SPE 81082

Application of Aphrons Technology in Drilling Depleted Mature Fields

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This paper was prepared for presentation at the SPE Latin American and Caribbean Petroleum Engineering Conference held in Port-of-Spain, Trinidad, West Indies, 27–30 April 2003.

Abstract

Depleted zones are intrinsic to most mature reservoirs throughout the world. The associated issues of effective, safe and economically viable well construction, completion and workover within low pressure environments become more challenging on a daily basis.

This paper discusses the application of aphron drilling fluid technology, which offers a unique alternative option that can significantly improve the operational and economic aspects for continued development of these marginal assets. The authors will detail the development of the unique micro-bubble technology and its successful application in a mature and depleted field in Mexico.

Introduction

When formation pressures are drawn down, the type and severity of critical operating issues are exacerbated with few solution options. When taken in combination, the operator is often faced with substantially increased costs and risk, particularly where HSE issues are concerned.

The problems associated with the pressure variances encountered in mature fields, coupled with the limitations of conventional fluid and equipment technologies to properly provide an equitable solution, have driven the need for a new approach to drilling and workover operations within depleted reservoirs in mature fields.

One of the latest approaches to this dilemma is the use of the aphrons drilling fluid technology. In hundreds of wells in diversified applications worldwide, the aphron technology has proven to be a viable solution within these difficult parameters.

Field experience has shown that even annular pressures exceeding depleted reservoir pressures by "several thousand" psi has not hindered the creation of the micro-environment seal and mitigating invasion. This feature alone has allowed operators to eliminate casing strings, safely workover highly depleted wells and even drill into normally pressure plays on wells with existing depleted production. All of this has been affected without compromising production. Because the seal is internal to the reservoir (Fig. 1), conditions for differential sticking do not exist. In many parts of the world, this feature has successfully enabled high-angle and horizontal well construction of highly depleted reservoirs using conventional equipment. No other fluids technology in the industry enables these types of operations. Since standard wellsite fluid mixing equipment is all that is required to employ the technology, it is highly compatible with normal wellsite operations. As a drilling, completion or workover fluid, the aphron technology functions as the backbone of the operation. Serving as the bridging technology between the difficult operating parameters of mature fields and the limits of conventional equipment when employed to develop these depleted reservoirs, the aphron technology offers a solution for prolonging the economic life of these assets.

Statement of Theory and Definitions

Aphrons[1] (micro-bubbles) are incorporated into a specifically engineered base fluid[2] to aid in mitigating losses in depleted / highly permeable zones. These micro-bubbles differ significantly from aerated fluids and foams. Aphrons do not coalesce. Upon entering the lower-pressure region within a depleted formation, aphrons remain discrete, yet will agglomerate to create a stable, but easily removed, internal seal called a "micro-environment".[3] Because affecting this seal requires a higher annular pressure than that of the reservoir, it readily cleans up with reservoir flow-back as production is initiated.

Synergies between the various features of the technology serve to minimize fluid invasion. The easily engineered high-LSRV (low-shear-rate viscosity) properties of the base fluid are achieved with high-yield, stress-shear-thinning (HYSST) polymers. This promotes design capabilities that are well suited for optimizing diversion of annular pressures away from the depleted formations, thus minimizing whole fluid invasion. The surfactant package and the associated "meniscus-wrapping theory"[1,4] provide additional invasion control. The "energized-environment"[4,5] associated with aphrons employed to form the internal "micro-environment" solids-free seal and the resultant localized increase in LSRV also contributes to mitigating invasion.

Compared to a conventional external seal, the benefits obtained from the solids-free internal seal provide unique solutions to depleted reservoir wellsite operations. Unlike a conventional external seal that requires constant filtrate invasion for maintenance, all further invasion stops once the micro-environment seal is established. This feature is very important when drilling or performing workover operations in depleted formations. When conventional fluid technologies are employed in such environments, it is not uncommon to observe very deep filtrate invasion with array induction logs (beyond the investigative capabilities of the tool). The reactive radial interface from a borehole exhibiting an invasion profile of 90 in. and deeper is quite considerable. Depending upon the characteristics of the formation, the invading filtrate may not have much direct detrimental effect on the reservoir. The invading filtrate however, may have a considerable effect on bordering reactive shales, thereby enhancing the propensity for the problems associated with shale breakout. Owing to excessive filter cake build-up in such environments, it is quite common to observe caliper logs exhibiting both severe breakout along these sand/shale interfaces and under-gauge sands. This is an ideal environment for swabbing and the creation of bridges from caving.

Another benefit of the non-conventional internal seal is its effect on differential sticking. The seal exhibits a gradual pressure drop (Fig. 1) from the annulus to the seal interface with the reservoir fluids. This pressure absorption profile sufficiently alters the near-bore pressure drop environment, which effectively negates differential sticking. This translates into a considerable reduction in risk when employing costly downhole tools during well construction in high-annular and low reservoir-pressure applications.[6]

Tajin Area Workover History

The Tajin area is located in the Poza Rica field in Eastern Mexico (Fig. 2). Previously, calcium carbonate plugs and salt plugs have been used to seal the completed zone, but most of the time, these pills did not work. Temporary gels have also been tried with poor results. The application was to set production equipment (valves) when the conversion to mechanical pumping or air-assisted pumping was necessary. Utilizing the aphrons save time sealing the depleted zones.

Aphron Workovers Parameters

The aphron fluid was employed for workover operations on the **Tajin 361** (v), **Tajin 364** (D-366) and **Tajin 321** wells of the Poza Rica field. The primary objectives were to minimize invasion while providing a stable and safe working environment for the re-completions of wells, which would no longer produce without the aid of a mechanical pump. The oil producing Chicontepec sands in this area are interbedded with reactive shales. Because of their tight features (Table 1), these shales were hydraulically fractured during their initial completion to optimize production. The potential problems common to re-completions in this area include:

- Frequent loss circulation into the depleted sands,
- Constant gas influxes, and
- A high potential for taking kicks.

The program design for the **Tajin 361** called for displacement of the aphron fluid (Table 2) into the well at the top of an existing cement plug set at 1730 m. This displacement covered the perforations across the oil producing depleted C-85 sands of the Chicontepec formation located between 1710 and 1730 m. These sands ceased flowing in March 1999. After a successful displacement the cement plug was drilled, providing additional communication with perforations in the low-pressure C-100 Chicontepec sands between 1830 – 1860 m. The well was then cleaned out and re-completed with a mechanical pump set about 1910 m MD (Fig. 3).

The program design for the **Tajin 364** well called for the aphron fluid to be displaced at the top of an existing cement plug located at 1703 m. This displacement covered the perforations across the oil producing depleted sands of the Chicontepec formation located between 1580 – 1598 m (C-40 sands) and 1607 – 1625 m (C-50 sands). These sands were fractured in August and September 1990, respectively. After a successful displacement, the cement plug was drilled, thereby providing additional communication with perforations in low-pressure Chicontepec sands between 1741 – 1747 (C-70 sands), 1756 – 1764 (C-80 sands) and 1775 – 1784 (C-85 sands) m. The C-80 sands were fractured in September 1989. A second cement plug below these sands was cleaned out, thus exposing another set of existing perforations between 2010 – 2035 m. The well was then re-completed with a mechanical pump set below this last set of perforations (Fig. 4a).

The program design for the **Tajin 321** called for displacement of the aphron fluid into the well and cleaning out fill across an existing set of perforations located between 1730 and 1750 m. This displacement covered the perforations in the depleted sands of the Chicontepec formation located between 1425 – 1460 m. and the top of the perforations located between 1730 – 1750 m. The well was then cleaned out to the top of the cement and re-completed with a mechanical pump set below this last set of perforations (Fig. 4b).

Aphron Workover Fluid Design

Table 2 details the base formulation of the aphron fluid employed on these workover operations. Tables 3, 5 and 7 provide the last recorded pressures for the sands and their equivalent densities in the **Tajin 321, 364** and **321** wells, respectively. Tables 4, 6 and 8 provide the initial and final properties of the aphron fluid that was employed for the various workover operations. Taking into account the minimal effect aphrons have on annular hydrostatic pressure[5] and using the lowest density of a fully compressed aphron fluid density (8.6 lb/gal), the estimated minimum static pressure differential encountered between the annulus and the hydraulically fractured sand reservoir in each operation was 260 psi, 1088 psi and 765 psi. This takes into account an estimated 50-psi reduction in annular pressure, instigated by the presence of aphrons. No additional bridging materials were employed in the aphron system on these workover operations and no loss of circulation was encountered.

Results

The features of the aphron workover fluid employed on these three wells provided many operational benefits to the operator. The micro-environment seal enabled the creation of solids-free bridging of the depleted producing sands with minimal invasion, while also providing a safe working environment for the necessary workover operations. The rheological properties of the system aided in optimizing hole cleaning when circulating and cuttings suspension when static. The environmental risk exposure for these operations was reduced significantly when compared to previous fluid and operational techniques employed in the area.

Compared to the centrifuged diesel employed previously, the aphron technology proved to be an economically viable solution. Comparative analysis of the fluid costs and their respective impact on operations resulted in a 45% reduction in cumulative fluid costs and a 43% savings in costs associated with time reduction (Fig. 5 and Fig. 6). Cumulatively, this translates into an average cost reduction of 44% per workover (Fig. 7).

References

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SI Metric Conversion Factors

bbl	x	1.589 873	E-01	= m^3
lbm	x	4.535 924	E-01	= kg
lbm/bbl	x	2.853	E+00	= kg/m^3
lb/gal	x	1.198 264	E-01	= g/cm^3
cP	x	1.0 *	E+00	= mPa·s
$lb \cdot sec^n/100ft^2$	x	0.478 8	E+00	= $Pa \cdot sec^n$
in.	x	2.54*	E+00	= cm
ft	x	3.048 *	E-01	= m
psi	x	6.894 757	E+00	= kPa
		(°F-32)/1.8		= °C

*denotes exact conversion

Fig. 1 - Internal Seal and Pressure Graph.

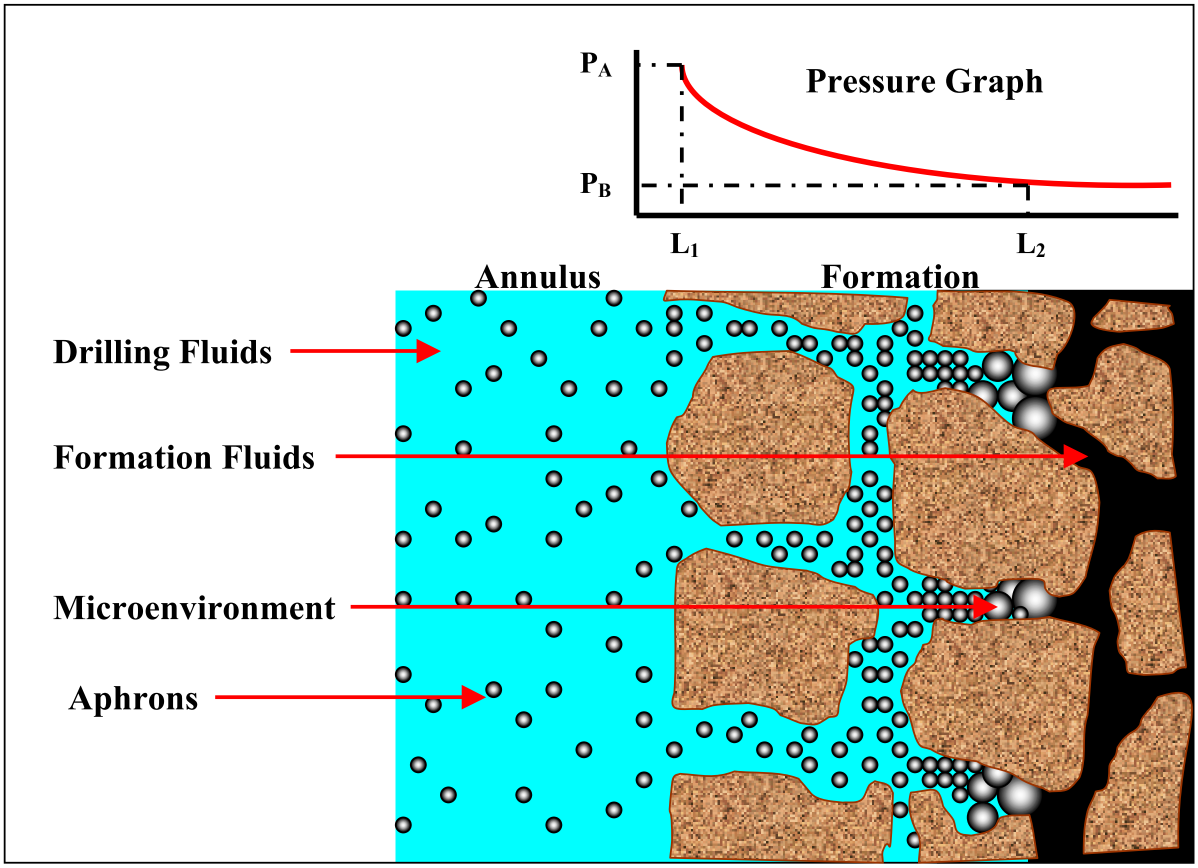

Fig. 2 - Tajin Area Map.

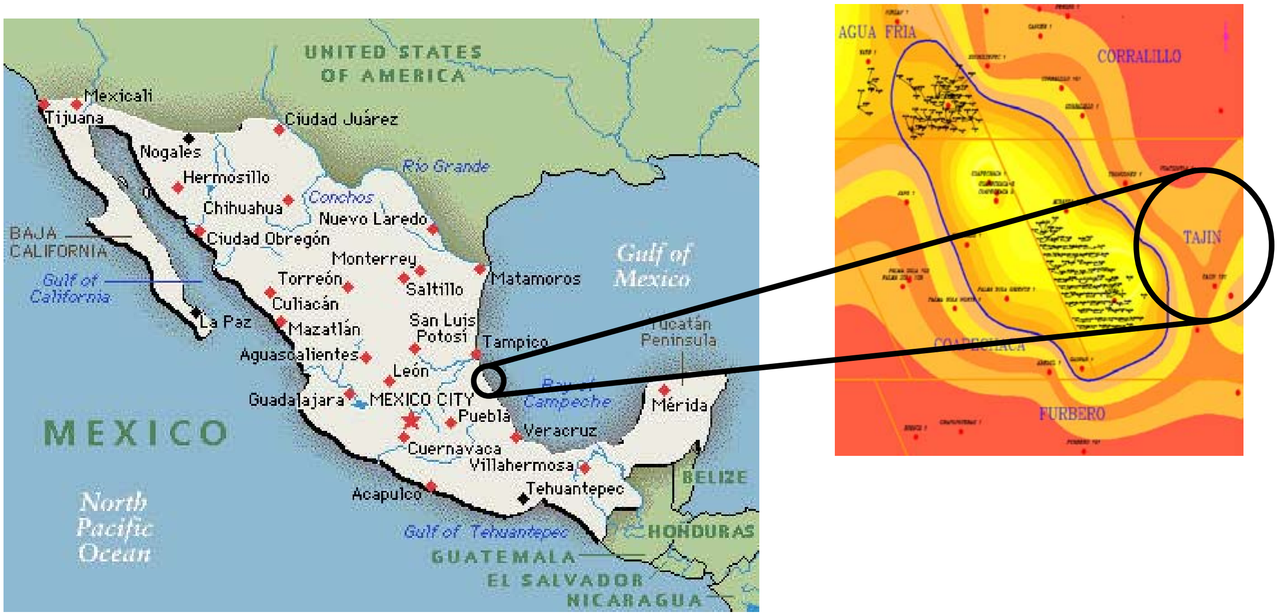

Fig. 3 -Tajin 361 Before and After Recompletion.

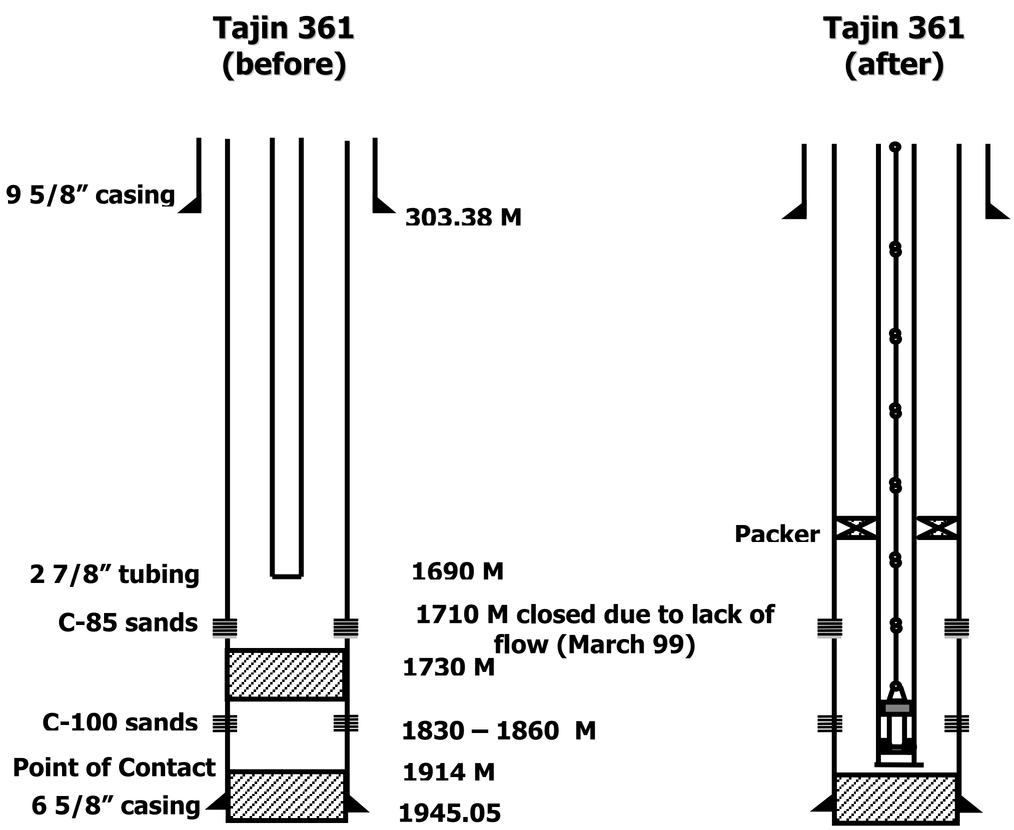

Fig. 4a - Tajin 364 Before and After Recompletion.

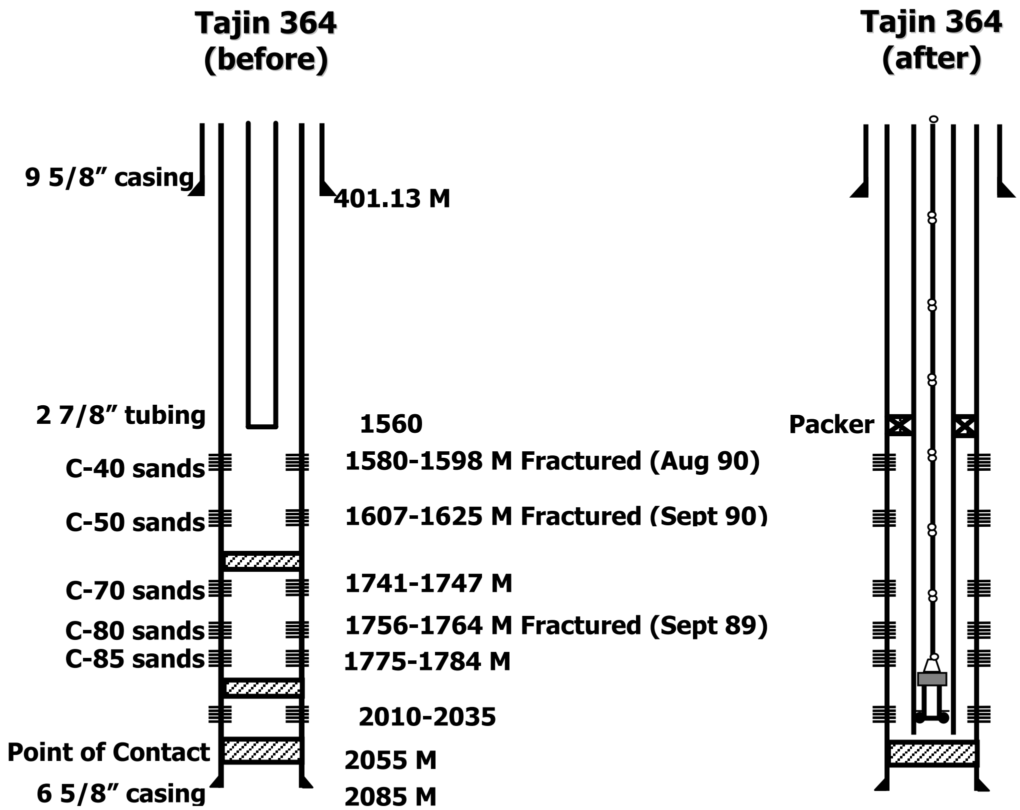

Fig. 4 - Tajin 321 Before and After Recompletion.

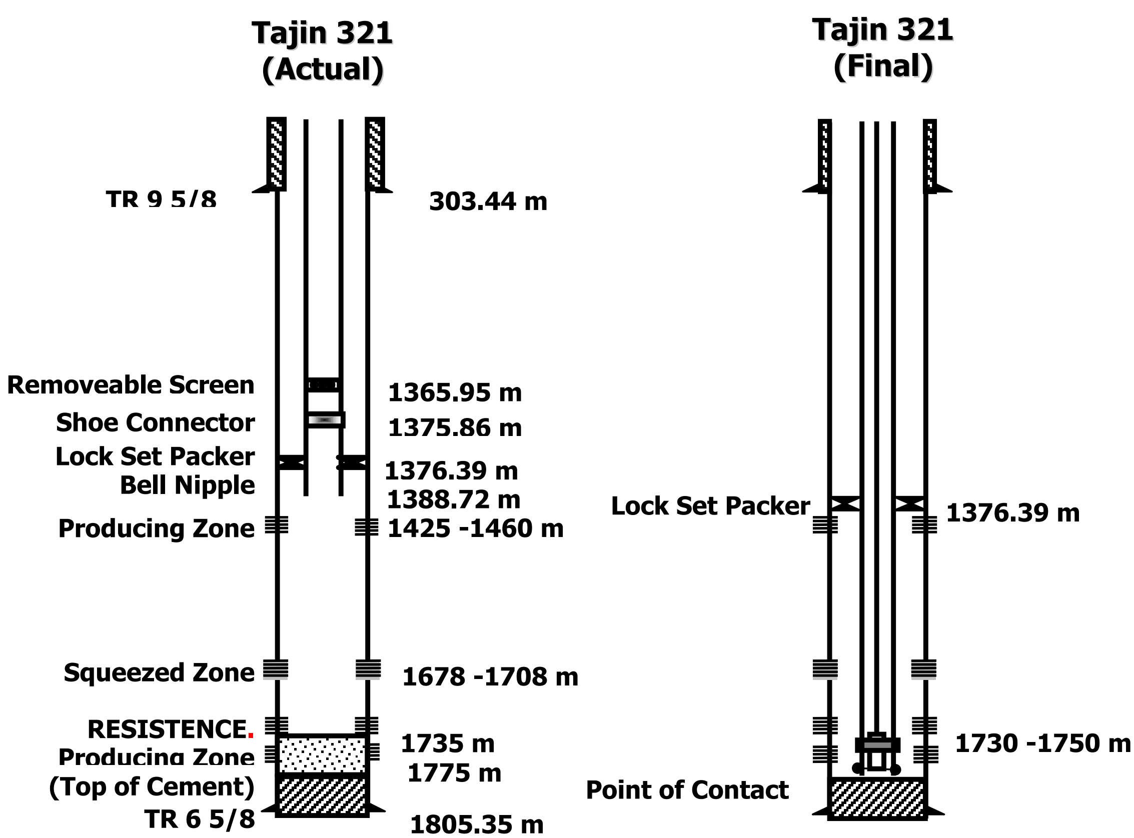

Table1 - Chicontepec Sands Features	
Well	**TAJIN 361 (V)**
Lithology	Interbedded sands and shales
Maximum Temperature (°C)	84
Permeability (mD)	0.2
Porosity (%)	9
Bottomhole Pressure (kg/cm^2)	161.5

Table 2 - Formulation of Aphron Workover Fluid	
Product Description	**Concentration**
Viscosifier (lb/bbl)	5.0
System Stabilizer (lb/bbl)	5.0
Non Caustic pH Control (lb/bbl)	0.5
Aphron Stability Enhancer (% by vol)	0.25
Aphron Generator (lb/bbl)	0.700
Soda Ash (lb/bbl)	3.0
Biocide (% by vol)	0.04

Table 3 - Reservoir Pressures Tajin 361				
Interval (m)	**Formation Pressure (psi)**	**Date Logged**	**Equivalent Density (lb/gal)**	**Equivalent Density (g/cc)**
1710 - 1730	2297		7.77	0.93
1830 - 1860	2480	May 83	7.81	0.94
1830 - 1860	2569	May 83	8.08	0.97
1830 - 1860	2500	August 85	7.87	0.94
1830 - 1860	2791	October 87	8.78	1.05
1830 - 1860	2686	November 87	8.45	1.01
1830 - 1860	2418	April 89	7.61	0.91

Table 4 - Aphron Workover Fluid Properties Tajin 361		
Properties	**Initial**	**Final**
Density (g/cc)	0.92	0.95
Funnel Viscosity (sec/1000 mL)	56	55
Plastic Viscosity (cP)	9	10
Yield Point (lb/100 ft^2)	39	36
6 rpm	24	21
3 rpm	23	19
10-sec gel (lb/100 ft^2)	23	18
10-min gel (lb/100 ft^2)	28	23
API Filtrate (mL)	10.4	11.0
Chlorides (ppm)	800	800
Calcium (ppm)	240	600
Brookfield LSRV 0.3 rpm (cP)	95,325	75,000
Aphrons (% void fraction)	10	12

Table 5 - Reservoir Pressures Tajin 364				
Interval (m)	Formation Pressure (psi)	Date Logged	Equivalent Density (lb/gal)	Equivalent Density (g/cc)
1580 – 1598	1745	January 91	6.29	0.75
1607 - 1625	1245	May 91	4.48	0.54
1607 – 1625	1890	May 94	6.81	0.82
1607 - 1625	1909	June 94	6.88	0.83
1607 - 1625	1565	February 93	5.64	0.68
1607 - 1625	1279	July 2001	4.60	0.55
1741 - 1747	2137	September 87	7.01	0.84
1756 - 1764	2166	February 89	7.11	0.85
1775 - 1784	1734	July 90	5.69	0.68
2010 - 2035	3892	December 81	11.19	1.34
2010 - 2035	3842	April 82	11.05	1.33
2010 - 2035	2404	May 83	6.91	0.83
2010 - 2035	2310	August 85	6.64	0.80
2010 - 2035	2395	April 86	6.89	0.83

Table 6 - Aphron Workover Fluid Properties Tajin 364		
Properties	**Initial**	**Final**
Density (g/cc)	0.92	0.92
Funnel Viscosity (sec/1000 mL)	52	52
Plastic Viscosity (cP)	9	7
Yield Point (lb/100 ft^2)	38	34
6 rpm	20	18
3 rpm	18	15
10-sec gel (lb/100 ft^2)	19	15
10-min gel (lb/100 ft^2)	25	21
API Filtrate (mL)	10.0	10.0
Chlorides (ppm)	800	800
Calcium (ppm)	440	320
Brookfield LSRV 0.3 rpm (cP)	82,345	86,200
Aphrons (% void fraction)	10	12

Table 7 - Reservoir Pressures Tajin 321				
Interval (m)	Formation Pressure (psi)	Date Logged	Equivalent Density (lb/gal)	Equivalent Density (g/cc)
1425 – 1460	1745	August 01	3.41	0.41
1730 – 1750	1890	May 00	8.45	1.01

Table 8 - Aphron Workover Fluid Properties Tajin 321		
Properties	**Initial**	**Final**
Density (g/cc)	0.89	0.92
Funnel Viscosity (sec/1000 mL)	55	55
Plastic Viscosity (cP)	10	10
Yield Point (lb/100 ft^2)	35	44
6 rpm	24	21
3 rpm	23	19
10-sec gel (lb/100 ft^2)	23	18
10-min gel (lb/100 ft^2)	28	23
API Filtrate (mL)	10.0	9.5
Chlorides (ppm)	900	800
Calcium (ppm)	200	200
Brookfield LSRV 0.3 rpm (cP)	57,088	62,400
Aphrons (% void fraction)	12	11

Fig. 5 – Cost versus Time.

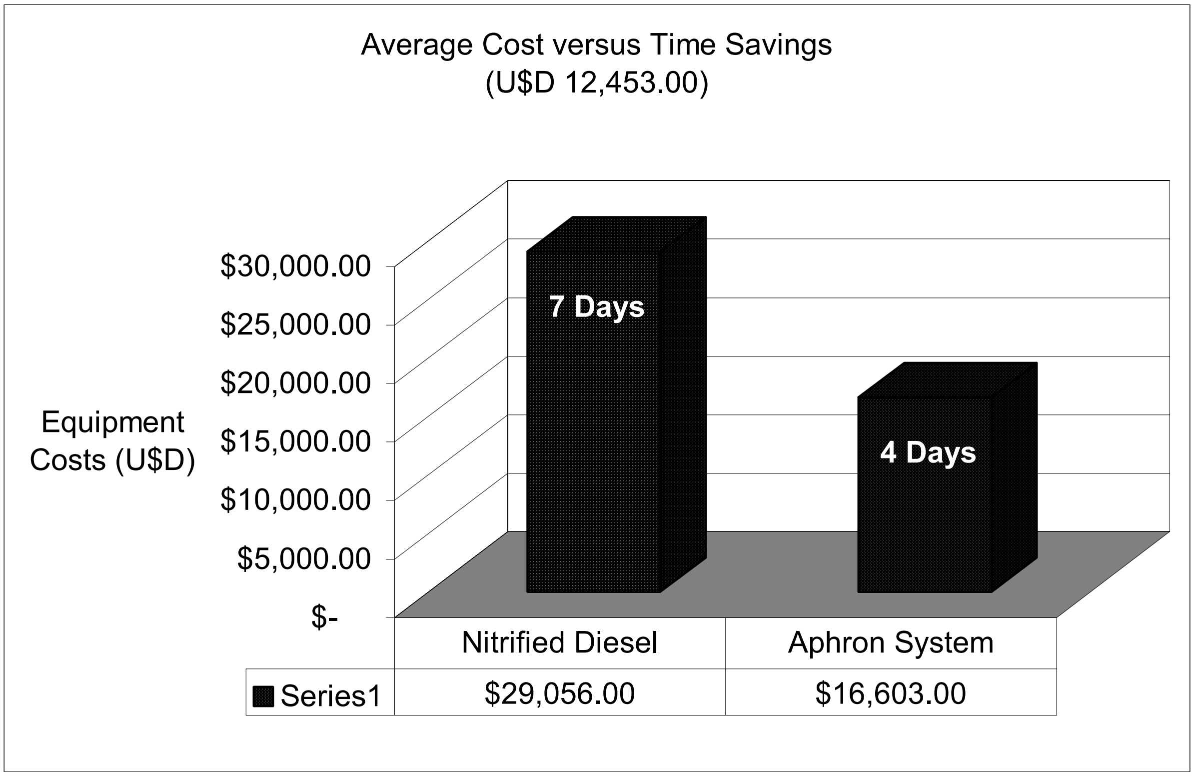

Fig. 6 – Comparative Fluids Costs.

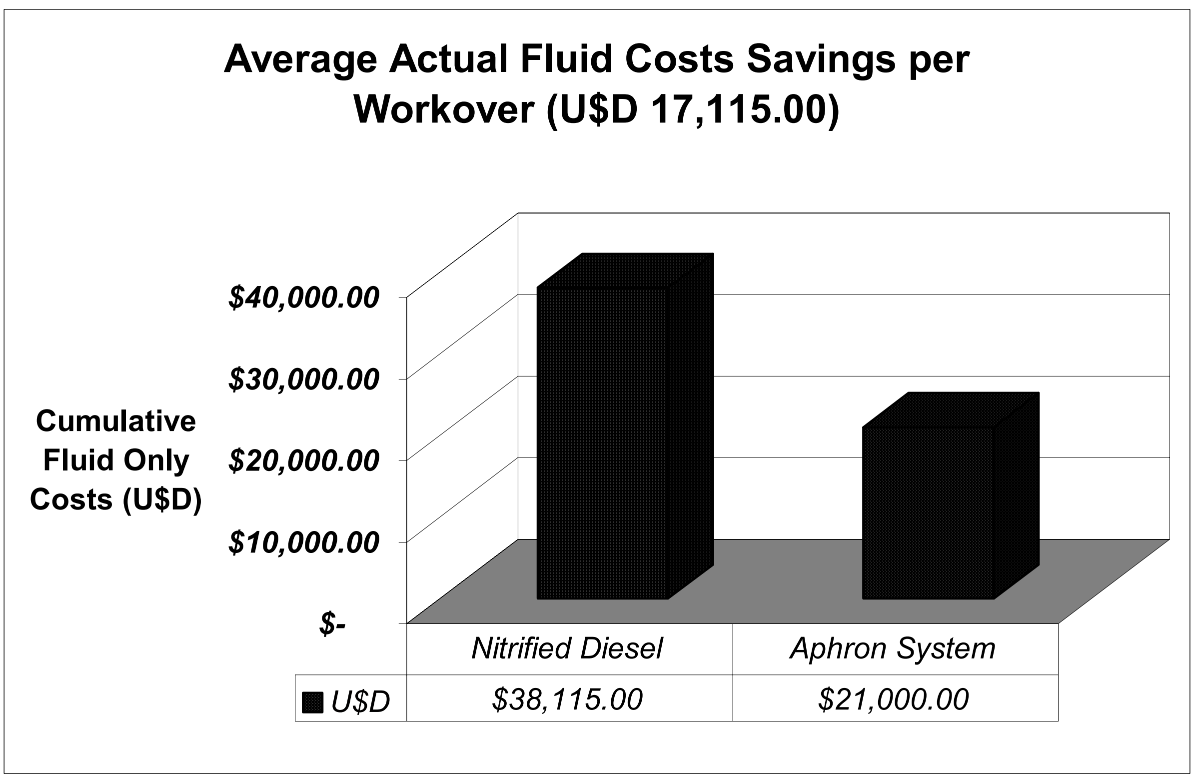

Fig. 7 – Cost Analysis.