased to 10 minutes.

At that point we saw something new in the behavior of the fluid. Most of the air volume returned at the end of each cycle, and eventually all of it at the end of the test. But the main problem now was the random nature of the volume readings (and to some extent the pressure readings). One possible cause was stick/slip of the piston in the cell. To test this assumption, the cells were sent back to the manufacturer and the piston was redesigned and fitted with two polyurethane gaskets energized by Viton O-rings. In addition, the bore of the cylinder was honed to a rough mirror finish, and powdered household lubricating graphite was used to reduce stick-slip further. The results using those cells were improved quite a bit, even though the volume and pressure readings still exhibited some erratic behavior.

The final experimental set-up is shown in Figure 1.

Figure 1. Fluid Density Apparatus

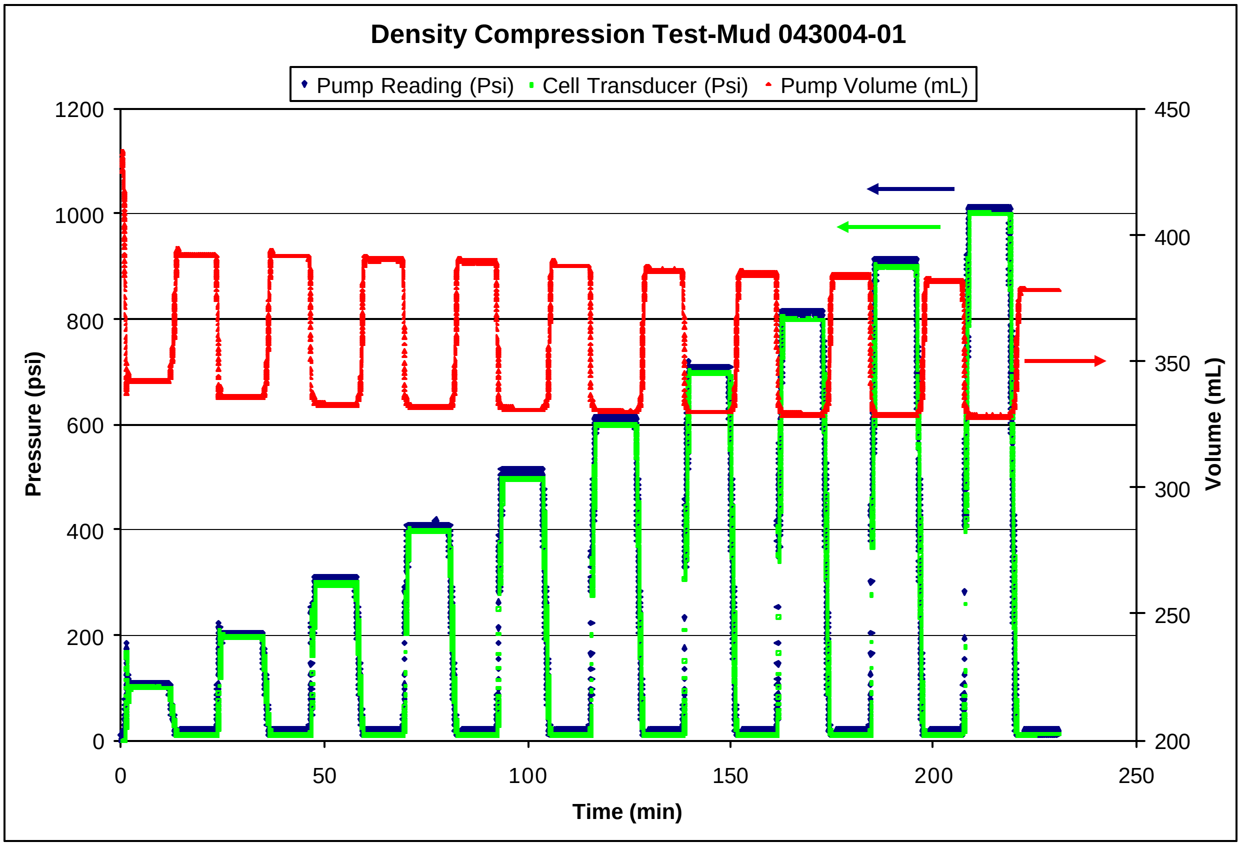


Schematic diagram for the density compression test

Results

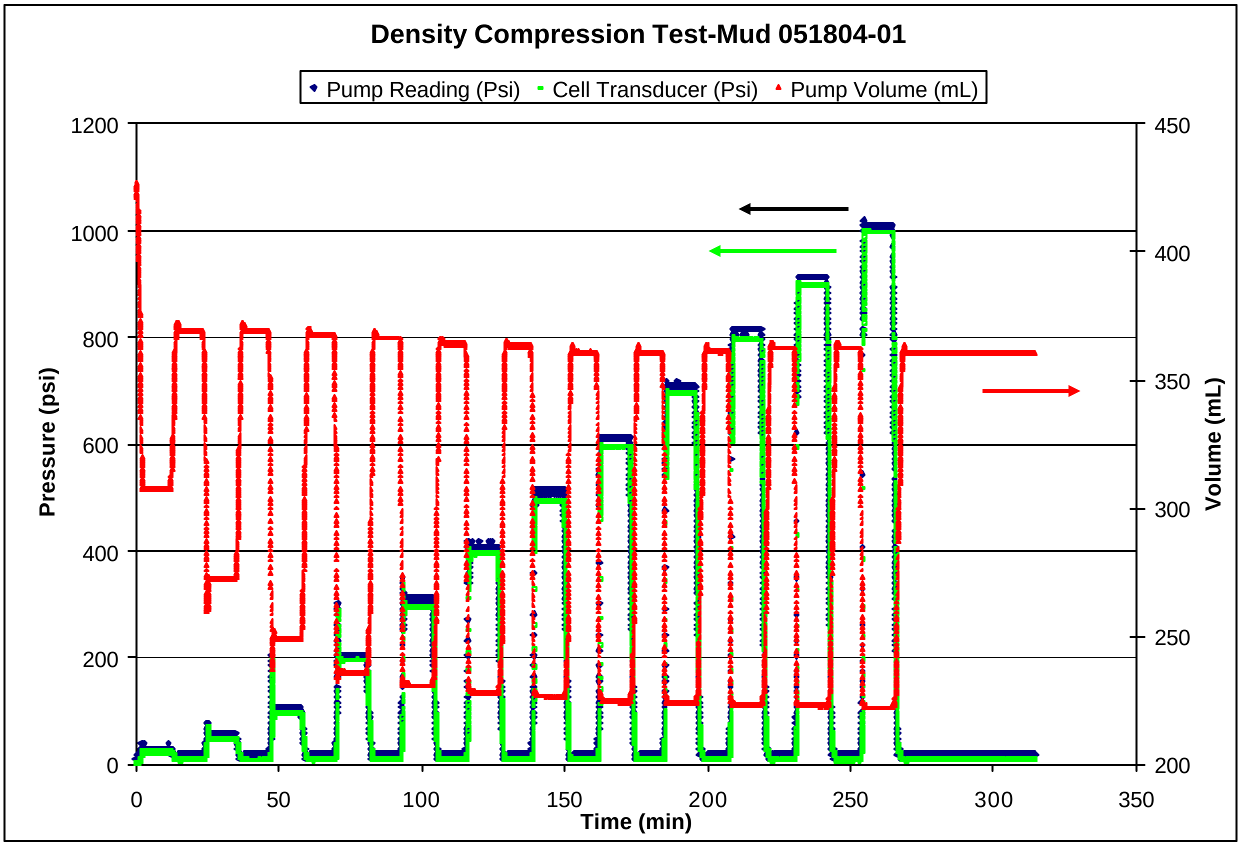
A couple of examples of test runs are presented below:

Figure 2. Fluid Density Test with Super Enhanced APHRON ICS Mud Sample 30% (Nominal concentration) Air



When the system is depressurized, it is assumed that air which is solubilized during a previous pressurization step requires significantly more time to come out of solution than air trapped within aphrons. Thus, the steady-state volume recovered after each depressurization step represents aphrons that retained their integrity during the previous pressurization step. Since there is some uncertainty in the position of the piston during the initial application of pressure to the system, the reference point is chosen to be the first depressurization step, i.e. after the 100-psi step in Figure 2 and after the 25-psi step in Figure 3, and this is assumed to represent 100% volume recovered (100% of the aphrons survive). All subsequent recovered volumes are compared to this volume. It should be noted that the pump pressure during the depressurization step does not drop to 0 psi, rather about 10 psi (again due to the stick-slip phenomenon mentioned earlier). Thus, each post-pressurization volume measurement was made at that same pressure of 10 psig.

Figure 3. Fluid Density Test with Super Enhanced APHRON ICS Mud Sample 55% (Nominal Concentration) Air

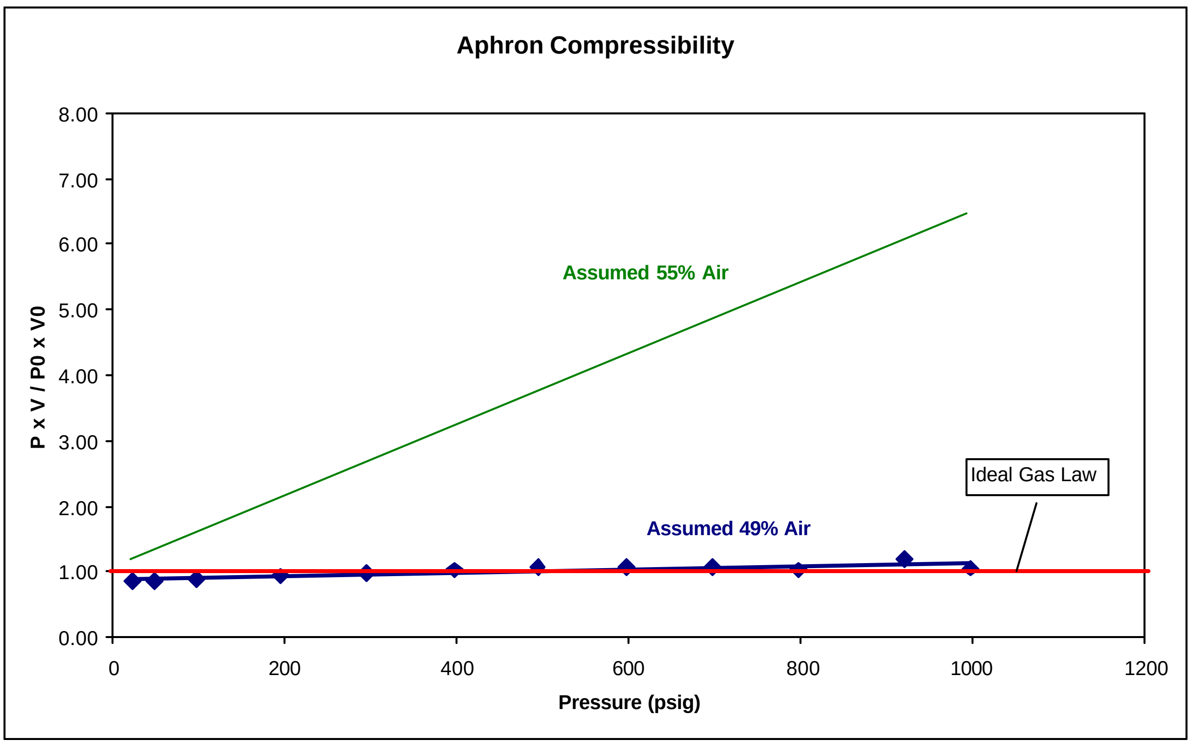


As shown in both Figures 2 and 3, use of graphite for lubrication, an elastomer on the floating piston that minimizes sticking and blow-by, and polishing of the cylinder bore produced very constant pressure and volume readings during the 10-min rest periods following each pressurization or depressurization step.

In the examples above, the amount of entrained air in the mud initially had been calculated from density measurements. However, this can be determined more accurately from the compressibility data, if it is assumed that the entrained gas follows the Ideal Gas Law: PV = nRT. For a fixed number of moles of air, n, at a constant temperature T, the product of pressure and volume, PV, should be constant. Thus, when a gas is compressed from P_1 to P_2, the change in volume from V_1 to V_2 should compensate exactly to give $P_1V_1 = P_2V_2$. This is illustrated in Figure 4 by the horizontal red line. The mud sample used in the data presented in Figure 3 nominally contained 55% air by volume. However, one can see that with 55% air, PV increases with increasing pressure. Through trial and error, one can determine that if the initial amount of air had actually been 49%, PV would remain constant throughout the test.

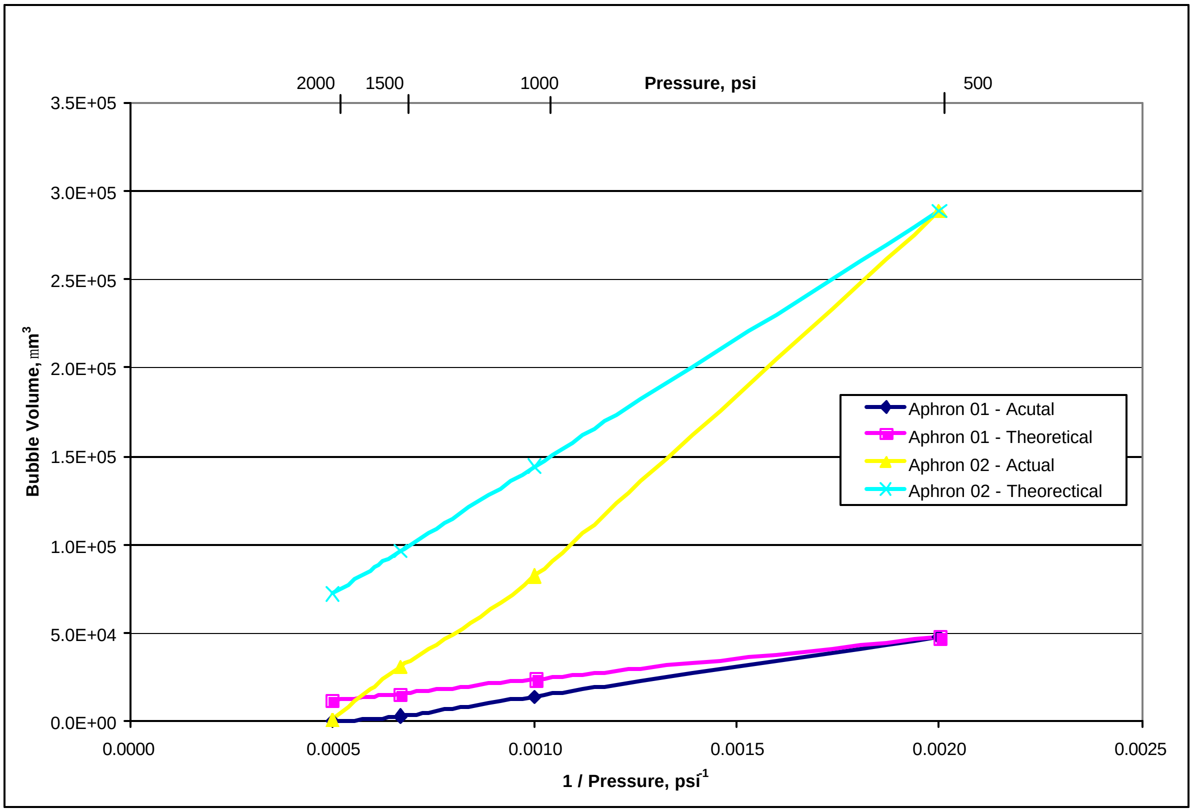
On the other hand, it is well known that the pressure within bubbles is greater than the pressure in the surrounding medium, and that this pressure differential increases with increasing radius of curvature, i.e. with decreasing bubble size. Furthermore, aphrons may possess a structure that resists compression. Taking the data at face value and assuming the concentration of air at ambient pressure is indeed 55% in the example shown in Figure 4, one may conclude that the volume of the aphrons at 1000 psi is about 6.3 times greater than expected from the Ideal Gas Law, i.e. the bubble diameter is about $(6.3)^{1/3} = 1.85$ times larger than predicted from the Ideal Gas Law. To determine which of these scenarios is true, Maribella Irving (a colleague on the Aphron Technology Team) photographed some aphrons in a Transparent APHRON ICS sample before and after applying 1000 psi pressure. The Ideal Gas Law predicts that the average bubble size upon increasing the pressure from 20 psig to 1000 psig should decrease by a factor of $(1014.7/34.7)^{1/3} = 3.1$. As shown in Figure 5, the aphrons decreased in size by a factor of about 4. Thus, it is concluded that the apparent discrepancy in V_2 is not due to resistance of the aphrons to compression but rather to error in the initial estimated concentration of air. In the case under discussion, 49% is a more accurate value than 55% for the initial concentration of air in the mud at ambient pressure.

Figure 4. Determination of % Entrained Air in Fluid



Analysis of Figures 2 and 3 indicates that, with increasing pressure, less and less volume is recovered when the system is depressurized, which we interpret as air which is lost from the aphrons and has gone into solution. However, the fraction of aphrons that is lost is relatively low, as shown in Figure 6. Here the data used was the set shown in Figure 3.

Figure 5. Effect of Pressure on Size of Aphrons in Transparent APHRON ICS Mud



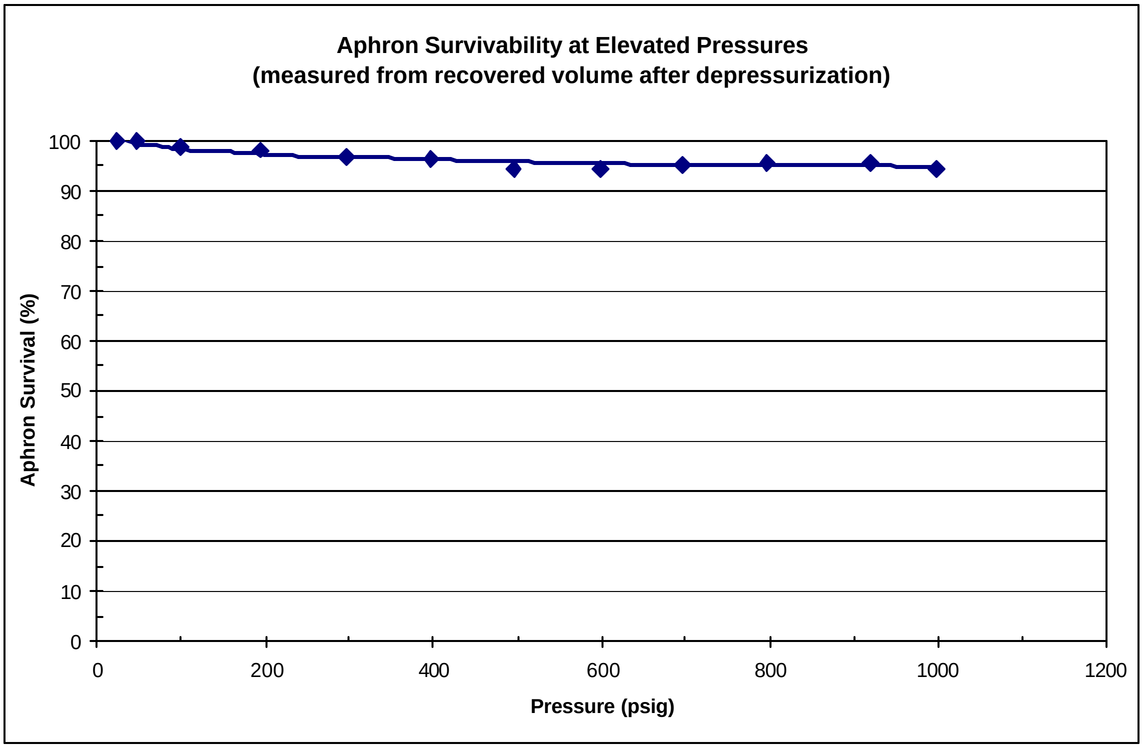
The fraction of aphrons that survive after each depressurization step is given by

$$P*(V_{cell} - V_{0fluidcell})/P_0*V_{0aircell}$$

where P_0 is the absolute pressure and $V_{0aircell}$ the volume of air at the beginning of the test series; P is the absolute pressure and $V_{cell} - V_{0fluidcell}$ is the volume of air after ach subsequent pressurization/depressurization step. $V_{0aircell}$ was 49%, as determined from the procedure described above. As shown in Figure 6, essentially all of the aphrons (> 95%) survived pressurization up to 1000 psig.

This may not always be the case. Indeed, in a concurrent aphron survivability study, it appears that the fraction of aphrons that survive elevated pressures is affected by the rate of pressurization and depressurization, the initial bubble size, and the concentrations of some components in the mud.

Figure 6. Effect of Pressure on Aphron Survival



Future Work

Our recommendation is that more experimental work be done in order to determine the effects of temperature and chemical composition on the density of aphron drilling fluids.