# “Enhanced Wellbore Stabilization and Reservoir Productivity with Aphron Drilling Fluid Technology”

## <u>Topical Report: Task 2.2 “*Pressure Transmissibility*”</u>


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## DISCLAIMER

## Objectives

Investigate the rate and magnitude of pressure transmission through aphron drilling fluids in simulated fractures and porous media to test the hypothesis that aphron networks can reduce mud loss via reduction of pressure transmissibility.

## Project Description

The rate and amplitude of pressure transmission of various drilling fluids -- particularly aphron drilling fluids – are measured in a long conduit and in sand packs to determine how pressure transmissibility can affect fluid invasion.

## Conclusions

Low-pressure, ambient temperature tests conducted in 20-ft long ¼” tubing to simulate a fracture showed that neither the rate nor the amplitude of pressure transmission in an aphron drilling fluid is affected by aphrons. The amplitude of pressure transmission is, however, inversely related to the viscosity of the base fluid. Polymer-based aphron drilling fluids (APHRON ICS) produce a higher pressure drop than clay-based aphron drilling fluids (EMS-2100), which are higher than DRILPLEX and FLOPRO NT, two conventional muds used for drilling in depleted fields.

Experiments at low pressure and ambient temperature with 20/40 and 70/100 sand packs of 100 and 8 darcy permeability, respectively, showed that character of pressure transmission and invasion of aphron drilling fluids in permeable media strongly depend on permeability and surface wet condition of the sand pack. In particular, it appears that for the lower permeability sand pack (70/100 sand), pressure transmission and depth of invasion are significantly reduced by the presence of aphrons. Finally, it appears that, at least under these conditions, aphrons migrate more rapidly than the bulk liquid phase and can congregate at the fluid front to reduce fluid flow.

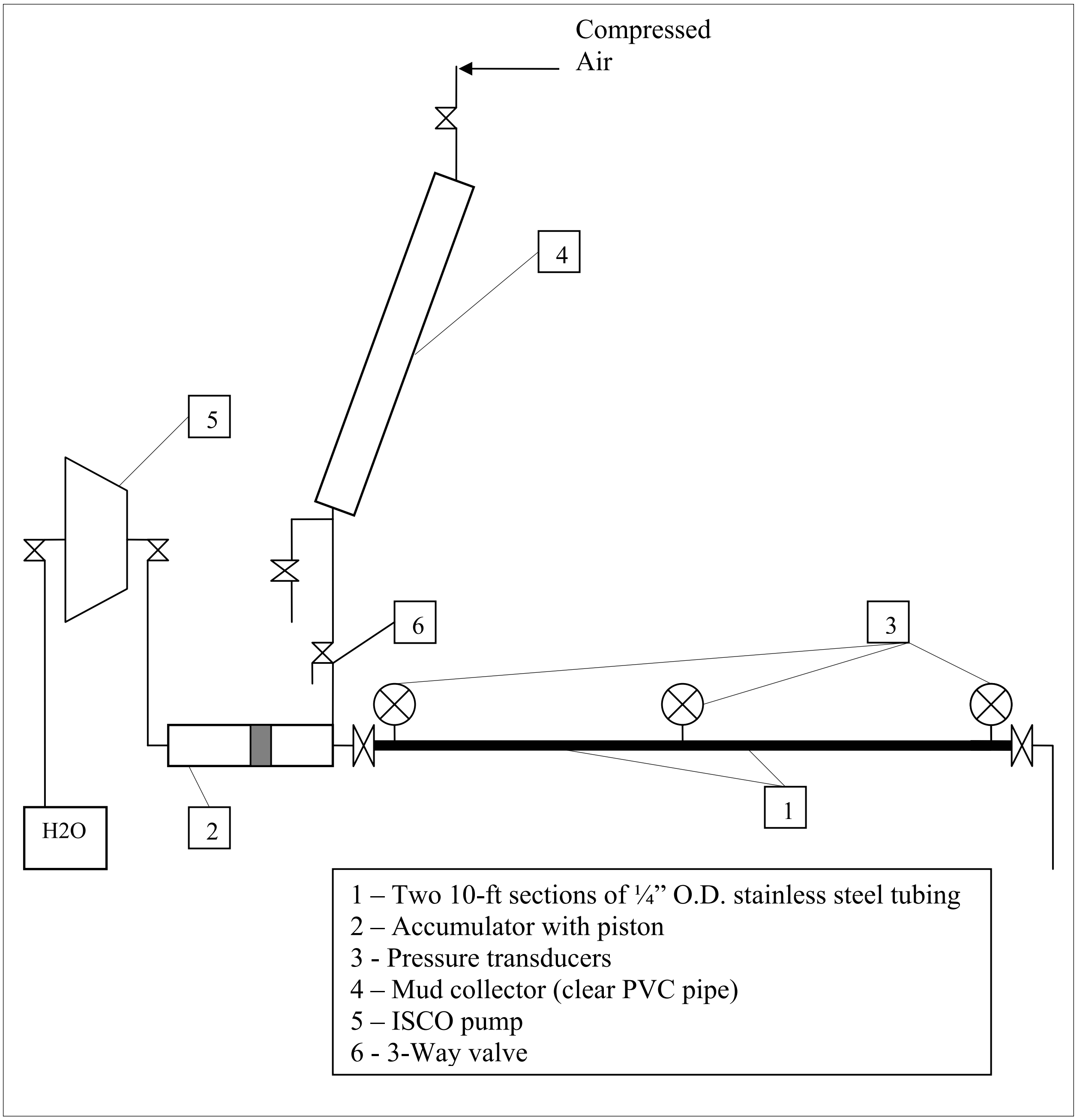
## Future Work

Future work will be directed at investigating aphron behavior in consolidated cores at elevated pressures and temperatures. This will include filtration and return permeability (formation damage potential) as functions of chemical composition and physical properties of the bubbles.

## Experimental Approach

In the first part of this project, tests on pressure transmission in a simulated fracture were carried out with various drilling fluids, including APHRON ICS muds. For this purpose, an ISCO pump and an accumulator with a moving piston were connected to a 20-ft section of 1/4” OD stainless tubing containing matched pressure transducers mounted at 0, 10 and 20 ft from the pump side. The experimental set-up is shown in Figure 1.

**Figure 1. Pressure Transmissibility Apparatus**




Although initially the tests were conducted at elevated pressure, later all tests were conducted at fairly low pressures to ensure that the aphrons would be stable. The simple test protocol involved applying a pressure increase from ambient to 125 psia, in 25 psia steps, holding for several minutes at each pressure, then depressurizing quickly from 125 psia to ambient (14.7 psia). The pump flow rate was limited to 5 mL/min to ensure pressure equilibration during pressurization.

In the second part of this project a new system was designed and constructed to monitor pressure transmission of aphron-drilling fluids in permeable media. A clear polyvinyl chloride (PVC) pipe measuring 36" length x 1" internal diameter was filled with two different sizes of sand and fitted with pressure transducers at the fluid entrance and exit. The initial inlet pressure was set at 100 psi, and the steady-state pressure drop through the sand pack system was measured as a function of the concentration of air, the size of sand and condition of sand pack under no-flow conditions. Subsequently, the exit port was opened to ambient pressure, the fluid was allowed to flow and the weight of filtrate was monitored continuously over a period of 30 min.

# Results

## Pressure Transmission in 20-ft ¼" tubing

In these tests, the outlet port was closed, and the inlet pressure ($P_1$) was raised to 2000 psi very quickly by opening the valve between the accumulator and the test section. The response at the outlet (P3), which was 20 ft away, was essentially instantaneous. Indeed, even with millisecond response of the data acquisition system, very little difference was observed among all of the fluids tested. Furthermore, reflection of the acoustic signal from the end of tubing produced complicated results which made it very difficult to extract the rate of propagation of the initial signal.

The test protocol was changed and consistent steady-state pressure differences between the pressure transducers ($\Delta P = P_1 - P_3$) was observed. Steady-state pressure differences were measured initially by applying a stepped pressure ramp from ambient to 2000 psig in the closed tube, holding for several minutes, then depressurizing at the same rate. Consistent pressure-differences ($\Delta P = P_1 - P_3$) were observed. Two aphron drilling fluids containing 5% and 38% air by volume were used. Both muds produced essentially the same results, indicating that the observed behaviors were the result of the base fluid and not related to the aphrons. On the other hand, $\Delta P$ appeared to decrease with increasing pressure, e.g. at 80 psi pump pressure, $\Delta P$ = 17 psi, whereas at 1000 psi pump pressure, $\Delta P$ = 5 psi (see Figure 2).

Immediately after decompression, some small bubbles (aphron-size) appeared, but some big air bubbles also formed gradually and continuously. This indicates that some of the aphrons survived pressurization to 2000 psig. The large bubbles evidently consisted of air that had escaped from the aphrons and dissolved in the base fluid. When the fluid was depressurized, the air simply came out of solution; the process was slow enough that the bubbles grew much like crystals growing from a supersaturated salt solution.

Because of the lower $\Delta P$ values observed at higher pressures and the belief that any effects of aphrons would most likely be manifested at lower pressures, subsequent testing was carried at very low pump pressure: < 150 psig.

**Figure 2. Pressure Transmission of Enhanced APHRON ICS Mud**

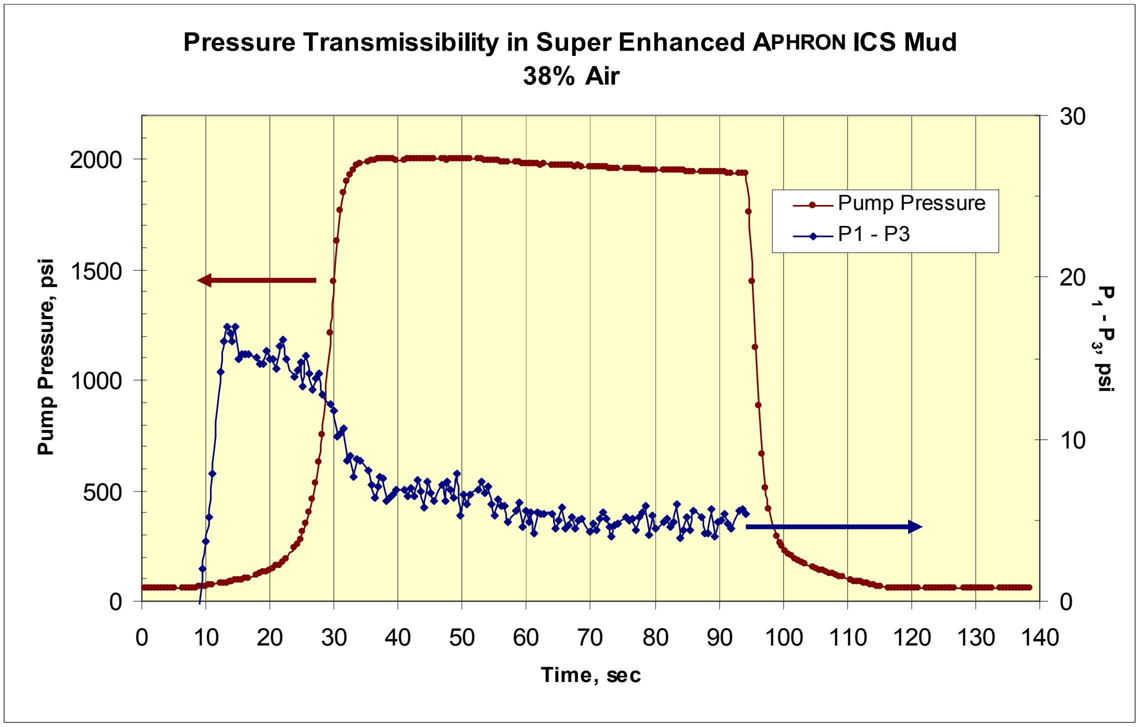



**Figure 3. Pressure Transmission of DRILPLEX Mud in 20-ft ¼" OD Tube**

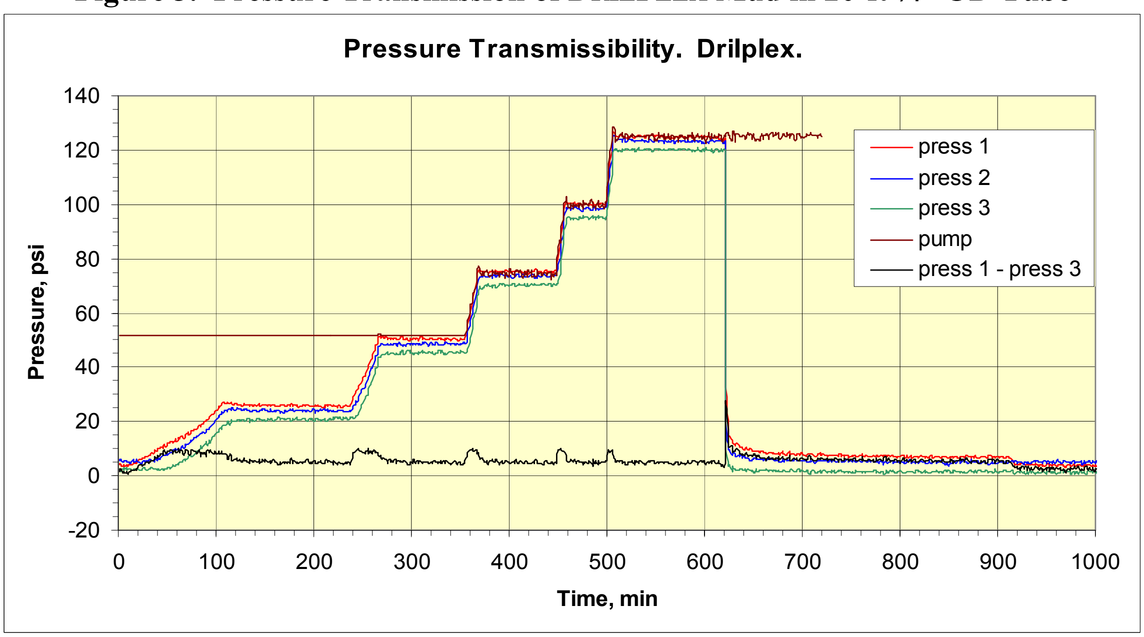
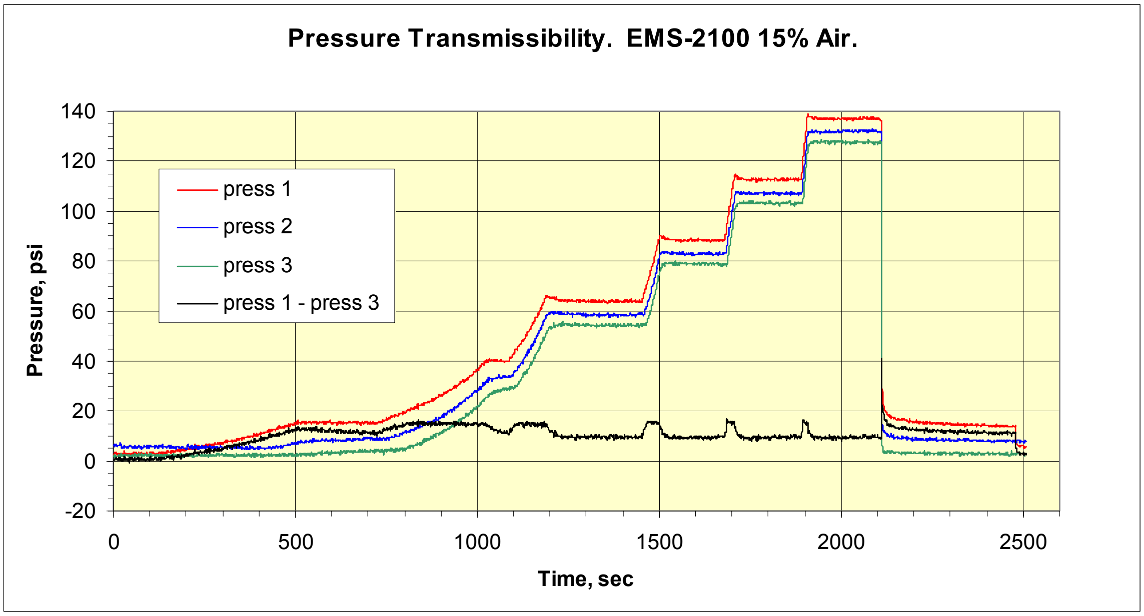


**Figure 4. Pressure Transmission of EMS-2100 Mud in 20-ft ¼" OD Tube**

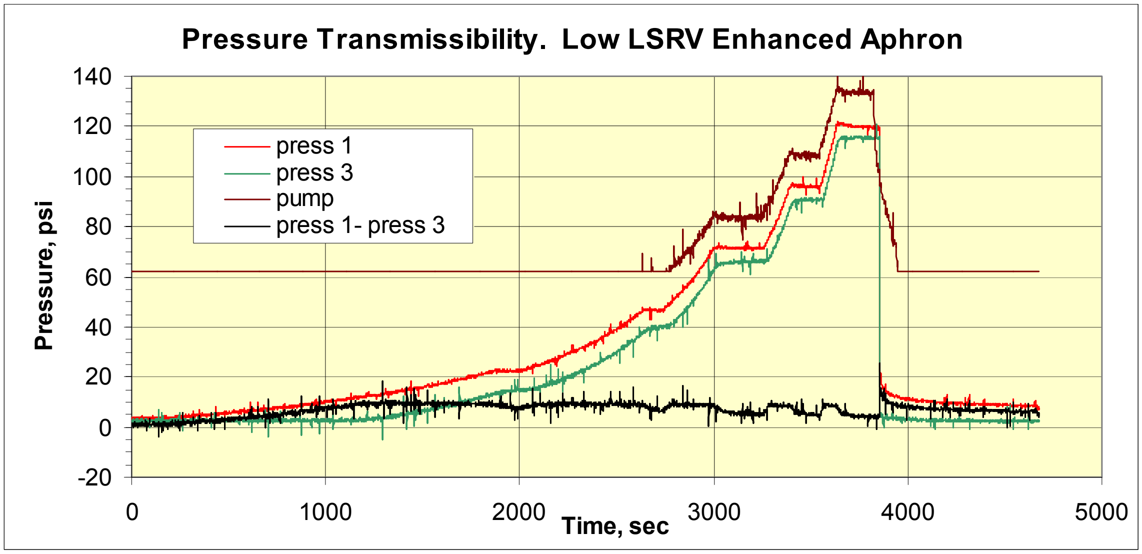



Two Enhanced APHRON ICS drilling fluids containing 5% and 38% air by volume and two conventional muds used for drilling in depleted fields (DrilPlex and FLOPRO NT) were used. Also, the new clay-based aphron drilling fluid, EMS-2100, was used for comparison. Both APHRON ICS tests produced essentially the same results. The result for EMS-2100 was close to those obtained for the APHRON ICS fluids. The DRILPLEX mud showed a lower pressure drop than the APHRON ICS muds, while the FLOPRO NT mud behaved like water and produced an almost negligible pressure drop. The results indicate that the APHRON ICS mud produces a greater pressure drop than the reference muds, but that the results are due to properties of the base fluid and are not related to the presence of aphrons. The pressure drops recorded between 0 and 20 ft from the pump ("Press 1 – Press 3" in the figures above) were as follows:

| | |
|---|---|
| APHRON ICS (5% and 38% Air) | 10 - 12 psi |
| EMS-2100 | 10 psi |
| DRILPLEX | 5 – 6 psi |
| FLOPRO NT | 1 – 2 psi |

Also, Enhanced APHRON ICS muds with low LSRV and 15% and 45% air were prepared to investigate the relationship between viscosity of base fluid and pressure drop. These muds contained 3 lb/bbl, rather than 5 lb/bbl, of Go-Devil and gave LSRV in the range of 104000 -118000 cP, which is about half the LSRV of regular APHRON ICS fluids. The result of one of these tests is shown in Figure 5. Pressure transmission experiments with these muds showed pressure drops in the 20 ft. tube in the range 5 to 8 psi for both concentrations of air, which is consistent with the 10 – 12 psi pressure drop observed with the regular high-LSRV APHRON ICS system.

**Figure 5. Pressure Transmission of Low-LSRV Enhanced APHRON ICS Mud**




## Pressure Transmission in Sand Packs

The flow tests were carried out in a 36” long, 1” ID transparent PVC pipe, using 20/40 and 70/100 mesh sand.

Water permeability of both sand packs was estimated using the Darcy equation, which relates volumetric flow and pressure drop with properties of the fluid and media. An ISCO pump connected to an accumulator (fitted with a floating piston) and a hydrostatically driven water column were used for creating a constant water flow rate.

$$Q = -\frac{kA}{\mu}\left(\frac{dP}{dx}\right)$$

where $Q$ = Volumetric Flow ($cm^3$/sec)
$k$ = permeability (darcy, ($cm^2$*cP)/(sec*atm))
$A$ = cross-sectional area, 4.37 ($cm^2$)
$\mu$ = viscosity, 0.89 at 26 $^{o}$C (cP)
$P$ = pressure (atm)
$x$ = length, 91.44 (cm)

Rearranging the equation above and incorporating the data provided here yields

$$k = 18.6 \frac{Q}{\Delta P}$$

Thus, the permeabilities of the 20/40 and 70/100 sand packs were determined to be 100 and 8 darcy, respectively.

Two series of experiments with Enhanced APHRON ICS muds were conducted with each size of sand pack. In the first series, the pipe was filled with dry sand or with wet sand which was blown dry with air or $N_2$. In the second series, the sand packs were filled with water at the beginning of each experiment and tested in that state.

The results of both series of experiments are shown in Figures 6-10. As indicated in Figures 6 and 7, the APHRON ICS mud effectively sealed both sizes of dry sand packs, and no filtrate was collected after 30 minutes in the Leak-Off test. But the pressure drop for both the centrifuged muds (no air) and the muds containing aphrons was 100 psi for 20/40 mesh sand, while for the 70/100 mesh sand it varied from 78 psi (no air) to 100 psi (with air). The procedure for preparing the dry sand pack did not change the character of pressure transmission, but it did change the depth of penetration of the mud. One experiment was conducted by filling the pipe with wet slurry of 70/100 mesh sand, followed by complete drying using air and nitrogen. The differential pressure established across this sand pack was 100 psi for the mud containing 18% air (about the same as for the sand pack filled directly with dry sand), but invasion of mud inside the previously wetted sand pack was about 3 times higher. This difference in the behavior of the two types of dry sand packs could be explained by a difference in the water-wet state of the sand pack; for the previously wetted sand pack, a water film covering the surface of the sand might very well have survived the air/nitrogen drying process.

**Figure 6. Pressure Transmission Across Dry and Water-Filled 20/40 Sand Packs**

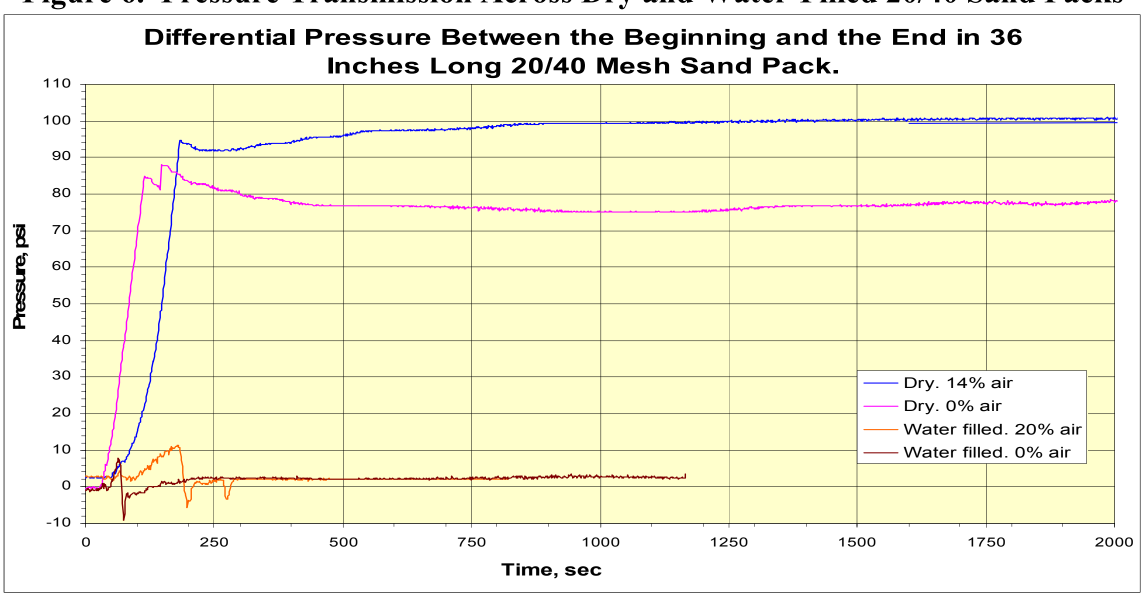
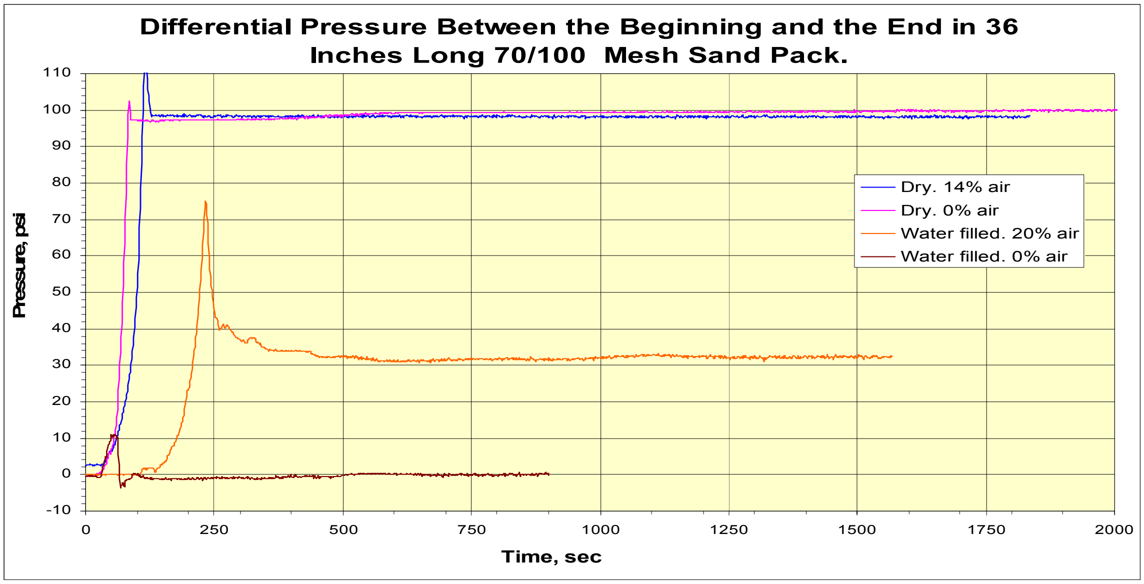


**Figure 7. Pressure Transmission Across Dry and Water-Filled 70/100 Sand Packs**




When the sand packs were completely filled with water at the commencement of the tests, pressure transmission took on a different character. These results are shown in Figures 6 and 7, with additional test results shown in Figure 8. High pressure from the pump propagated very fast in sand packs filled with water. The differential pressure established across 20/40 sand packs was almost nil in muds containing 0% and 20% air. For the 70/100 sand packs, however, a consistent difference was observed for aerated muds compared to deaerated muds. As indicated in Figure 8, muds with 0% air showed 10-30 psi less pressure drop than muds containing 13 to 22% air.

**Figure 8. Pressure Transmission of Enhanced APHRON ICS Across Water-Filled 70/100 Sand Packs**

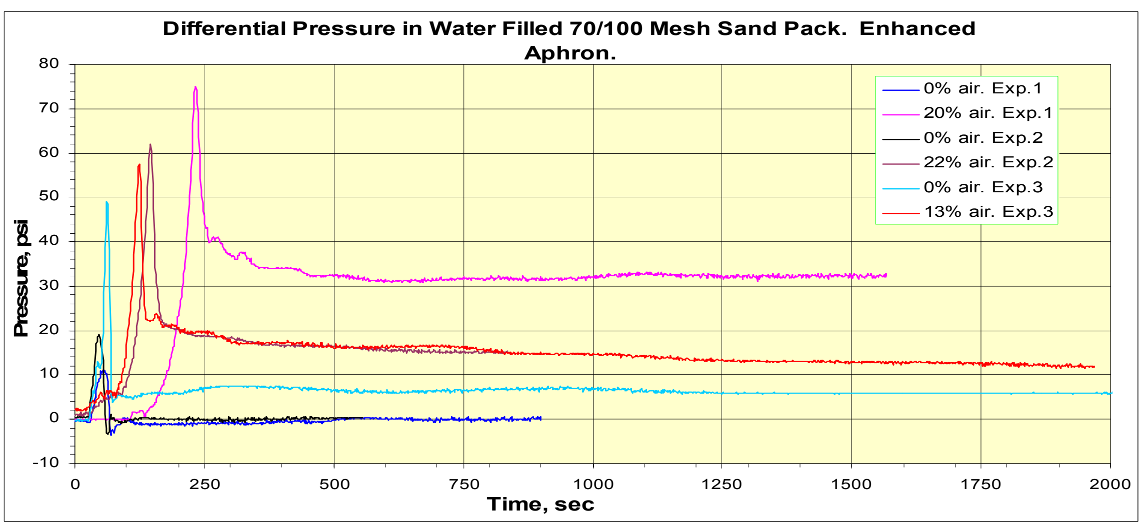


**Figure 9. Leak-Off of Enhanced APHRON ICS in Water-Filled 70/100 Sand**

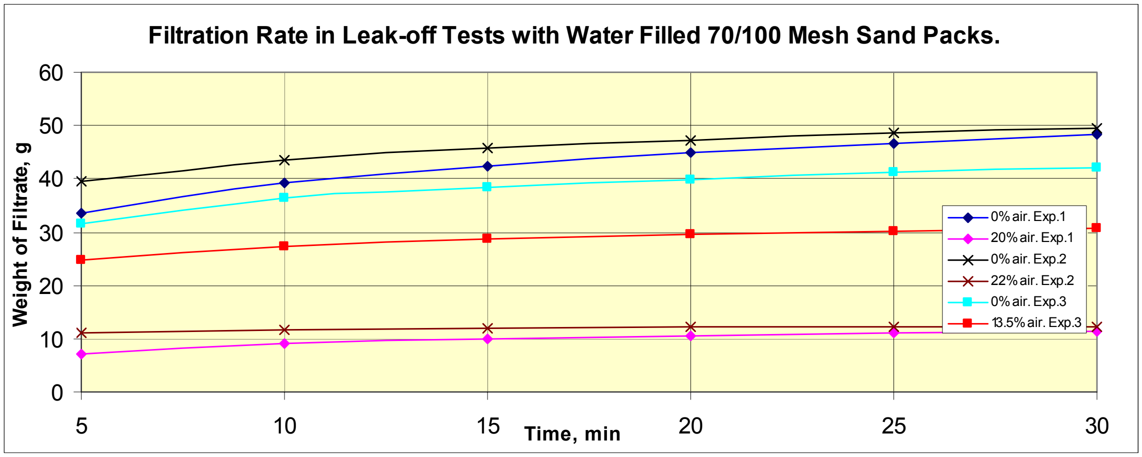
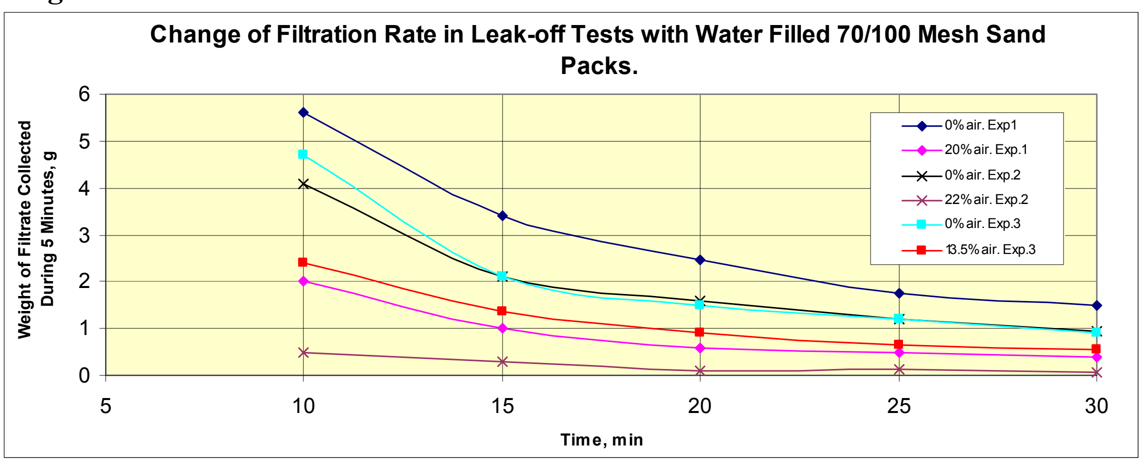



**Figure 10. Leak-Off Rate of Enhanced APHRON ICS in Water-Filled 70/100 Sand**




In addition, both the filtration rate and the rate of change of the filtration rate were lower for aerated muds than for deaerated muds, as shown in Figures 9 and 10. Invasion of mud in sand packs filled with water was very small in all cases compared to dry sand packs, as one might expect from the high void volume of the dry packs.

These experiments show that the difference in permeability of 20/40 and 70/100 sand packs (100 vs 8 darcy) strongly affects the ability of bubbles (presumably aphrons) to reduce depth of fluid invasion and pressure transmissibility. While aphrons appear to be effective in the water-filled 70/100 sand, this is not the case in the 20/40 sand. In addition, both pressure transmissibility and invasion of aphron muds in a sand pack depend heavily on the packing method and the presence of water in the sand pack. Since sands downhole are generally considered to be water-wet, the water-filled sand pack tests probably reflect downhole conditions best, and future testing with sand packs will be carried out in this manner.

**Flow Visualization**

During the sand pack tests with the Super Enhanced APHRON ICS mud, an unusual phenomenon was observed: the bubbles appeared to move faster than the bulk fluid and to concentrate at the front of the moving mud. This may be related to the "jump" that bubbles are thought to experience in viscoelastic fluids and to the well-known phenomenon that in "bubbly flow" bubbles tend to migrate to the pipe wall; a sand pack may crudely be considered as a bundle of mini-pipes. The anomalous behavior of the bubbles was observed in both sizes of sand packs with any aphron drilling fluid containing air bubbles, as long as there was a pressure difference along the length of the sand pack. The most pronounced effect was observed with the 20/40 mesh water-filled sand pack. Unfortunately, the brown color of both the sand and the APHRON ICS mud made for difficult viewing of this phenomenon.

To overcome these hurdles, we constructed a flow system consisting of a 12" length x 1 ¼ " internal-diameter clear acrylic pipe and used the Transparent APHRON ICS mud in place of the Super Enhanced APHRON ICS mud. From previous experience, we know that the aphrons are lighter in color than the base fluid, and the contrast is highest with small bubbles and a strong color for the base fluid. To record the phase behavior of the mud during flow, the Transparent mud was saturated with RIT #6 blue dye (same dye that is used in Blue Streak). The front end of the acrylic pipe was connected to a valve and to an accumulator containing a floating piston. The back end of the pipe was opened to the atmosphere. At the beginning of the experiment, the valve was closed and a pressure of 100 psi was applied to the mud in the accumulator. Then the valve was opened, and mud began to move through the sand pack. To limit the speed of mud movement inside of the pack, pump flow rate was limited to 25 mL/min.

Figure 11 shows one exposure from the video stream of the test. The colored mud was moving from right to left, and the leading edge of the fluid had passed the middle of the pipe. At the leading edge, the fluid was light in color, and microscopic examination revealed that region to be composed primarily of bubbles. The highest color intensity was at the pipe entrance, and few bubbles were apparent. One might argue that the loss of color while traversing the sand pack was due to depletion of the dye, but examination of the sand grains during and after the test showed no sign of dye adsorption.

**Figure 11. Dyed Transparent APHRON ICS Mud Flowing through 20/40 Sand Pack**

Additional visualization studies will be carried out and complemented with high-pressure leak-off tests to determine the conditions under which this phenomenon manifests itself and whether it has implications for the internal sealing mechanism that has been postulated for aphrons.