SOLAR POWERED ROD PUMPING SYSTEM, WHERE BIGGER IS NOT BETTER

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ABSTRACT
Continuous Fiberglass Rod pump jack systems designed for low horsepower requirements are beginning to be used for dewatering of gas wells. A solar panel charging system provides power to the DC motor and a bank of batteries are incorporated to provide power on overcast days and at night. These systems are easily transportable and erected; and are designed for low maintenance. The continuous fiberglass rod string is spooled into the well from a trailer instead of running rods with a conventional work over rig. Typically less than one horsepower solar powered DC electric motors are used for the prime mover to drive the pumping unit. The Low Volume Pumping System, LVPS, usually produces less than 10 barrels of liquid per day from the well. This innovative technology is currently applied to shallow gas wells in remote locations where electric power may not be available and where a small amount of liquid loading is reducing gas flow from the well.

The LPVS is designed for the removal of solids in the produced fluids, resists wear and tear due to abrasion and control run time to prevent over pumping the well. The controller allows for multiple run cycles throughout a 24-hour day, to match the system's pump displacement with the liquid inflow into the wellbore. Some applications have included trash cups on the continuous rod string to prevent solids from settling down in the pump during idle times. Recent installations have included insert pumps instead of the original tubing pump design.

This system is installed in three configurations: 1) Solar Powered – using batteries charged with solar panels, 2) Hybrid – using available electricity and 3) Just the continuous fiberglass rod with a conventional pumping unit. In any configuration the goal is to minimize friction losses, so a small motor can power the system. Small diameter plunger limits both the fluid load lifted by the rods and limits the amount of fluid volume that can be produced to the surface, but only a few barrels per day of water can lead to liquid loading and killing flow from a gas well. Dynamometer and fluid level measurements will be presented to show the performance of an existing system. Depth limitations for the ½" diameter fiberglass rod will be discussed. Small diameter pump, small pumping unit size and light weight continuous rods allow the operator to use less than 1 hp motor to power the system.

INTRODUCTION OF SOLAR POWERED PUMPING UNITS

Sucker rod pumping systems were introduced to the oil field in the 1800s and utilized the beam section of the Cable-Tool drilling rig. These pumping systems were used until the 1920s when the "Horse-Head" pumping systems were developed. Through the years the need to produce wells at increased depths has resulted in construction of massively sized pumping units having long beams, large gearboxes, and powerful motors. The need to produce more fluid has led to increased stroke length provided by increases to both the height and the length of the beam. New technology solar powered rod pumping system is one more beam pumping system introduced in this case where bigger is not better, but low operating cost efficient pumping is most important.

In early 2003, BP's Farmington, New Mexico office initiated a project to dewater gas wells in the Fruitland Formation from depths of 1329-1359 feet deep using an unconventional approach. A search had been underway to find a low horsepower pumping system that could efficiently remove small quantities of water. Ranchers in the Southwest had been using a solar powered beam pumping system to produce water for agricultural purposes, such as providing water for livestock. This technology had been developed to replace windmills by providing power to the pumping unit with a series of solar panels, know as an array. Research was done to evaluate the feasibility of adapting this system to the oil and gas company's efforts to dewater liquid loaded low rate gas wells. A team was put together to in the Farmington area to coordinate efforts to assist with the installation and service of these solar power beam-pumping systems. A local rod pump service company was called on to work with BP to help in the merging of the solar pumping system with a low-pressure gas well.

DELIQUIFICATION OF LOW LIQUID VOLUME GAS WELLS

Throughout the world liquid loading is reducing the gas flow rates from gas wells. Liquid loading occurs when the gas velocity flowing to the surface is too slow to carry liquids to the surface and liquid falls back and collects in the wellbore and tubing of the gas well. This accumulated height of liquid applies pressure on the formation and reduces the flow of gas and at some point liquid accumulation may stop all flow of gas from the well. If the formation no longer has sufficient pressure to overcome the pressure from liquid loading then the gas flow rate is reduced and gas flow may cease. The gas wells in the Farmington area had once been capable of flowing gas to the surface. Over time, the reservoir pressure decreased to a point that the critical velocity of the well could no longer carry all of the fluids to the surface and out of the wellbore. While the well was still capable of producing gas, the accumulated liquids became an obstruction to achieving maximum gas production rates. Eventually the well will reach a point that the fluids are no longer lifted out of the tubing string and the gas production completely falls off. Prudent operators choose to install some type of artificial lift at this point, to keep the gas production at an acceptable level. This paper is going to discuss the application of solar power low volume beam pumping systems, **Figure 1**, to dewater liquid loaded gas wells.

PUMP DESIGN

The first five solar power beam pumping systems applications were run with 1 1/16” tubing pumps. These pumps were similar to conventional tubing pumps in that the pump barrel tube was part of the tubing string. Like most tubing pumps, both the hold-down assembly and standing valve assembly were retrievable when pulling the plunger with the rod string. The 6-foot API RH chrome internal dimension, ID, plated barrel included collars that connected directly to the tubing, with a seating nipple installed at the bottom of the barrel. The plunger assembly was similar to a water well pump in that it consisted of fiber cups instead of a spray metal sealing surface. Since the initial applications designed for coalbed methane and sandstone wells producing fines, it was expected that the cups would be superior in handling any solids that settled down onto the top of the pump during the idle time. Both the traveling valve and standing valve were standard beam pump designs and materials.

After the first four installations proved successful and reliable, another operator in the San Juan Basin began to express an interest in looking for candidate wells. They ran their first installation in July 2006 and used the tubing pump design described previously. During the design process of the second installation, issues concerning use of the tubing pump resulted in a change to the pump design. The design refinement that was made was to replace the tubing pump with a conventional small diameter rod insert pump and potentially provide large cost savings of running an insert pump on the continuous fiberglass rod string instead of a tubing pump. The driver behind this idea was to pull the entire pump out with the rod string, which would eliminate the need for a workover rig to pull the tubing to inspect, repair or replace a damaged pump barrel.

The 20-106-RHAC-3-2-2-1 pump for this operator’s second well was designed as an 1 1/16” diameter stroke-thru insert pump, with the continuous fiberglass rod connecting from the surface directly onto the valve rod bushing. A 2-foot minus 0.002-inch spray metal plunger was run in place of the cup type plunger. The 28-inch stroke, single valved pump was spaced out with minimal unswept area to provide the highest possible compression ratio. A conventional insert pump-seating nipple was run in the tubing string and the hold down assembly was fitted with +30 seating cups.

Prior to running the first insert pump, there was some concern about seating the pump, since the weight of the rod sting was minimal. Once on location, the pump was run into the well until it reached the seating nipple. The rods were stacked and the tubing was loaded with water. This process proved adequate pressure to provide the required force needed to seat the seating cups and holddown assembly.

TUBING DESIGN

An initial concern for pumping with such a low fluid velocity was the challenge of producing solids in the tubing string. To increase the liquid velocity a 1.25 inch ID tubing was chosen for the first applications. This smaller ID tubing was selected to maintain high liquid velocities and to keep any coal fines or other solids moving to the surface during the pumping cycle. Experience with this system when pumping water for livestock found that severe rod on tubing wear filled the pump with metal shavings. Poly-lined tubing was used and the problem from the fiberglass rods cutting into the steel tubing disappeared. Poly-lined tubing is widely used in the oil industry and successfully eliminates rod on tubing wear. The coefficient of friction on the poly-lined tubing is much less than the unlined J55 steel tubing, also the use of the poly-lined tubing may prevent the continuous fiberglass rod from buckling and stacking in the tubing. The first installation did not include poly-lined tubing until a later service job, and poly-lined tubing was run on the next three installations.

Due to the shallow depths and small fluid load none of the installations have included tubing anchors. Even though the tubing movement should be less than 1 inch, one operator plans to run a tubing anchor, so that data will be available for comparison between anchored and unanchored tubing strings.

The last two installations do not have poly-lined tubing in the well due the additional cost and availability. Prior to the installation, extra attention was paid to insure that the tubing used was clean and drifted to reduce the chance of internal rough spots causing damage to the fiberglass rods. The most recent installation utilized the existing 2 3/8" tubing installed in the well. Dynamometer data collected on the wells without poly-lined tubing show the minimum measured surface rod loads to be much lower than loads measured on wells with poly-lined tubing. In one well without poly-lined tubing the measured down stroke polished rod loads are near zero and the bridle becomes slack when the polished rod is lifted by hand as the rods fall. Added friction from the fiberglass rods contacting the tubing is the likely cause of the low surface loads. Poly-lined tubing and/or sinker bars will most likely be required in wells with pump depths greater than 1850 feet, because at deeper depths the extra friction will prevent the rods from falling properly on the down stroke. Without poly-lined tubing the measured minimum rod loads indicate increased drag is occurring on the down stroke, but to date no damage has been detected and it is unknown if the additional friction is sufficient to result in rod-on-tubing wear failures.

CONTROLLING RUN TIME

Due to the low liquid volumes produced from the wells the pump capacity exceeds the inflow and pump run time should be controlled so that pumping occurs only when sufficient liquids are present at the pump intake. The Low Volume Pumping System (LVPS), in both Solar and Hybrid applications, utilizes a programmable run-time controller, **Figure 2**, to cycle the pump from 1 to 8 run cycles per 24-hour period. This controller is user configurable and can be programmed in 15-minute increments to establish the length of each on time periods.

SOLAR PANELS

The initial systems were installed with power supplied by solar panels and deep cell batteries. Original expectations were that the battery bank would not be required if the operator chose to run the system when the sun shined. However, the fifth installation did not include batteries and it was discovered that the solar panels did not provide enough amps to start the unit after being down overnight. The solar panels and battery bank designs are based on the energy requirements for each individual application. **Figure 3** shows a solar array installation having 64 square feet of solar panels on a LVPS in the Farmington, New Mexico area. Depending on the horsepower requirements, some systems have more solar panels than others.

The 12-volt battery banks use six to eight batteries hooked in series. Later installations have utilized a 24-volt system. In 2007 some of the batteries installed in 2003 have had to be replaced. Usually the solar panels are installed in a large array and mounted on a sturdy pole, high off the ground to provide an unobstructed view of the southern sky.

Several installations have included sun tracker system, which follows the sun and optimizes the solar panels' collection of light. These tracker mechanisms involve a gas piston system and Freon gas sensor, which allows the solar panel array to follow the sun across the sky during the day. Approximately one hour of daylight is required to re-orient the tracker and array of panels to face the rising sun.

New advances in GPS tracking technology have provided a security option for the solar panels. Microchips can be installed in the solar panels in case they are unexpectedly removed from the well location, the solar panels can be tracked to their new location and "reclaimed". If security of the solar panels is a concern, then the GPS tracking technology can be added during the initial design.

PUMPING UNIT

The LVPS pumping unit design is based on a conventional type of pumping units – only to a much smaller scale. **Figure 1** shows one of the most common sized units having a non-standard API Pumping Unit Description of C-8-12.5-28. The gearbox rating is 8,000 inch pounds, the structure rating is 1250 pounds, the maximum stroke length is 28 inches and the current stroke length is set to 20 inches.

Counter balance weights can easily be added to the crank to balance the net gearbox torque on the gearbox of the pumping unit. A protective cage surrounds the moving parts of the pumping unit to prevent injury during operation. The light weight of the pumping unit allows the entire unit to be easily moved on the cement base to align the horse head with the wellhead.

Figure 4 shows design plots of the required motor horsepower size for pump intake depths up to 3000 feet at 4.72 strokes per minute, SPM. For the C-8-12.5-28 a 1/3 horsepower or smaller DC motor could be used as the prime mover to provide power to the pumping units up to the pump depth limit of approximately 2800 feet. **Figure 5** shows other parameters and the pump displacement for standard sized LVPS for pump depths up to 3000 feet and a 36" stroke unit, with a 1 1/16" pump at 3,000' can be operated with a 1/3 horsepower motor but at 4.73 SPM will only have a 5 BPD pump displacement. Under the same pump displacement at a pump depth of 2500 feet, with a 28" stroke length, the polished rod horsepower will be 0.07 and a 1/4 horsepower motor will be sufficient to drive the LVPS. Both **Figure 4** and **Figure 5** can be used to quickly size the DC motor and select the size of LVPS pumping unit for both pump depth and production rate necessary to remove liquid loading.

POLISHED ROD

A stainless steel liner allows the fiberglass rod string to pass through the stuffing box and a miniature polished rod clamp is attached to the polished rod (1/2" diameter fiberglass rod). The carrier bar is attached to the pumping unit through a bridle similar to a conventional pumping unit. **Figure 6** shows a close up of the polished rod, fiberglass sucker rod, polished rod clamp, and carrier bar. The stuffing box seals against the polished rod liner while another set of seals contain wellbore fluids by sealing against the outside diameter of the fiberglass rod string. In recent installations a lubricator was added to the wellhead to prevent scale buildup on the polished rod.

SUCKER ROD

A continuous 1/2" diameter fiberglass rod is used for the sucker rod string in these LVPS, whether Solar powered or Hybrid. The ½ inch diameter fiberglass sucker rods weigh about one pound per 20-foot length of the rods. This size fiberglass rod has a tested maximum tensile strength of 72,500 psi or maximum 14000 pounds of pull on the ½ inch diameter fiberglass sucker rods. **Figure 7** shows the rod being run into the well from a spool rig on a trailer, utilizing a stand to guide the rod into the well. All installations to date have included rubber cups applied to the rod and spaced about 50' apart. The purpose of these cups is to catch any solids that settled down in the tubing during idle times. The guides are split so that they are applied to the rod and the split is glued back together. On the rod strings pulled to date have only moderate wear has been seen on some of the guides.

A special adapter is used to connect the fiberglass rod to the top of the pump. This adapter has holes perpendicular to the rod, which allow holes to be drilled through the rod. The shear pins are inserted through the fitting and the pump's pull rod is bolted to the fiberglass rods. The quantity of shear pin designed into the connection are sufficient to carry more than 3 times the maximum expected fluid load the pump will apply to the rods. In a 1650' well, the combined static fluid load and rod weight is less than 900 pounds when using a 1 1/16" pump. In hybrid systems, where the fiberglass rod must be attached to a conventional polished rod, a similar adapter will be used at the top of the rod string. **Figure 8** shows both the original cup type plunger design and the insert conventional spray metal plunger design. On top of each plunger is the adapter where the fiberglass rod and shear pins connect the rod string to the pump.

FLUID LEVEL AND DYNAMOMETER MEASUREMENTS

Figure 9 shows the acoustic trace generated to determine the distance to the fluid level down the casing annulus. The acoustic pulse traveled down the casing annulus reflecting signals back to the microphone from changes in annular cross-section of the well bore from the tubing collars, the perforations, and the liquid level. Analyzing the acoustic reflection from the tubing collars spaced on average of 33.708 feet apart, determined that the acoustic velocity of the gas in the casing annulus to be 1440 ft/sec typical for a 0.55 specific gravity high methane content hydrocarbon gas. The reflected compression (down kick) labeled LL on the acoustic trace is identified at 1.89 seconds indicates the depth to the top of the liquid level is 1357 feet from the surface. An anomaly in the annulus above the liquid level detected at a depth of 1307 feet, as indicated by a strong reflected rarefaction (up kick) on the acoustic trace, is the top of the perforated interval. The fluid level shows the well to be unloaded with the liquid level at the pump intake depth set close to the bottom of the perforated interval and the flow of gas from the formation is not restricted due to backpressure on the formation due to liquid loading.

Dynamometer[1] data was acquired using a horseshoe load cell mounted between the polished rod clamp and carrier bar of the LVPS, **Figure 1**. Dynamometer card in **Figure 10** show the pump filled with fluid and **Figure 11** shows the pump 36% filled in a pumped off condition. **Figure 10** is stroke number 2 collected immediately after the well had been shut down for 30 minutes, just enough liquid had collected at the pump intake to fill the pump for only 4 strokes and then the well pumped off. The full pump displacement was equal to 0.8 cups per stroke of liquid volume filling the pump barrel and volume was calculated using the 12.7-inch effective pump stroke length. When well pumps off to a near constant 36 % pump fillage, the effective pump stroke length is 4.8 inches with a corresponding 0.3 cups per stroke liquid displacement. After the first 4 strokes were acquired 83 additional pumped off strokes were acquired, and it was observed that no liquid was discharged into the tank during any stroke after pump off occurred. It was concluded that **Figure 12** shows the amount of leakage between the plunger and barrel partially refilling the pump with 0.3 cups of liquid per stroke and the net full pump displacement per stroke is 0.5 cups (0.8-0.3). This observation based on pump cards fillage was substantiated at a later date by doing a simple test at the well with a quart container (4 cups in one quart). After the well had been shut down for many hours, when turned on it required 12 strokes to get a good flow of water into the tank. After funneling all of the water flow into the empty quart container it took just a little less than 8 strokes to fill the quart volume and a repeat test resulted in the same number of 8 strokes filling the quart volume. This test was important because the results helped prove that dynamometer analysis could be used to effectively weigh the 159 pounds of 1350 feet 0.5-inch rods buoyed in tubing fluid. Total Well Management[2] methodology can be applied to analyze a well even when a very small 556 pound fluid load is applied by the 1.0625 inch diameter pump to the 156 pounds of rods in tubing fluid. The performance of the LVPS can be accurately analyzed when using the horseshoe dynamometer load cell.

COMPARE DESIGN TO MEASURED DATA

A predictive program[3] using a damped wave equation model was used to calculate the results displayed in **Table 1**. There is good agreement between the predicted and measured values for this LVPS. The weight of rods in fluid, minimum polished rod load, and the polished rod horsepower were almost an exact match. The pump displacement and effective pump stroke are predicted to be slightly larger than the values calculated from the measured data, but the leaky pump is probably responsible for these differences. The predicted minimum load at the pump is –118 pounds and would result in buckling of the fiberglass rods. Only –18 pounds were calculated from the measured data and this –100 pound difference is primarily due to using the low friction poly-lined tubing to reduce drag on the rods. The 3264 in-lb measured net gearbox torque was similar to predicted torque and both values show the gearbox to be loaded to less than 40 percent of the gearbox rating. The measured peak polished rod load is greater than predicted by 100 pounds, and for a LVPS this load should be investigated and is most likely due to a slightly too tight stuffing box. Overall the predictive program does a very good modeling the performance of the LVPS and the resultant calculations from the predictive program are displayed in **Figures 4, 5, and 12**. These figures can be used to size the LVPS for desired pump depths and production rates. The predictive program does a good job modeling the 0.5-inch diameter continuous fiberglass rod string.

LIMITATIONS

Using the lightweight 0.5-inch diameter continuous fiberglass rods is the primary reason the LVPS has low polished rod horsepower and low surface loads. But the disadvantage of using 0.5-inch diameter fiberglass rods is the amount of stretch that occurs when even a small diameter pump applies the fluid load to the rods. **Figure 12** displays the fluid load applied to the rods by a 1.0625-inch diameter pump and the resulting inches of surface stroke lost to the static rod stretch used to pickup the fluid load. For example for a pump depth of 3000 feet the fluid load would be 1142 pounds and the rods would stretch 29.1 inches. Approximately 12 inches of effective pump stroke from a 1.0625-inch diameter pump results in a pump displacement of 10 barrels per day. By adding about 12 inches (12+29.2) to the static stretch on **Figure 12**, then 41.2 inches would be the minimum surface stroke length to get about 10 BPD production at a 4.72 stroke per minute pumping speed.

With no change to the existing system C-8-12.5-28 except going to the 28” stroke, the maximum pump depth is approximately 2300 feet in depth with a pump displacement of 6 bpd and a polished rod load of 1150 pounds (ignoring any unaccounted friction). At 2300 foot depth the loading on the gearbox would increase to about 6330 inch pounds of net gearbox torque. The polished rod horsepower would increase to approximately 0.1 and the 1/3 horsepower DC motor should be of sufficient size to drive the system.

At a pump depth of 3000 feet depth a larger pumping unit would be required, a 36-inch stroke length would result in 3 barrels per day pump displacement and all of that displacement would probably be lost to slippage past the cup plunger. A pumping unit with a 48-inch stroke would result in a pump displacement greater than 11 barrels per day.

A pump depth of 5000 feet is approaching the maximum depth for the 0.5-inch diameter continuous fiberglass rods, because the fiberglass rod would be loaded to 68% of their stress rating. With 100-inch stroke a C-30-30-100 pumping unit with a 1.1 HP motor 125 feet of 1.25-inch diameter weight bars would have an effective plunger stroke of 24 inches with a pump displacement of 15 BPD. Both poly-lined tubing and weight bars may be required, but a 5000-foot pump depth is probably the practical depth limit for these lightweight 0.5-inch diameter continuous fiberglass rods.

RESULTS AFTER SEVEN INSTALLATIONS

All installations were on wells in the Farmington, New Mexico area. On the first four installations fluid production rates ranged from 2 barrels to 10 barrels of water per day and gas production rates range from 60 MscfD (thousand standard cubic feet per day) to 180 MscfD. All four of these installations had pump-setting depths between 1300 feet and 1800 feet. Installation number five was different and involved unlined 1.25 inch tubing. This system was installed in July 2006 and the production currently averages less than one barrel of water per day. Installation number six was set below 2300 feet, but this installation was pulled and re-ran as the seventh installation in a different well. This seventh installation is powered by solar power and has recently had a speed change from 3 to 4.5 strokes per minute to increase production and lower the fluid level below the perforations. The volumes after the speed change are just less than one barrel of water per day and gas production rate exceeds 140 MscfD.

CONCLUSIONS

Throughout the country, the hottest topic in the artificial lift business is deliquification of gas wells. Many Operators are attempting to remove less than 10 barrels of liquid per day out of a well that is capable of producing as much as 150 MscfD or more of gas. The Low Volume Pumping System described in this paper brings forth a solution to producing minimal amounts of water from wells less than 5,000'. While not mandatory, the poly-lined tubing will reduce wear and corrosion related failures. The continuous fiberglass sucker rod string will resist corrosive fluids without damage.

Current applications utilize solar energy, but hybrid systems are an option if 110 volts are available. These systems are reliable based on the original installations are still operating after 3 years. The cost of operation is almost non-existent, when utilizing the solar power panels. Even the hybrid systems are very economical, due to using a 1/3 or 1/2 horsepower motor as the prime mover for the LVPS. At depths of 2300 feet the LVPS is capable of moving 6 BPD with a 1/3 horsepower motor.

Using a two man crew, this Low Volume Pumping System can be installed on a 1800 foot deep well in approximately four to five hours, with the use a continuous fiberglass spool trailer instead of a costly workover rig. A pump change requires the spool trailer; a qualified two-man crew and can take less time than three hours to complete the job. Utilizing the spool trailer for installations and pump changes allows the operator to quickly change out a pump for very low workover cost, keep liquid loading from reducing gas production and maintain a revenue stream without being shut-in waiting on a workover rig. The innovative LVPS technology is successfully being applied to produce liquid loaded shallow gas wells in remote locations where electric power may not be available.

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3. QRod Design Program Download, http://www.echometer.com/software/qrod/index.html

Table 1
Compare Design Calculations to Measured Data

Property	Measured	QRod
Weight Rods in Fluid - Lbs	155	156
Minimum Fiberglass Load - Lbs	-13	-118
Min Polished Rod Load - Lbs	131	133
Peak Polished Rod Load - Lbs	795	695
Net Geaxbor Torque - in-Lbs	3264	3000
Pump Displacement - BPD	7.9	8.42
Effective Plunger Stroke - in	12.7	13.5
Polished Rod HP	0.087	0.083

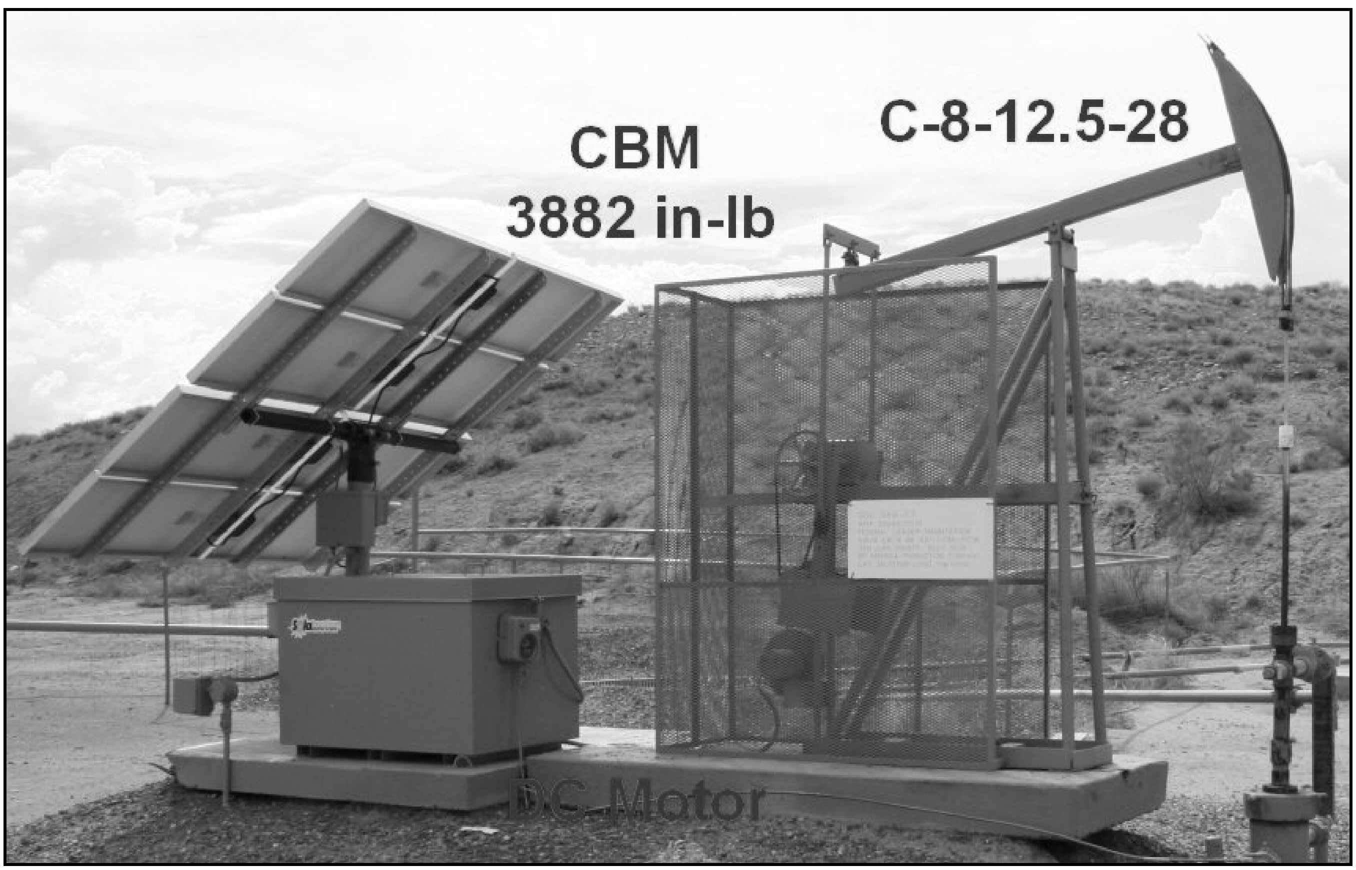

Figure 1 – Low Volume Pumping System

Figure 2 - Programmable Controller

Figure 3 – 8 ft x 8 ft Solar Panels

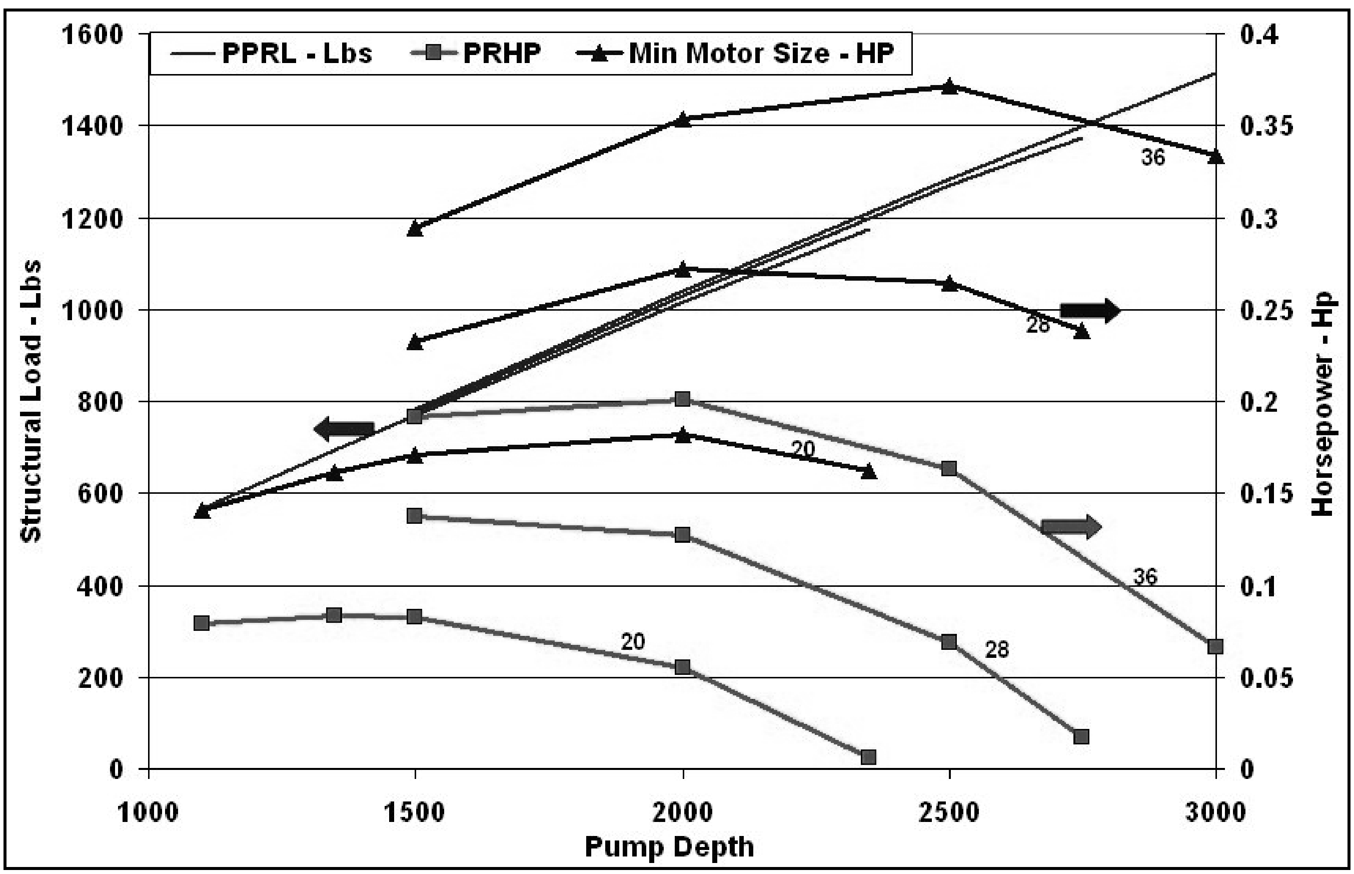

Figure 4 – Required Horsepower for Standard Sized LVPS for Pump Depths Up to 3000 Feet

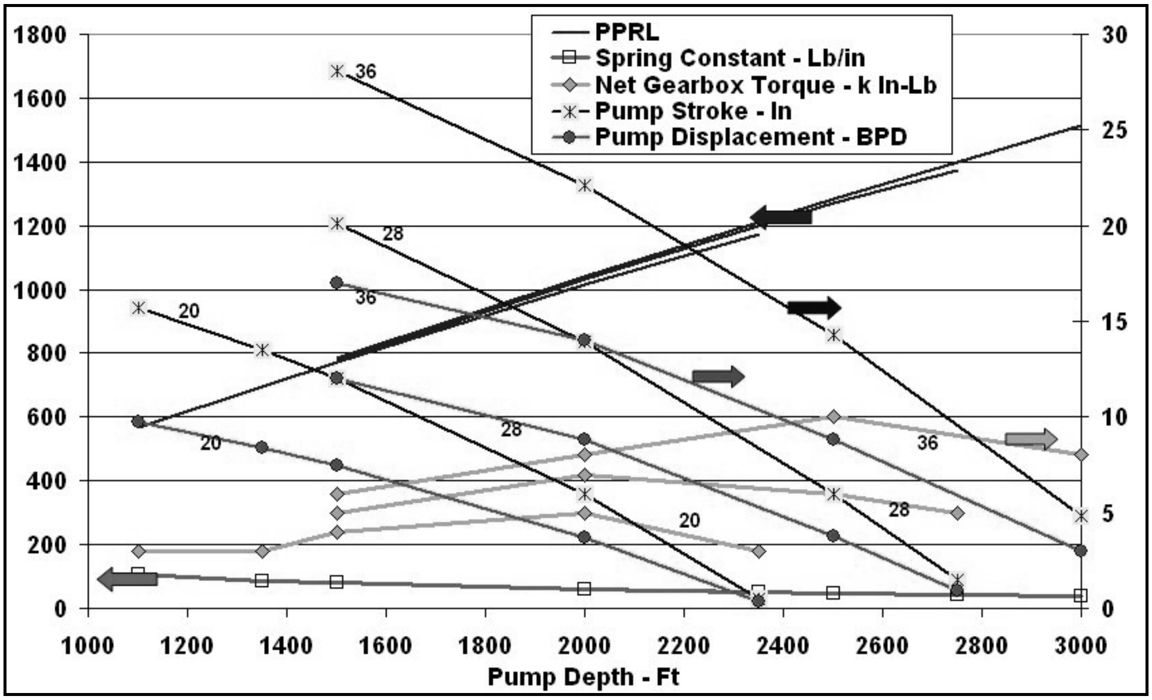

Figure 5 – Pump Displacement for Standard Sized LVPS for Pump Depths Up to 3000 Feet

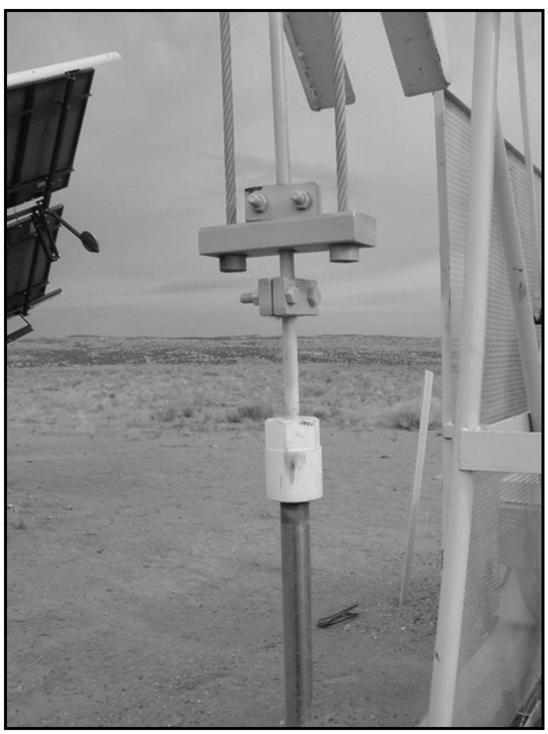

Figure 6 - Polished Rod, Fiberglass Sucker Rod, Polished Rod Clamp, And Carrier Bar

Figure 7 – Spooled Rods Being Ran in Well

Figure 8 – Compare Plungers

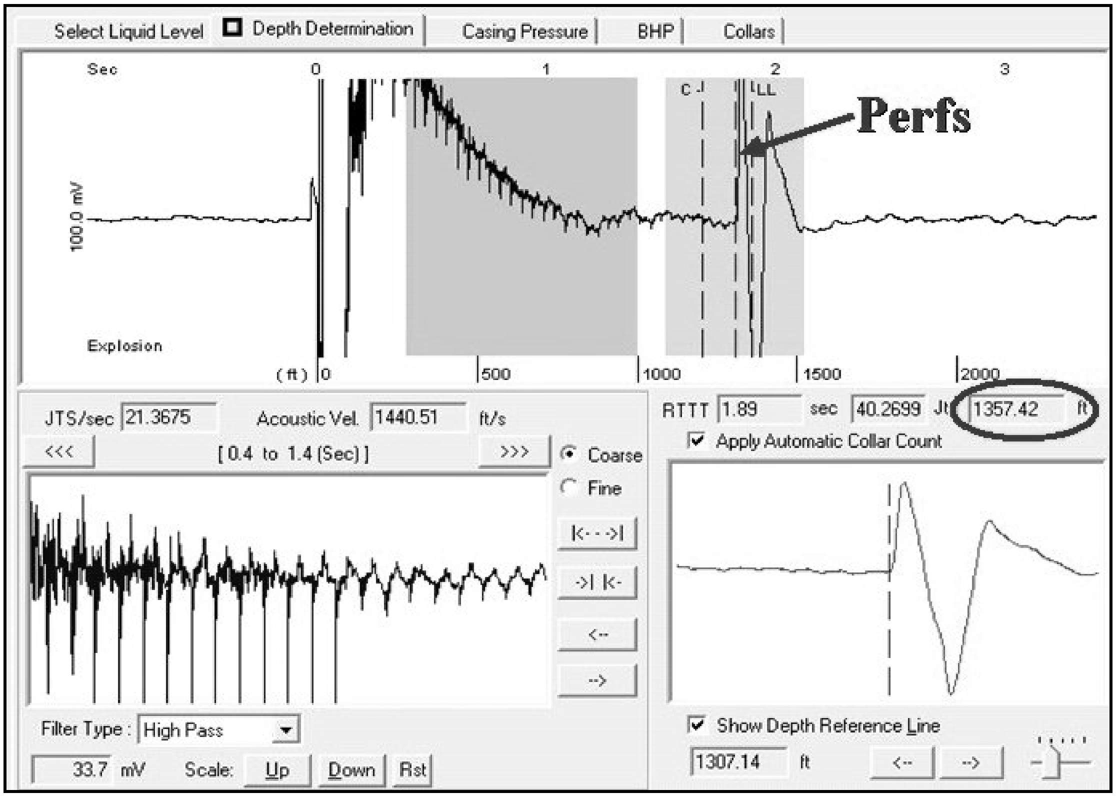

Figure 9 - Fluid Level at Pump Intake Below Perforations

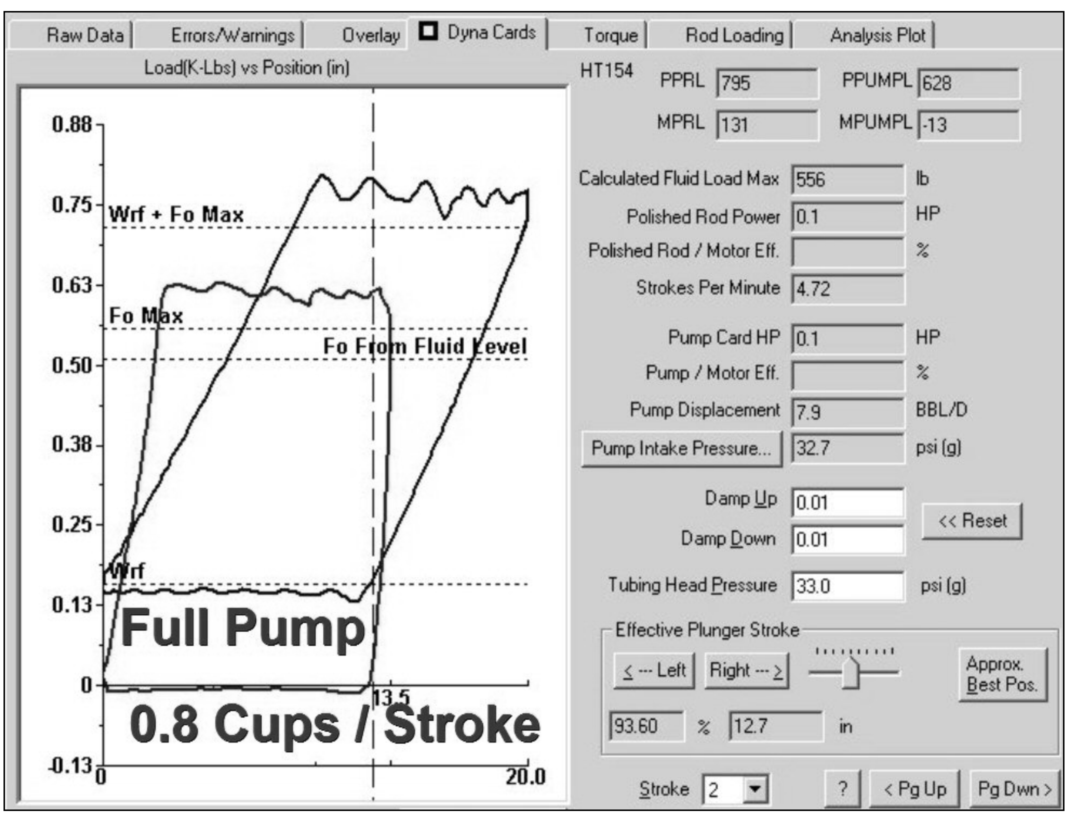

Figure 10 – Dynamometer Analysis ~ 0.087 PRHP, 4.72 SPM, 7.9 BPD Pump Displacement

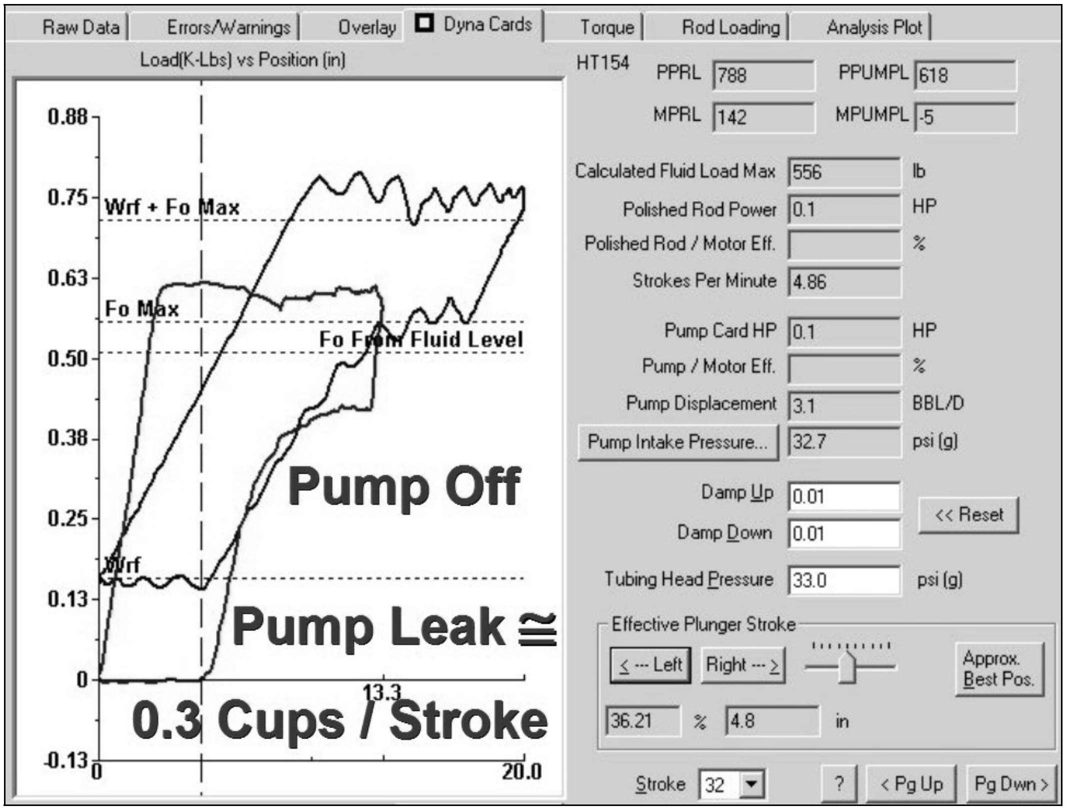

Figure 11 - Dynamometer Analysis ~ 0.055 PRHP, 4.86 SPM, 3.1 BPD Pump Displacement

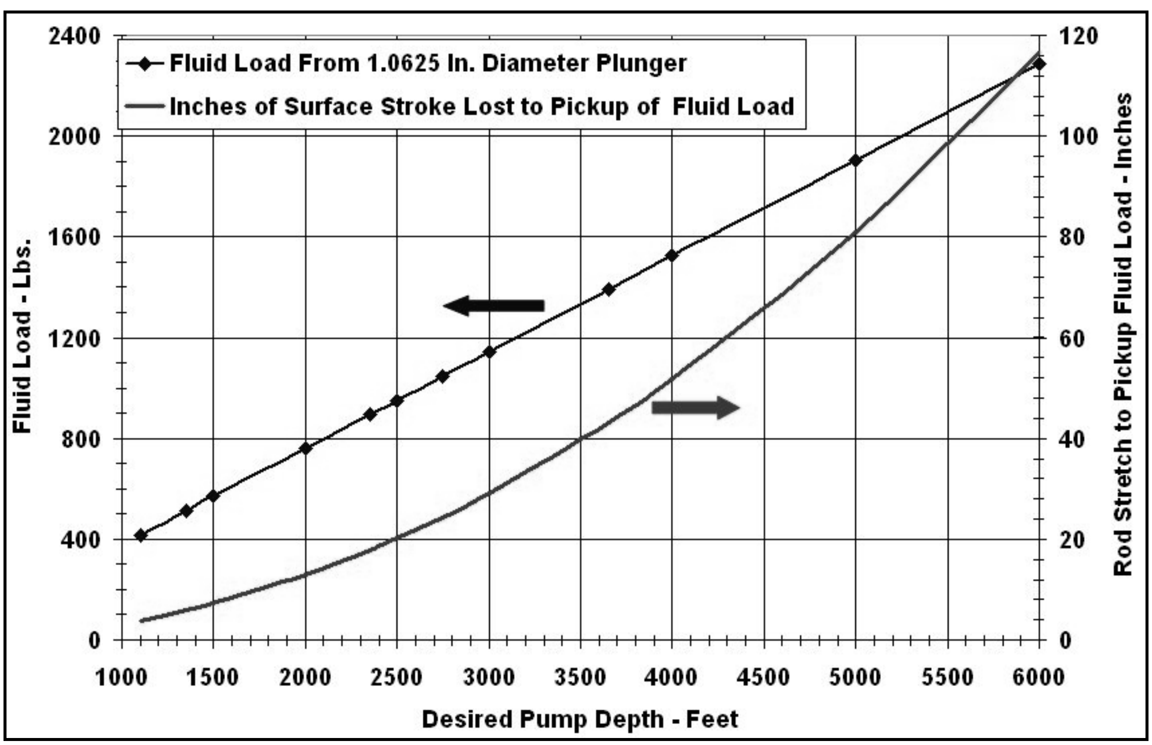

Figure 12 – Inches of Surface Stroke Lost to Stretch of Rods Picking Up Fluid Load