TITLE PAGE

Evaluating Casing Plunger Cup Design
Final Report
For the Period: June 1, 2005 to December 31, 2006
Author: Windel Mayfield
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PAAL,LLC
9500 Cedar Lake Ave.
Oklahoma City, Oklahoma 73114

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ABSTRACT

PAAL has completed the program entitled “Evaluating Casing Plunger Cup Design”. Elastomers were tested using a PAL casing plunger to transport standard ASTM dumbbell specimens down hole where they were exposed to the same environment that the plunger experiences. After exposure the dumbbell specimens are tested using a small lab tensile tester located at the well site. Testing at the well site ensures that the data measured is more accurate than would be available if tested in a lab at a later time. Five separate compounds were included for exposure in each test, with each test lasting 60 days. The same plunger was modified by incorporating two data loggers to measure and record the temperature and pressure surrounding the plunger. The tensile data, temperature, and pressure data were used to evaluate cup performance. From the collected data significant improvements were made in the cup performance and reliability.

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EXECUTIVE SUMMARY

The novel cup design employed in the PAL Casing Plunger is based upon a cup having its outside diameter smaller than the casing inside diameter and utilizing a mechanical force to expand and seal the cup to the casing. The lower cup is expanded when the plunger encounters the collar stop, set at the lower end of the casing, and the tool weight is allowed to compress the cup height and expand the cups outside diameter. With the internal valve closed and the lower cup expanded to form a seal, gas from the formation begins to build pressure beneath and inside the tool. This internal pressure increase expands the upper cup until it contacts the casing and forms a second seal. Pressure continues to increase until the tool and the fluid above the tool begin to move up the well bore. In this application it is clear that the single most important element affecting the tool operation is the design of the sealing cup.

It was believed by many elastomer design chemists that the best material to withstand the down hole environment would be a nitrile based compound formulated with a filler of N330 carbon black. N330 carbon black is widely used in the oil field rubber molding industry in dynamic applications to provide a compound with high abrasion resisting properties. Casing plunger sealing cups commonly operate in 8,000 foot plus depths lifting as many as 15 barrels of fluid in a single trip. Many times the casing in these wells is 10-50 years old, and has corroded surfaces, cement, salt, or chemical deposits built up on the ID of the casing. The fluid being lifted in the wells frequently is 160-180 degrees Fahrenheit and can be a combination of oil, salt water, condensate, and paraffin. Nitrile polymers are manufactured with varying acrylonitrile(ACN) percentages ranging from 26% thru 50%, with the higher percentages having higher chemical resistance; but producing rubber a compound with a higher modulus. Often this higher modulus will render a compound unusable for many applications. After conferring with three different chemists skilled in the art of rubber formulation it was decided to develop a compound based on a 45% and 50% ACN levels. These materials were evaluated by placing ASTM dumbbell specimens of five compounds inside a chamber attached to four conventional PAL casing plungers and allowing the plungers to cycle in four different well environments. In this chamber the specimens were exposed to the same well bore environment that the cups experience. After sixty four days of exposure the dumbbells were removed and tested for loss of tensile strength by using a tensometer at the well site to compare tensile strength before and after exposure. The tensile strength remaining after exposure correlates well with the cups expected life in each particular well. The loss in tensile strength comes about as the material experiences a volume swell due to exposure to various substances present in the fluids and gasses in the environment. The associated swelling also affects the materials abrasion resistant qualities which results in a reduced life span for cups. It should be noted that raising the ACN level of a formula is not the answer to all situations as this raises the modulus of the compound and often makes the cup too stiff to work properly in light load applications. As usually is the case, maintaining a balance of properties is better than trying to maximize all properties.

In order to better understand the down hole temperatures and pressures experienced by the PAL casing plunger two temperature and pressure data loggers(see appendix) were incorporated into the valve shaft mechanism, with one recorder measuring below the top cup and the other measuring above the top cup. Data collected using this arrangement facilitates computing the pressure differential across the top cup. Charts contained in the "Experimental" section show an upper and lower log recorded on 11-01-06 on well titled Ruth 1-36 located in Oklahoma. The plunger in this well is programmed to make four cycles per day while lifting two to three barrels of fluid per cycle. Cups for this plunger are molded from the 45%ACN level compound ("H") previously mentioned. The collar stop, or lowest point in the production cycle, is set at 7507 ft depth with the cups running over 850 cycles which computes to 1,200+ miles of lift. Upon inspection these cups appear to have 70% of the original wall thickness still available. Cups in this well operate at a temperature of 156 degrees Fahrenheit for a period in excess of 200 days with no appreciable consequences.

The physical configuration of the PAL cup was changed to try to utilize a new compound we developed called 9002. This compound measures 90 durometer shore A, is made from 31% ACN level, and has a very high modulus. Even with the configuration changes we made, 9002 would not make and hold the necessary seal needed for successful operation. No further testing is planned for this compound at this time.

This subcontract has allowed the development, testing, and refinement of two rubber compounds used primarily for casing plunger cups. The first compound "H" is based on a 45% ACN level polymer and is used in wells to lift fluids containing salt water or oil. In two such wells the Ruth 1-36 and the Gregg A22 , "H" compound maintained tensile strength of 2406psi and 2416psi respectively, which have proven to be sufficient to achieve excellent cup performance. The second compound "7500" developed is based on a 50% ACN level polymer and it will be used in wells producing condensate or where high load carrying capacity is required.

EXPERIMENTAL

The program utilized to evaluate casing plunger cup design used a TT2100 Tensile Tester manufactured by Benz Testers (www.benztesters.com) of Providence, RI to compare tensile strengths of elastomers before and after exposure to well-bore environments thus showing how much degradation occurred. The test samples were cut to shape with an ASTM die which conforms to ASTM D 412 standards, also available from Benz Testers.

The data acquisition unit used to collect the down-hole pressure and temperature is an OM-CP-PRTEMP1000 unit made by Omega Engineering of Stamford, CT (www.omega.com). The unit is completely self contained in a stainless steel housing, making it submersible and resistant to most down-hole environments. The unit will measure and record 16,383 temperature and 16,383 pressure measurements. The data can be downloaded into a computer via a USB cable. The software available allows the data to be printed in tabular or graphic form.

Typical physical properties as measured on compound “H” and “7500” are listed below.

	“7500”	“H”
100% Modulus	925PSI	734PSI
300% Modulus	NA	3253PSI
Tensile	4008PSI	4241PSI
Elongation	421%	403%
Durometer	85	79
Specific Gravity	1.23	1.22

RESULTS and DISCUSSION

The goal when this project was started was to produce a casing plunger cup that would be able to perform in demanding well conditions. One of the rubber formulations that was developed for trial was tagged compound "H". This formulation is made using Zeon Chemical Company's Nipol Elastomer DN4580 which is a 45% ACN level nitrile made for high fuel (hydrocarbon) resistance and low fuel permeability. Since July of 2005 cups molded from "H" compound have been used on the PAL plunger in the Ruth 1-36. This plunger was installed on 3-23-05, and was used to replace rods, tubing, down-hole rod pump, and a Big M 228-246-86 pump jack which was powered by a C-96 motor operating on produced gas. The collar stop was set at 7507ft, which is the first joint above the perforations. Cups made from compound "H" have been used in this well since July 2005 with great success. One set of cups ran in excess of 850 cycles at four cycles per day. These cups lifted over 1,912 barrels of fluid and traveled over 1,200 miles before being changed. The cups had less than 30% of their wall abraded. With the PAL plunger installed, this well experienced a 68.5 mcf/day increase in gas production and a 1.2 bbl/day increase in oil production. One often over looked fact when evaluating casing plunger increases is the fact that the C-96 motor previously used to produce this well consumed over 5 mcf of gas each day. When using the PAL casing plunger this 5 mcf of gas now goes into the pipeline for our use and not into the atmosphere as exhaust.

PAL cups made from "H" compound are being used successfully in more than 30 wells, with most showing an increase in production above previous production methods. This rubber compound improvement process is an open ended on-going process however; this "H" compound must be judged a success.

CONCLUSION

The testing and compound development done under this subcontract has led to casing plunger cups that perform well under a wide range of down-hole conditions and provide an exceptional cup life. The testing procedure utilized here, namely carrying the lab equipment to the well site to provide quick accurate results, has allowed several rubber compounds to be evaluated in a short period of time. This program would not have been possible without the support of the DOE and SWC. This support should be credited for the advances made here.

REFERENCES

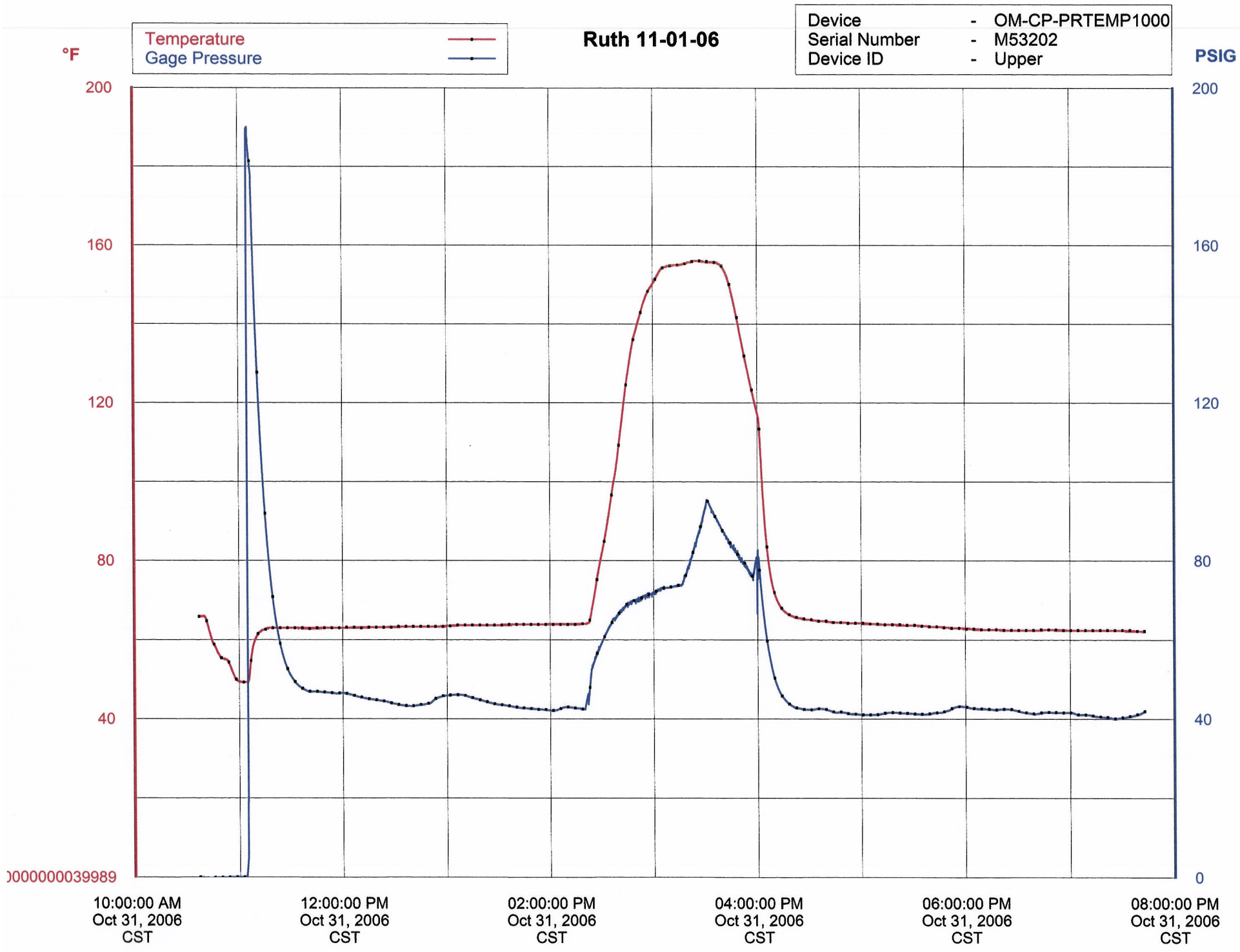
None cited.

APPENDIX

1. WELL TEST DATA
2. RUTH UPPER TEMPERATURE-PRESSURE GRAPH
3. RUTH LOWER TEMPERATURE-PRESSURE GRAPH
4. OM-CP-PRTEMP1000 DATA SHEET
5. OMEGA ENGINEERING ID SHEET
6. PAAL TECH BULLETIN-RUTH 1-36

WELL TEST DATA

TEST DATE	DURATION DAYS	LOCATION	COMPOUND	ACN%	POLYMER %	FILLER %	TENSILE	STD TENSILE	RETENTION %
2/15/2006	7	BANNER GREG	7500	50	58.74	29.37	3222	3774	85.37%
2/15/2006	7	BANNER GREG	H	45	56.72	28.36	2278	3248	70.14%
2/15/2006	7	BANNER GREG	G	26	63.29	23.41	2412	3104	77.71%
2/15/2006	7	BANNER GREG	13	45	46.6	44.28	2937	3413	86.05%
3/3/2006	14	MASSEY	7500	50	58.74	29.37	2861	3774	75.81%
3/3/2006	14	MASSEY	H	45	56.72	28.36	3057	3248	94.12%
3/3/2006	14	MASSEY	G	26	63.29	23.41	2679	3104	86.31%
3/3/2006	14	MASSEY	13	45	46.6	44.38	3230	3413	94.64%
4/5/2006	14	GREG A22	7500	50	58.74	29.37	2848	3774	75.46%
4/5/2006	14	GREG A22	H	45	56.72	28.36	2680	3248	82.51%
4/5/2006	14	GREG A22	G	26	63.29	23.41	1901	3104	61.24%
4/5/2006	14	GREG A22	9002	31	37.27	53.1	2933	4258	68.88%
4/5/2006	15	GROVE	7500	50	58.74	29.37	2790	3774	73.93%
4/5/2006	15	GROVE	H	45	56.72	28.36	2659	3248	81.87%
4/5/2006	15	GROVE	9002	31	37.27	53.1	3089	4258	72.55%
4/5/2006	15	RUTH	7500	50	58.74	29.37	3206	3774	84.95%
4/5/2006	15	RUTH	H	45	56.72	28.36	1984	3248	61.08%
4/5/2006	15	RUTH	G	26	63.29	23.41	2398	3104	77.26%
4/5/2006	15	RUTH	9002	31	37.27	53.1	2943	4258	69.12%
5/24/2006	64	GREG A22	7500	50	58.74	29.37	3100	3774	82.14%
5/24/2006	64	GREG A22	H	45	56.72	28.36	2416	3248	74.38%
5/24/2006	64	GREG A22	G	26	63.29	23.41	2093	3104	67.43%
5/24/2006	64	GREG A22	9002	31	37.27	53.1	2741	4258	64.37%
5/24/2006	65	GROVE	7500	50	58.74	29.37	3047	3774	80.74%
5/24/2006	65	GROVE	H	45	56.72	28.36	2510	3248	77.28%
5/24/2006	65	GROVE	G	26	63.29	23.41	2481	3104	79.93%
5/24/2006	65	GROVE	9002	31	37.27	53.1	2864	4258	67.26%
5/24/2006	64	RUTH	7500	50	58.74	29.37	3305	3774	87.57%
5/24/2006	64	RUTH	H	45	56.72	28.36	2406	3248	74.08%
5/24/2006	64	RUTH	G	26	63.29	23.41	2182	3104	70.30%
5/24/2006	64	RUTH	9002	31	37.27	53.1	2889	4258	67.85%


Temperature
Gage Pressure
Ruth 11-01-06
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Serial Number - M53202
Device ID - Upper
°F
PSIG
200
160
120
80
40
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200
160
120
80
40
0
10:00:00 AM Oct 31, 2006 CST
12:00:00 PM Oct 31, 2006 CST
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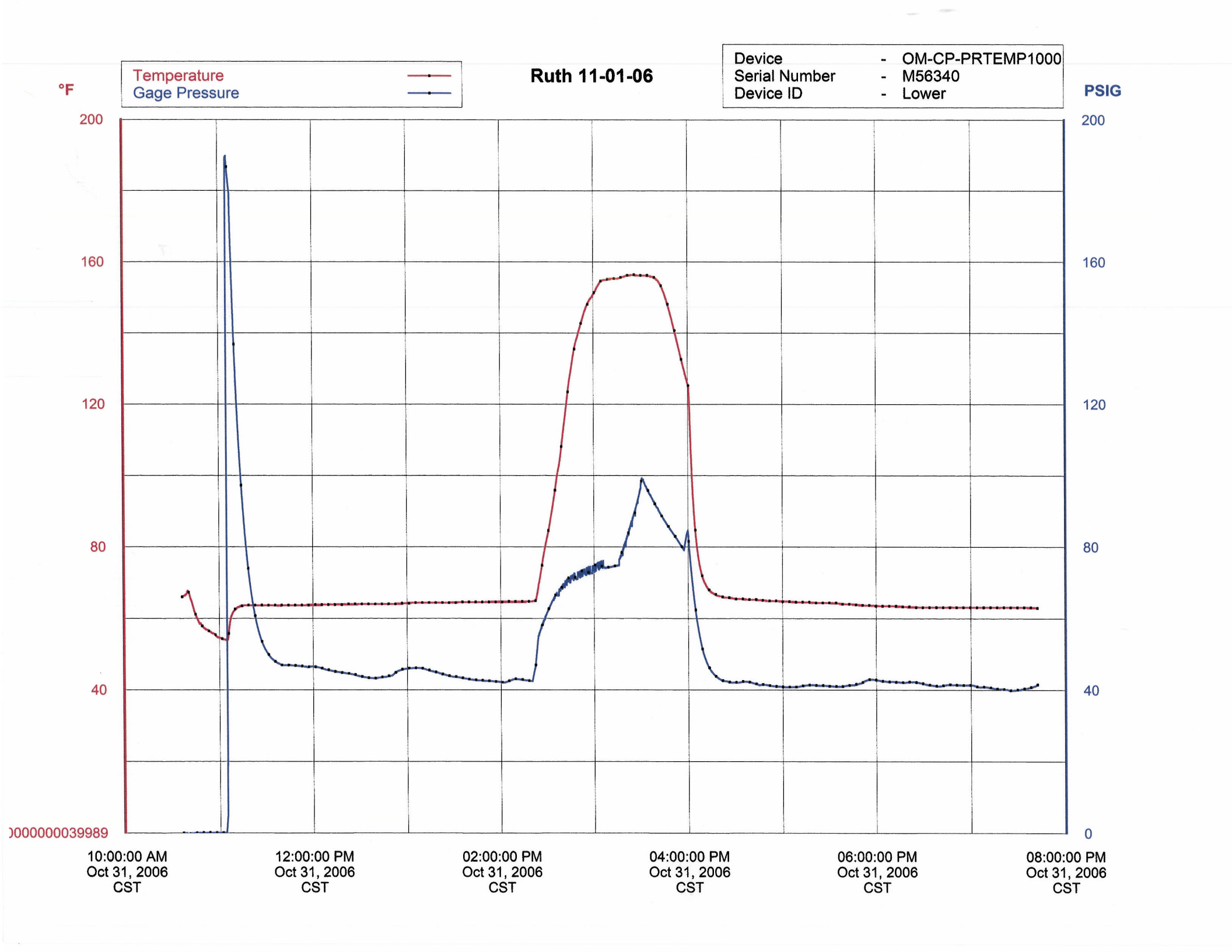
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Gage Pressure
Ruth 11-01-06
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°F
PSIG
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40
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160
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04:00:00 PM Oct 31, 2006 CST
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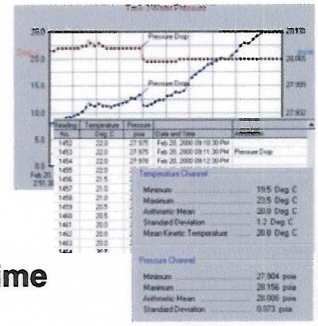

OM-CP-IFC110, $99, Windows software displays data in graphical or tabular format

OM-CP-PRTEMP1000-0-30-A-SS fully submersible datalogger, $649, shown smaller than actual size

OM-CP-PRTEMP1000-1-100-A-SS datalogger with 1/4" NPT fitting, $649, shown smaller than actual size

The OM-CP-PRTEMP1000 submersible pressure and temperature datalogger is a battery powered, stand-alone device used for automatically recording pressure from 0 to 500 psia and temperatures from -40 to 80°C. This all-in-one compact, portable, easy to use device will measure and record up to 16,383 temperature and 16,383 pressure measurements.

TheOM-CP-PRTEMP1000 is a major leap forward in both size and performance. Its real time clock ensures that all data is time and date stamped. The storage medium is non-volatile solid state memory, providing maximum data security even if the battery becomes discharged. Its small size allows it to fit almost anywhere. Data retrieval is simple. Plug it into an available COM port the easy to use software does the rest. The software converts your PC into a real time strip chart recorder. Data can be printed in graphical or tabular format and can also be exported to a text or Microsoft Excel file.

Specifications

Temperature Sensor: Semiconductor
Temperature Accuracy: 0.5°C
Temperature Resolution: 0.1°C
Temperature Range: -40 to 80°C (-40 to 176°F)
Pressure Sensor: Strain gage
Pressure Adapter: 1/4" male NPT or fully submersible
Pressure Range: 0 psia to 30 psia, 100 psia or 500 psia (psig models also available)
Pressure Accuracy: ±0.3% FSR @ 25°C;
- Temperature Compensated Range: 0 to 80°C
- Temperature Effect on Span: ±1% FSR @ 25°C; ±0.2% typical
- Temperature Effect on Offset: ±1% FSR @ 25°C; ±0.2% typical

Pressure Resolution: 0.002 psia (0-30 psia/psig nominal range); 0.005 psia (0-100 psia/psig nominal range); 0.05 psia (0-500 psia/psig nominal range)
Pressure/Temperature Calibration: Digital calibration is available through software
Calibration Date: Automatically recorded within device to alert user when calibration is required
Recording Interval: 2 secs to 24 hrs selectable through software
Start/Time: Start time and date are programmable through software
Real Time Recording: Device may be used with PC to monitor/and record data in real time
Power: 3.6 V lithium battery (included)
Battery Life: 1 year typical
Time Accuracy: ±1 minute per month at 20°C
Data Format: Date and time stamped; Gauge: psig, bar, atm, torr, Pa, KPa, MPa, Absolute: psia, bar, atm, torr, Pa, KPa, MPa, mmhg, inHg altitude ft, altitude M, °C, °F, °K, °R
Weight: 340 g (12 oz)
Computer Interface: PC serial, RS-232C COM or USB
Software: WIN 95/98/NT/2000/XP
Operating Environment: -40 to 80°C (-40 to 176°F), 0 to 100% RH non-condensing
Dimensions: 32 mm dia x 163 mm L (1.25 x 6.4")
Material: Stainless steel

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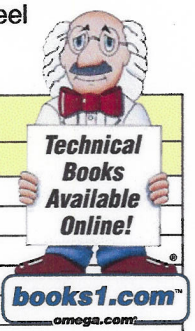
OM-CP-PRTEMP1000-(*)-100-A-SS	649	Range: 0-100 psia
OM-CP-PRTEMP1000-(*)-500-A-SS	649	Range: 0-500 psia
OM-CP-PRTEMP1000-(*)-30-G-SS	649	Range: 0-30 psig
OM-CP-PRTEMP1000-(*)-100-G-SS	649	Range: 0-100 psig
OM-CP-PRTEMP1000-(*)-500-G-SS	649	Range: 0-500 psig
OM-CP-IFC110	99	Windows software and 1.2 m (4') RS-232 cable with DB9F termination
OM-CP-IFC200	119	Windows software and 3.7 m (12') USB interface cable
OM-CP-BAT102	10	Replacement 3.6 V lithium battery
CS-3785	150	McGraw-Hill Dictionary of Scientific and Technical Terms



Insert 1 for 1/4" NPT or 0 for fully submersible dataloggers. Operator's manual and RS-232 cable are included with the **OM-CP-IFC110 Windows software (software sold separately). To order datalogger with NIST calibration certificate, add suffix "-cert" to model number and add $60 to price (NIST calibration for temperature only).*

Ordering Example: OM-CP-PRTEMP1000-1-100-A-SS-CERT** pressure and temperature datalogger with NIST calibration certificate, 1/4" NPT fitting, 0-100 psia range, **OM-CP-IFC110** Windows software and RS-232 cable, $649 + 60 + 99 = **$808.

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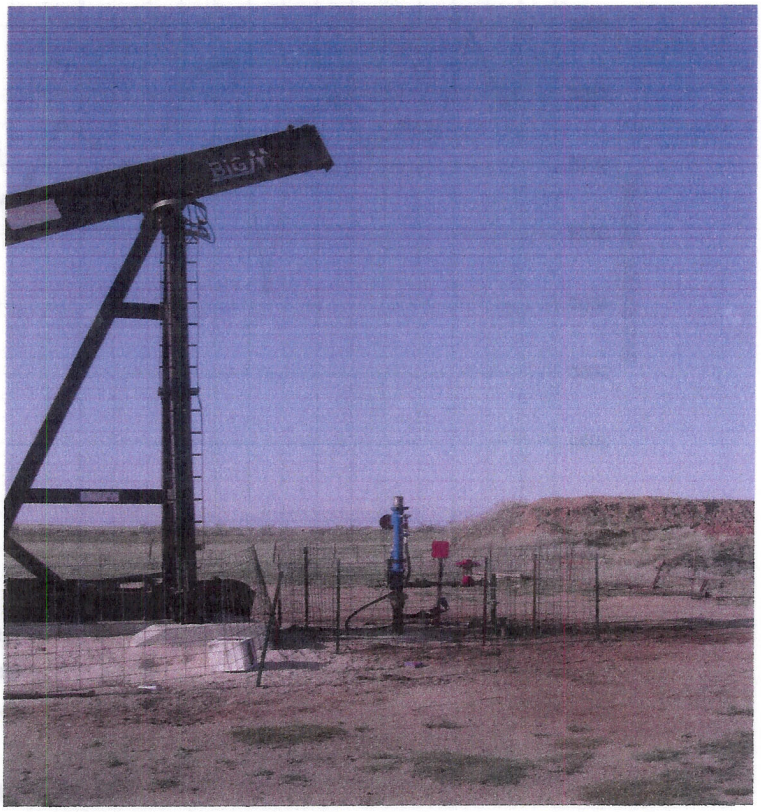
PAAL LLC

Technical Bulletin

RUTH 1-36

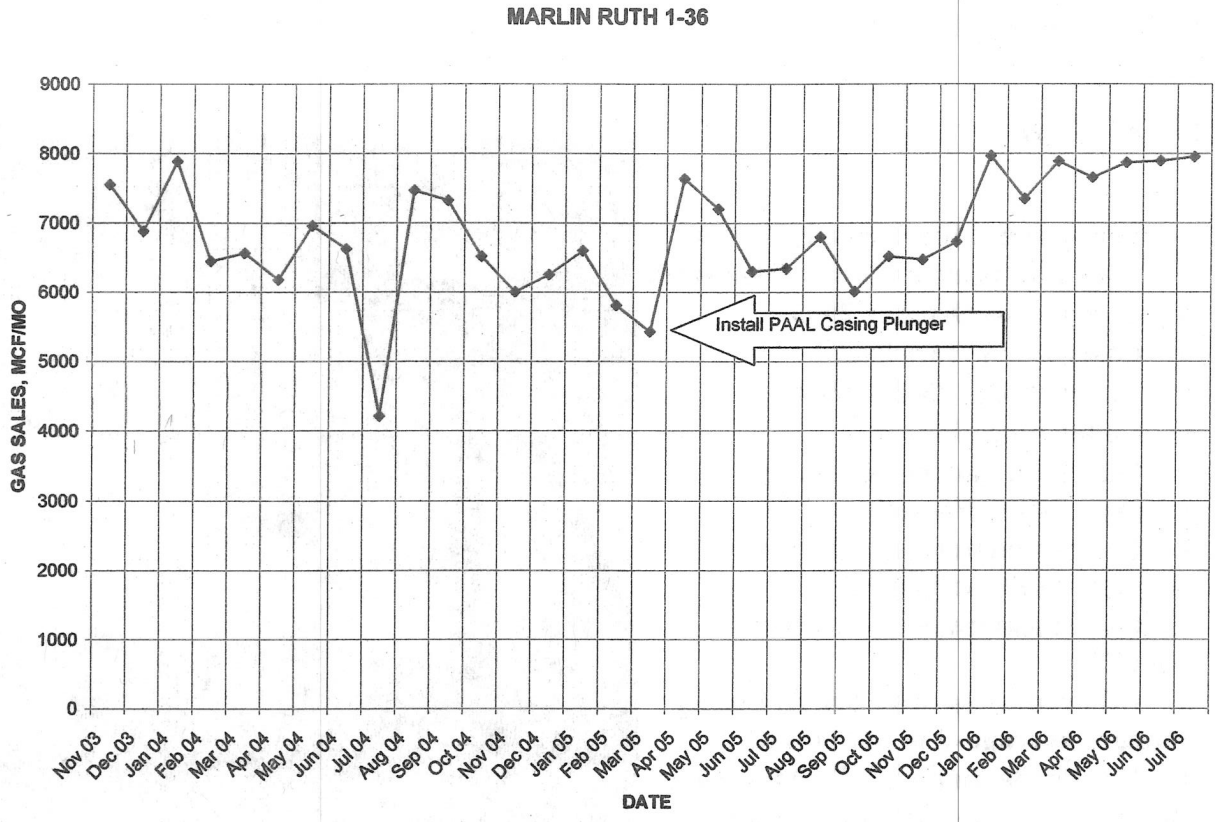
- **Formation- Morrow and Chester**
- **Location- Beaver County Oklahoma**
- **Completed- October 2003**
- **Casing- 4 ½" 11.6 lb/ft**
- **Perforations- 7546-7772 ft**
- **Collar Stop- 7507 ft**
- **Oil Production on rod pump average- 200 bbl/month**
- **Gas Production on rod pump average- 5500 mcf/month**
- **Gas consumption motor fuel- 5 mcf/day**
- **Oil production with PAAL Casing Plunger average- 236 bbl/month**
- **Gas Production with PAAL Casing Plunger average- 7555 mcf/month**
- **Plunger cycles per day- Four set with controller**
- **PAAL Casing Plunger Cup Life- 600+ Cycles**
- **Payout- Less than two months**



PAAL CASING PLUNGER USED TO REPLACE PUMP JACK, RODS, TUBING, AND DOWNHOLE PUMP

PRODUCTION DATA: MARLIN OIL--RUTH #1

DATE	GAS, mcf	OIL, bbl	SW, bbl	TOT, bbl	COMMENTS
Jan 05	5955	210		210	Produced w/Big M 228-246-86 w/ C-96 motor
Feb 05	5491	195		195	
Mar 05	5465	180		180	Install PAL 3-23-05
Apr 05	8015	317	33	350	
May 05	8356	272	42	314	
Jun 05	7230	252	48	300	
Jul 05	7440	239	51	290	
Aug 05	7227	254	42	296	
Sep 05	6314	177	24	201	Down 5 days due to high line pressure.
Oct 05	7491	210	24	234	
Nov 05	7847	210	21	231	
Dec 05	8077	195	33	228	


MARLIN RUTH 1-36
GAS SALES, MCF/MO
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Install PAAL Casing Plunger
Nov 03
Dec 03
Jan 04
Feb 04
Mar 04
Apr 04
May 04
Jun 04
Jul 04
Aug 04
Sep 04
Oct 04
Nov 04
Dec 04
Jan 05
Feb 05
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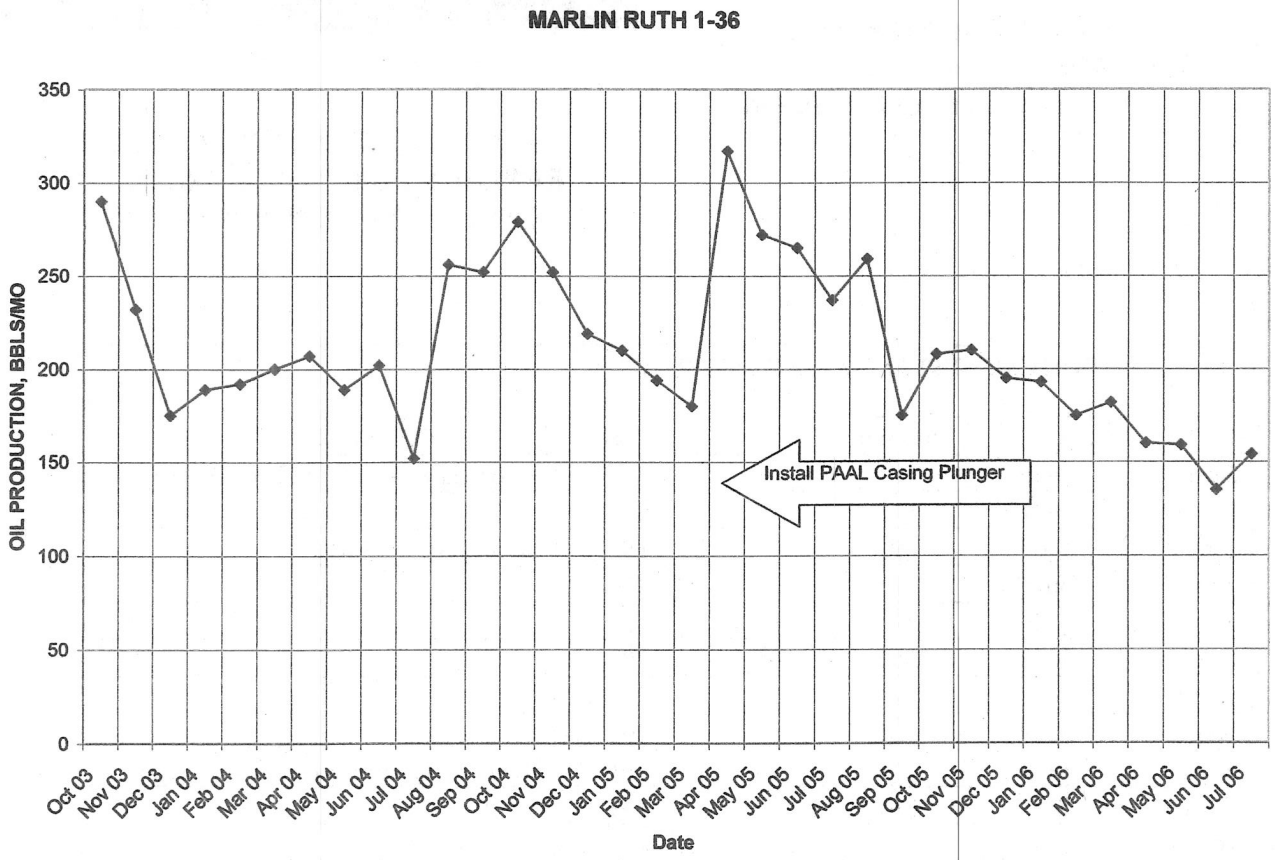
Apr 06
May 06
Jun 06
Jul 06
DATE


MARLIN RUTH 1-36
OIL PRODUCTION, BBLS/MO
350
300
250
200
150
100
50
0
Install PAAL Casing Plunger
Oct 03
Nov 03
Dec 03
Jan 04
Feb 04
Mar 04
Apr 04
May 04
Jun 04
Jul 04
Aug 04
Sep 04
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Date