LEBRO PUMP SYSTEM- FILLING THE GAP AT LOW STROKES PER MINUTE

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ABSTRACT

A growing majority of oil and gas fields in North America are mature reservoirs or heavily depleted proposing many challenges for economic production. Especially in low pressure reservoirs, liquid loading, has become one of the main hurdles to overcome when attempting to economically produce natural gas. Deliquifying wells using artificial lift is a prominent method used to tackle these issues. This paper discusses the challenges faced in the Oil and Gas industry with an eye for deliquifying mature or depleted reservoirs. It explains the pros and cons of the beam pumping unit (pump jack) and the LeBro pumping system currently being tested; it compares the cost of installing a beam pumping unit vs. a LeBro pumping system; it talks about testing done on horizontal Coal Bed Methane wells, and future design and implementation on deep well applications (~12,500').

INTRODUCTION

Low reservoir pressures in mature gas fields, coupled with declining production rates and increased liquid loading[1], make economic production under these conditions difficult. As a gas well's production rate declines below the critical velocity[2], entrained water will begin to condense and fall back down the wellbore. This liquid loading increases the back-pressure on the formation face and consequently reduces gas flow from the reservoir. Produced water, coming from water-bearing zones or free formation water, is another common source of liquid loading which can hinder or completely kill gas production in a well. Without sufficient flow velocity, artificial lift is essential in preventing liquid loading; it can provide additional pressure to lift the fluid (i.e. gas lift) or provide mechanical assistance (i.e. downhole pumps and plungers) to help unload liquids.

When considering conventional rod pumped wells, well debris and gas interference problems are common. Well debris, which can be iron sulfide, salt, carbon, rust, formation fines, sand, etc., tends to settle on the downhole pump when the beam pumping unit is intermittently shut down due to a pumped off[3] condition. If the accumulation of this fill is large enough, pump trouble may ensue. Gas interference can cause incomplete fillage of the pump, leading to fluid pound and greatly reduced equipment life. Ideally, one would like to install an artificial lift system that is able to pump continuously without over-pumping the wells.

Historically, beam pumping units have been a common approach used to deliquify wells. However, in fields with low reservoir pressure, this can be a challenge. Beam pumping units are most effective when used to deliquify wells with relatively high fluid volumes (>60 BPD). Due to the declining nature of mature reservoirs, fluid levels have decreased to a point where beam pumping units are less efficient. This is due to the cost of the unit, installation cost, and the power needed to operate them. The low fluid volume also requires additional cost for peripheral equipment parts to slow down the beam pumping unit (i.e. jackshaft, high speed wiper, Variable Speed Drive (VSD), etc.),

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[1] **Liquid loading** is the inability for a well to lift the fluids associated with gas production to surface - SPE 107467.

[2] **Critical gas rate** is defined as the minimum gas flow rate that will ensure the continuous removal of liquids from the wellbore i.e. the gas production rate below which the produced gas will no longer be able to lift the produced liquids. (Lea J.F and SPE 100590-MS).

[3] **Pumping-off** is the point where there is insufficient fluid above the downhole pump to accomplish flow past the standing valve and into the compression chamber of the pump.

which also decreases the pump efficiency due to slippage, resulting in an increase in operating expenses, thus reducing the economic viability of these units.

The LeBro Unlimited Stroke Pumping System is a pumping unit that has recently been placed in service and has shown to deliquify mature wells economically. This unit is cost effective and power efficient. The LeBro pump system has the versatility to work efficiently at low strokes per minute (SPM), pump continuously while handling moderate amounts of fluid (< 60 BPD), and adjust its stroke to accommodate fluctuations in fluid production. Furthermore, the LeBro pump system can be effectively used in a wide variety of wellbores, including shallow mature gas wells, horizontal Coal Bed Methane (CBM) wells, and it can be potentially modified for deep well (up to 12,500') applications.

COMPARING A BEAM PUMPING UNIT TO A LEBRO PUMP SYSTEM

Beam pumping units have been the backbone of artificial lift for many years. This type of lift method has proven its ability to lift high volumes of liquids efficiently at high strokes per minute (>6 SPM) and long stoke lengths. However, to accommodate lower fluid volumes at a minimum stroke length, the pump speed must be decreased to approximately 2-5 SPM. In order to accomplish this, the beam pumping unit needs auxiliary equipment which decreases efficiency due to slippage and other downhole issues. Current procedures include the installation of auxiliary equipment such as a VSD coupled with a timer to reduce the stroke per minute to < 5, pump-off controllers (POC) or jack-shafts. The jack-shaft allows a reduction in speed while the other equipment mentioned actually shut the unit down for a period of time. However, shutting the beam pumping unit down allows time for suspended fill to settle. The fill can potentially stick the downhole pump and cause costly workovers that decrease the full cycle well economics.

In contrast, the LeBro pump system, designed and distributed by NCX Incorporated (NCX), works efficiently at less than 8 SPM without the need of auxiliary equipment. By implementing non-counterbalance weight technology, the complete control of the rod string and the actual pump displacement can provide the ability to slow down the system to any time cycle (i.e. 1 SPM, 1 stroke every 2 minutes, or 1 stroke every 5 minutes). In addition, the LeBro unit can be set for the upstroke and downstroke to have different timings, allowing it to control and manipulate the pumping cycle more efficiently. A beam unit is unable to optimize the lift on the upstroke or the fall on the downstroke, because the upstroke and downstroke timing are slowed equally while using a VSD or jack shaft. The LeBro unit is designed to operate at lower velocities and within the limitations inherent to the hydraulic surface equipment (8 SPM or less) due to heating and loss of working fluid viscosity. For this reason, the LeBro unit is only recommended for wells where lower SPM are required.

Well specific optimization is very limited with traditional beam unit applications. In particular, the structural strength required for lifting a loaded rod string and complex gear box design on a beam unit, inhibits cost effective design modifications on a well by well basis. The only significant field optimization that can be made is properly matching the horsepower of the prime mover to the application. In contrast, the LeBro pump system's 3 ¼" x 54" stroke actuator is designed to accommodate 10 or 12 foot pumps and has a wide depth and weight capability range. This actuator replaces beam pumping units from sizes 15 to 114; resulting in the ability to design the hydraulic unit to match the horsepower demand of each individual well.

Another feature of the LeBro pump system is it does not require a stuffing box. Instead, a hydraulic drive actuator (Figure 1) is connected to the wellhead through a hammer union mechanical seal arrangement which is able to prevent outside wellhead leaks (Figure 2). The benefit of this mechanical seal arrangement is that, in case of seal leakage (i.e. if end gland seals are damaged or worn); the loss of any hydraulic fluid is confined to the inside of the wellbore rather than the outside of the wellhead. Additionally, the end gland incorporates easily replaced threaded wear guide inserts which prolong the seal life and prevent end gland or rod damage in a side load condition (Figure 3). Furthermore, a low liquid level sensor is installed in the hydraulic fluid reservoir (on skid) to shut-down the equipment when it detects a low level condition in the hydraulic fluid reservoir tank. Thus, the shut down of the equipment will minimize any probable hydraulic leakage into the wellbore.

In addition to having a small environmental footprint, the LeBro actuator has less external moving parts (no counter balance) than those associated with a beam unit, making it safer to operate and easier to maintain.

Table 1 lists the pros and cons of a beam unit vs. a LeBro pump system, specifically targeting low liquid producing gas wells at low SPM (i.e. 3 SPM or less and with continuous pump action).

COST COMPARISON

Table 2 shows a cost comparison between a beam unit and a LeBro pumping system. This cost comparison includes expected preventative and corrective maintenance issues encountered on each system.

As seen in Table 2, there is an initial cost reduction in excess of 50% and an estimated 60% decrease in annual operating expense of the LeBro pumping system versus the beam pumping unit.

CASE STUDIES

Based on historical beam unit performance, it was evident an alternative artificial lift option needed to be evaluated for use in low pressure reservoirs with liquid loading. The following case studies present findings from using the LeBro pump system.

Case Study #1

The Texas Hugoton field is part of the greater Kansas Hugoton field. The field extends through the Panhandle of Texas and up into Kansas. The Texas Hugoton is a gas field, dolomitic reservoir, and was first produced in the 1920s with rates of 1-6 MMCFD. After 80 years of production, this field is now in its mature phase with average production of 50-150 MCFD. Individual wells' current rates range from 5 to 200 MCFD. The wells produce mostly dry gas and, because of the low rates, are subject to liquid loading. The field is a mix of cased and open-hole completions, therefore the water source could be coming from free formation water or a water-bearing formation.

BP's first trial was on the Bywaters Estate #2-399 well, which forecasted to make about 20 MCFD, with an initial rate of 60-80 BWPD and leveling off at 10-15 BWPD. Therefore, it was important to find an artificial lift system that could be flexible enough to lift large amounts of liquid initially, and then later be slowed to a lower SPM while maintaining efficient and continuous fluid movement. Due to the long T&A'd period (1998-2008), one of the main concerns about reactivating the well was the unpredictable response. Therefore, a low cost artificial lift system with a simple installation was needed, and if necessary, the ability to move the equipment to a different location at low cost.
Although the well was expected to produce more than 50 BPD of fluid initially, NCX designed a LeBro pump system to lift a maximum of 50 BWPD, estimating the initial liquid production would quickly decrease below 40 BWPD.

A 54" stroke was installed at an initial rate of 40 BPD at 4 SPM. After a month, the well was still making in excess of 40 BWPD with only 5-8 MCFD of gas. As a result, the stroke was increased to approximately 6.5 SPM, with a lifting rate of 55 BWPD, and continued to operate for another month. Once again, the gas production did not increase, however the LeBro pump was able to perform above design parameters (40-50 BPD). The LeBro pump lifted 55-60 BPD at 6.5 SPM and had the ability to lift more if stroke would have been increased to 7-8 SPM. After testing the well, it was plugged and abandoned. This was due to the cost of hauling large amounts of liquid every day, without the benefit of increased gas production.

The next well tested with the LeBro skid was the Gorman JMA #1. This well is under an irrigation system adding an extra degree of complexity to the testing of the pump system. The LeBro pump system proved to be very mobile and cost effective due to the small size of the unit. To date, there is no information on the Gorman JMA #1, as the move of the LeBro pump occurred at the writing of this paper.

Case Study #2

Pioneer Natural Resources (PXD) has installed three LeBro pumping systems to date, and the results of these are included in this case study. All of the wells produce from the Red Cave formation in the West Panhandle Field of Texas. The Red Cave formation is a Late Permian (Leonardian) sabkha complex with productive tight sand lenses. A heavy oil rim is present along the southern, western and northern margins of the West Panhandle field. Many of PXD's Red Cave wells in the western part of the field experience liquid loading and have extremely low flowing pressures (~14 PSIA).

PXD installed the first LeBro pump system on the Bivins 123R. The well was drilled in 2002 with an initial sustained production rate of ~100 MCFD. Initially, it did not produce high amounts of fluid (approximately 10 BBLS per month), but after 4 years, fluid production steadily increased to 2-3 BBLS of fluid per day. The large amounts of fluid being produced caused production to decline rapidly to ~10 MCFD. In order to prevent liquid loading and sustain production, this well needed to be swabbed once every 2 months, making it very expensive to maintain. When the well was swabbed and the liquid was removed, production would spike up to 60 MCFD but then rapidly decline once liquid began to fill the wellbore.

One of the unique challenges faced when evaluating this project was PXD does not own the oil rights in the Texas Panhandle; therefore the gas and fluid produced had to have a Gas to Oil Ratio (GOR) above 100,000 (e.g. 100 MCF per 1 BO). Consequently, it was essential to ensure gas production was high enough to offset any oil production and remain above the required GOR value. Otherwise, in accordance with the Texas Railroad Commission (TRCC), it would be considered an oil well and require PXD to shut the well in. The fluid collected while swabbing was approximately 20% oil, so it was critical to have a significant uplift in gas production to guarantee a GOR above 100,000.

The LeBro pump system was installed in March of 2008 and production increased drastically peaking at 328 MCFD. A 54” stroke actuator was set at an initial rate of 30 BPD at 8 SPM. In May 2008, the pump stuck due to very thick oil (~23 API gravity oil) and had to be replaced. Since this repair, production has leveled off at 60 MCFD (Figure 4) with a GOR well above 100,000. Currently, the well is treated with 10 BBLS of condensate every other week to treat for asphaltene and prevent pump damage downhole. It is also treated with 10 BBLS of fresh water every other week to mitigate salt problems. Fluid production has declined to 5 BPD and currently the system is set at 1.5 SPM. When the weekly batch treatments are performed, the speed of the pump is increased to 8 SPM. This is done to pump off the fluid being introduced into the wellbore and prevent liquid loading.

The second LeBro pump system was installed on the Bivins 139R. This well was drilled in 2006 with a sustained production rate of approximately 6 MCFD and produced approximately 7 BBLS of fluid per month. Although it did not produce significant fluid volumes, it was assumed that low reservoir pressures, combined with liquid loading, were the main factors involved in the well’s poor performance. When the well was swabbed, production increased to 26 MCFD, which when compared to the uplift gained on the Bivins 123R during swabbing, provided high hopes for positive results.

A 54” stroke actuator set at an initial rate of 30 BPD at 8 SPM was installed in mid June of 2008 and production did not increase as expected. Production peaked at 30 MCFD and rapidly declined to a mere 11 MCFD (Figure 5). This small increase in production was not enough to overcome the GOR hurdle and the unit was removed after six weeks on location. Although the LeBro pump system performed as expected, reservoir performance was not sufficient to consider this a successful project.

The third LeBro pump system was installed on the Bivins 86R. This well was drilled in 1979 with a sustained production rate of approximately 275 MCFD. There are no records of the amount of fluid the well produced initially. The Bivins 86R was TA’d from 1998 to 2007. When put back on production in 2007, this well produced approximately 5 MCFD. Workovers discovered major salt problems downhole, therefore freshwater was dumped to alleviate the issue and increase production. After large amounts of salt and water were recovered from the wellbore, production would spike to 150 MCFD after a cleanout, but unfortunately it declined very rapidly.

The unit was installed in July 2008 and production peaked at 280 MCFD. A 54” stroke actuator was set at an initial rate of 30 BPD at 8 SPM. In November 2008 there were problems with the temperature switch on the hydraulic unit. The switch was replaced under warranty and there have not been any more problems encountered.

Currently, the well is treated with 10 BBLS of fresh water every week to mitigate salt problems. Fluid production has declined to 10 BPD and currently the system is set at 2 SPM. When the weekly batch treatments are performed, the speed of the pump is increased to 8 SPM. Gas production has leveled off at 110 MCFD (Figure 6). Unlike the Bivins 123R and the Bivins 139R, this well produces nearly 100% salt water, therefore the GOR issues did not have to be addressed.

The major cost associated with installing a LeBro pump in the PXD Texas Panhandle field is running electricity to location. Due to the failure with the Bivins 139R and high electric prices, NCX designed a test LeBro pump system, powered by propane and easy to transport. Currently wells are tested for 1 month time periods to observe the uplift in production and to ensure the GOR will be high enough to merit a permanent LeBro unit on location.

HORIZONTAL COAL BED METHANE (CBM) APPLICATION

Case Study #3

In the Arkoma Basin, Devon Energy produces from shale, coal, and sandstone formations. The coal formations, primarily Hartshorne, are being tapped from two fields, Enterprise and Rattlesnake. The Hartshorne Coal formation averages 5' of thickness across the fields. Drilling began in late 1994. The wells drilled during that time were shallow (<2500' TVD) vertical wells. The IP on these wells averaged <100 MCFD and 3-10 BWPD. In 2002, beam pumping units were installed on the vertical wells to alleviate liquid loading issues. In 2003, horizontal drilling began in the fields. Lateral length ranged from 1500'-2800'. The horizontal wells had IPs in excess of 600 MCFD and 50 BWPD. The water rate quickly died down to 5-10 BPD. Typical decline on the horizontal wells is near 30%, but can reach as high as 60%. The water rate drops significantly as the gas rate declines. In 2007, drilling had ceased and production numbers were falling rapidly due to falling pressures (40 PSI and below) and liquid loading.

As a result, Devon began installing beam pumping units on the horizontal wells. The beam pumping units helped to relieve the liquid loading and lessen the decline of gas production. The Prater 1-14, Figure 7, is an example of a horizontal well with a beam pumping unit installed. Within one year, 39 beam pumping units were installed on horizontal wells and field decline had decreased by 10%.

While production numbers were showing improvement, mechanical problems were brewing. The beam pumping units installed, CH57-109-42BB, operate most efficiently at 11-12 SPM. Low water rates and "high" pumping speeds consistently left the wells in pumped off conditions making room for coal fines to plug the pumps. In some instances, pump changes occur once a week and in others, once a year, as a result of the build up of coal fines. Also, most of the wells are not close to electricity sources so the beam pumping units are run using 18 HP Kohler engines, which do not fare well in cold weather. Typically, the coal wells have a hard time coming back after being shut in for any amount of time, therefore, pump off controls were not considered the best option. Also, due to the large amount of coal fines, the stuffing box rubbers need to be replaced every few days. Not only is it time consuming and costly, but it makes a dirty job for the lease operator.

In contrast, the LeBro Unit offers lower pumping speeds, constant pump action, elimination of the stuffing box, and resistance to cold weather. The LeBro Unit can pump at speeds lower than 1 SPM allowing Devon's wells to avoid running in a pumped off condition. The consistent pump action allows for less build up of coal fines. If coal fines were to build up, the pump could be long-stroked without the use of a rig, saving Devon hundreds of dollars per occurrence. Also, the elimination of the stuffing box saves the company time and money spent changing stuffing box rubbers almost daily.

Devon installed the first LeBro pump system on the Denny 1-2 in January of 2009 and production increased peaking at 429 MCFD (Figure 8). A 54" stroke actuator was set at an initial rate of 11 BPD at 1.25 SPM. Initially the well produced approximately 5 BPD. Currently the system is set at 2 SPM and the well is producing 2-5 BPD.

During a recent ice storm, while beam pumping units were going down one by one, the only issue stopping the Denny 1-2 was the absence of electricity (i.e. down power lines). The hydraulic unit was able to withstand the cold weather, while continuing to operate efficiently.

DESIGN FOR DEEP WELL APPLICATION

NCX has implemented the LeBro pump systems down to ~5700' in the Pennsylvania formation on multiple wells in the Texas Hugoton field. Their record shows success in lifting fluids at moderate depths (~5700'). BP is working with NCX to design a deep LeBro pump system for use at depths up to 12,500'. Table 3 shows the problems at an increased depth and the ways NCX was able to solve the problems. Designs for future deep well application of the LeBro pump system have been completed. The design will be tested as soon as a deep well candidate is identified.

CONCLUSION

The data collected from the case studies indicates the LeBro pump system does have an application for a depleted reservoir with low to moderate volumes of fluid, regardless of reservoir type. The LeBro pump system was successfully implemented in multiple Texas Panhandle Red Cave wells and Enterprise Coal Bed Methane wells. This demonstrates the LeBro pump system has the versatility to efficiently work at low strokes per minute, maintain continuous pumping while handling moderate amounts of fluid (< 60 BPD), the ability to adjust its stroke to accommodate changes in fluid production and the ability to manage coal fines.

It was identified that the LeBro pump system, at current settings, cannot be used at high speeds (> 8 SPM), because of inefficiencies due to friction and high temperatures that reduce the viscosity of the working fluid, or depths greater than 6,000'. A new design has been completed that may allow for applications at depths up to 12,500'.

Refer to Table 4 for a complete list of pros and cons and conclusions found for the LeBro pump system.

Table 1
Comparing and contrasting a beam pumping unit vs. the LeBro pumping system
(focusing on low SPM)

Beam Unit	**LeBro Unit**
• Pros o Reliable (good history) o Efficient at high SPM (> 5 SPM) • Cons o Not as efficient at low SPM o Not very power efficient at low SPM o High installation and maintenance cost	• Pros o High efficiency at low SPM (< 5 SPM) o Power efficiency greatly increased o Cost and preventative maintenance decreased o No outside moving pieces (safety) o Small environmental footprint o Height greatly reduced (irrigation systems) o Lower installation cost and ease of installation • Cons o Not efficient at high SPM o New technology o Very little history (~3 yrs)

Table 2
Cost, Maintenance, and Power Comparison between a beam pumping unit and the LeBro pumping system.

Beam Unit		**LeBro Pump**	
Equipment	**Cost**	**Equipment**	**Cost**
Lufkin 57-109-48	$27,000	Hydraulic skid w/ VFD 20 hp electric engine & actuator cylinder	$16,697
Piping and Labor	$1,500	Piping + Labor	$500
2"x1/2"x12" Downhole Pump	$3,000	2"x1/2"x12" Downhole Pump	$3,000
Transportation and setting of the beam unit	$6,500	Hydraulic fluid	$400
20 hp electric engine	$800	Change over	$185
VFD	$3,500	Hammer union	$75
Oil fluid and 250	$500	Hydraulic hoses	$1,000
Stuffing box	$500		
Building pump pad	$1,000		
Pump off controller with installation	$1,800		
Environmental kill	$300		
Total	**$46,100**	**Total**	**$21,857**
Preventative & Corrective Maintenance		**Preventative & Corrective Maintenance**	
Oil change/packing stuffing box (bi-monthly)	$300	Check hydraulic fluid level	$0
Bearings greased (monthly)	$150	Change oil (annually)	$400
Change gear oil (annually)	$150	Change hydraulic filters (every 2 months)	$40
Replace saddle bushings (3 to 6 years)	$2,800	Change seals (rare)	$50
Replace tail bushings (3 to 6 years)	$2,650	Repair actuator - worn shaft (rare)	$500
Replace wrist pin bushings (3 to 6 years)	$1,650	Replacement of whole cylinder (5 to 10 years)	$2,500
Other		**Other**	
Power consumption (annual electricity bill)	$1,920	Power consumption (annual electricity bill)	$1,200
Total Average Annual Upkeep & Maintenance	**$7,248**	**Total Average Annual Upkeep & Maintenance**	**$2,728**

Table 3
Obstacles NCX encountered when designing a LeBro pump system for use at increased depths (up to 12,500') and the ways they were able to solve the problems.

• **Obstacles**	• **Solutions**
o Weight of the rods plus hydrostatic	o Increase size of actuator accordingly to exceed lifting weight
o Weight applied to well head equipment.	o Use x-heavy fittings and insure well head is flange and not slip type
o Pump efficiency (possibility of slip in lower metal plunger)	o Decrease plunger clearance or increase fall rate
o Compressibility of well fluids.	o Allow additional hp and SPM for loss of pump displacement if high gravity oil
o Static stretch	o LeBro pump design stroke cycle results in less loss of static stretch
o Rod compression, normal loss of down hole stroke length and over travel	o Retaining static stretch reduces or eliminates rod compression
o Actuator friction and heat. Well deviation at surface	o Surface controls, proximity sensors, and replaceable wear guide to protect shaft and end glands. Adjustable soft shift hydraulic valves.
o Hydraulic system shock when valves open or close at higher fluid GPM rates	

Table 4
Pros and Cons of the LeBro pump system

• **Pros**	• **Cons**
o Artificial lift that works at low SPM at efficient working parameters o Cost effective o Energy efficient o Low maintenance o Easy installation o Lifts low volumes of murky fluid without pumping off o Solves height issues (irrigation) o Greatly decreases moving parts (safety) o Smaller environmental footprint. Stuffing box eliminated o Able to long stroke pump to clean up obstruction or fill (less rig time)	o Reliability. Not enough history (~3 yrs) o Not efficient at high SPM (>8 SPM) o Limited well depths until further testing

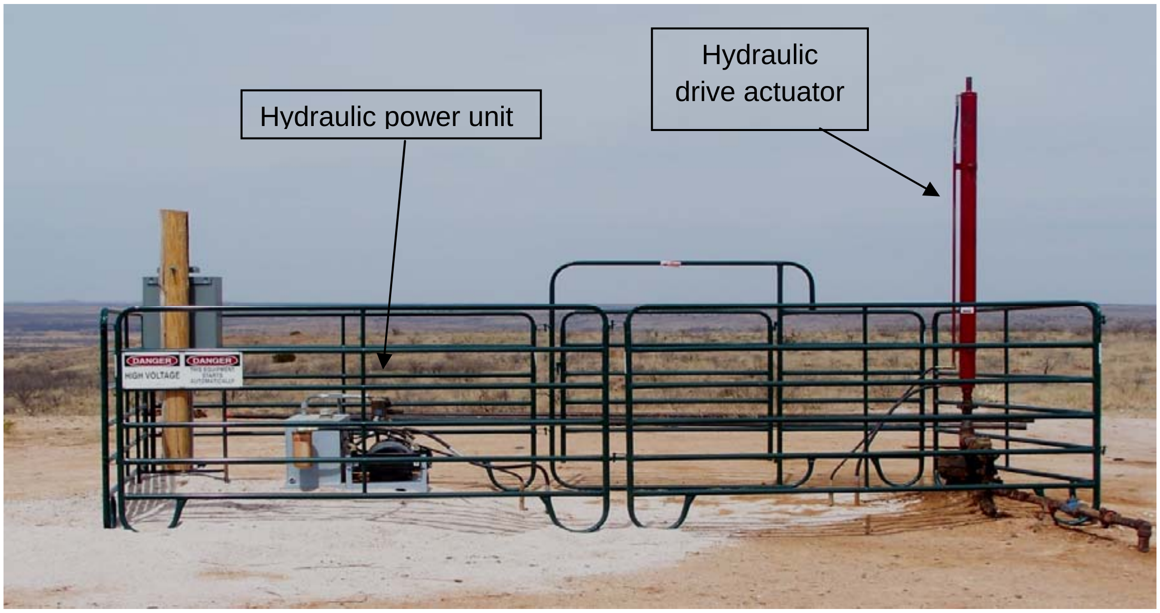

Figure 1 - LeBro Unlimited Stroke Pumping System illustrating the hydraulic power unit and the hydraulic drive actuator.

Figure 2 - Wellhead to actuator hammer union.

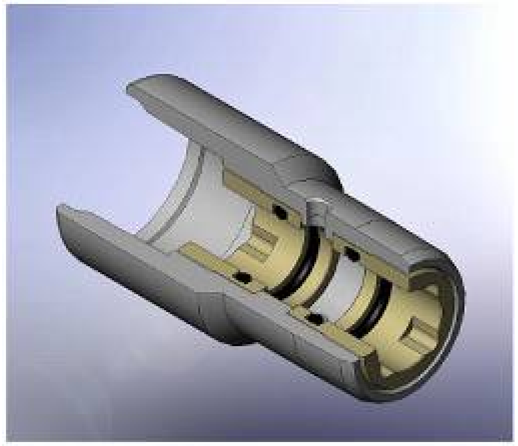

Figure 3 - LeBro Sealing Arrangement

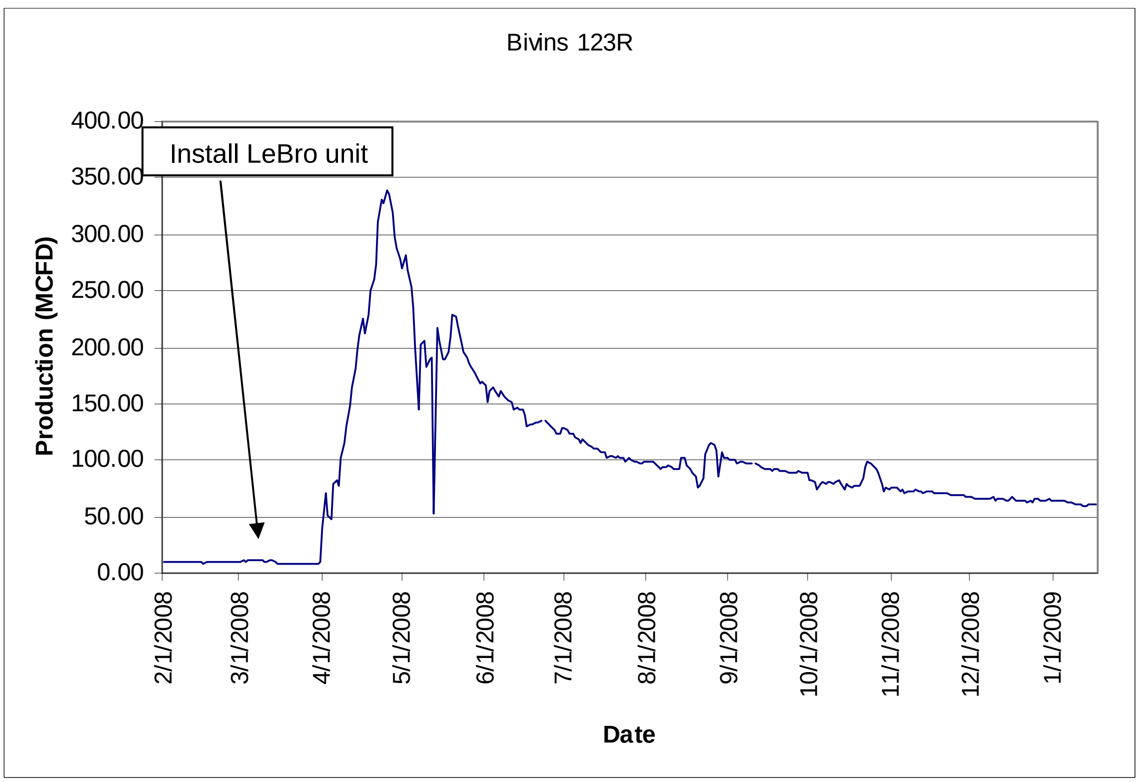

Figure 4 - Bivins 123R production curve illustrating the installation of the LeBro Pump System.

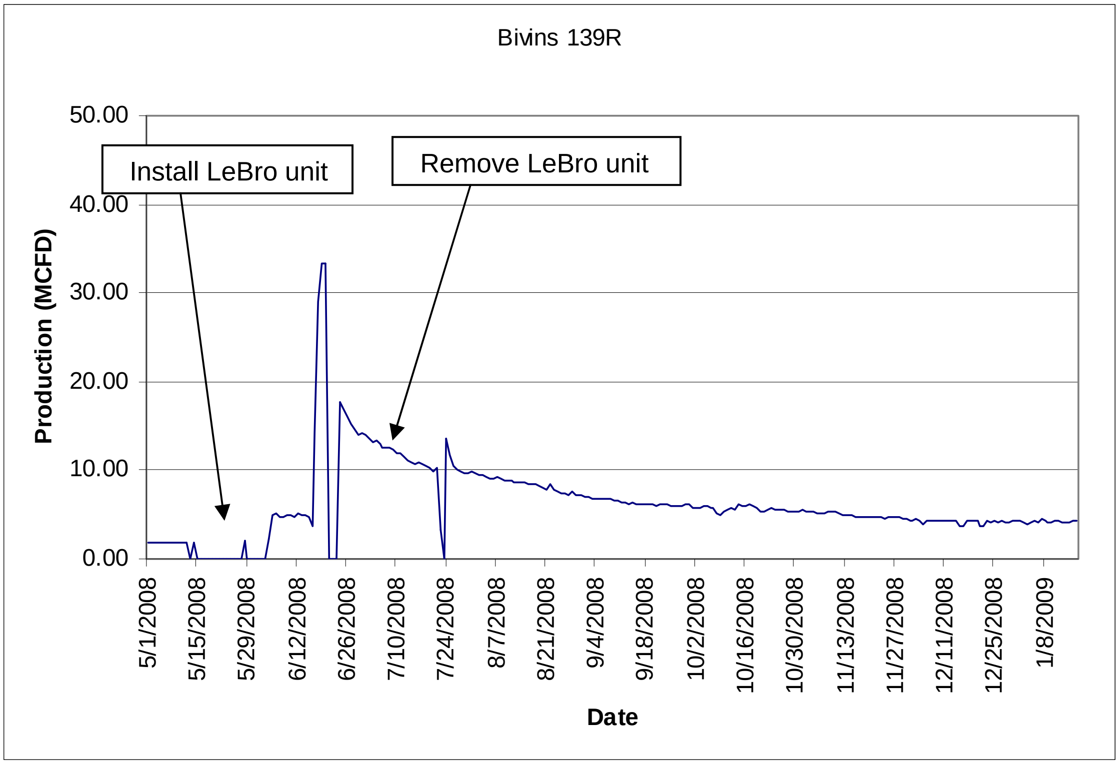

Figure 5 - Bivins 139R production curve illustrating the installation of the LeBro Pump System.

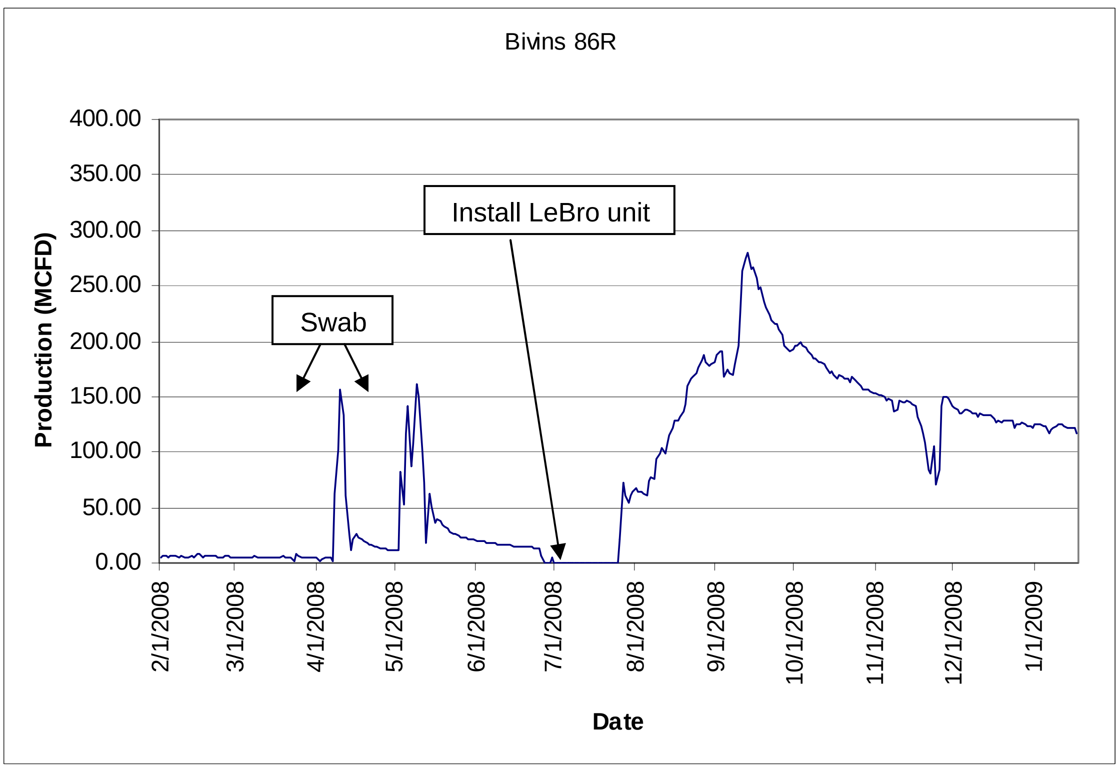

Figure 6 - Bivins 86R production curve illustrating the installation of the LeBro Pump System.

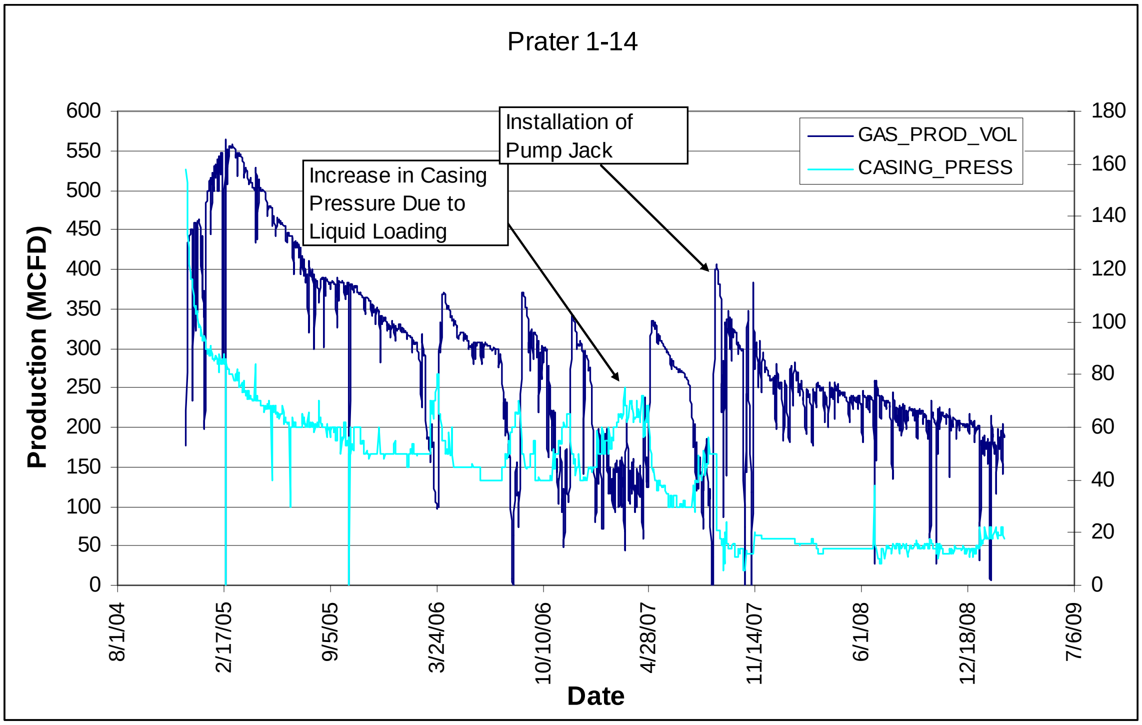

Figure 7 - The Prater 1-14 production curve – example of a horizontal well with a beam pumping unit installed.

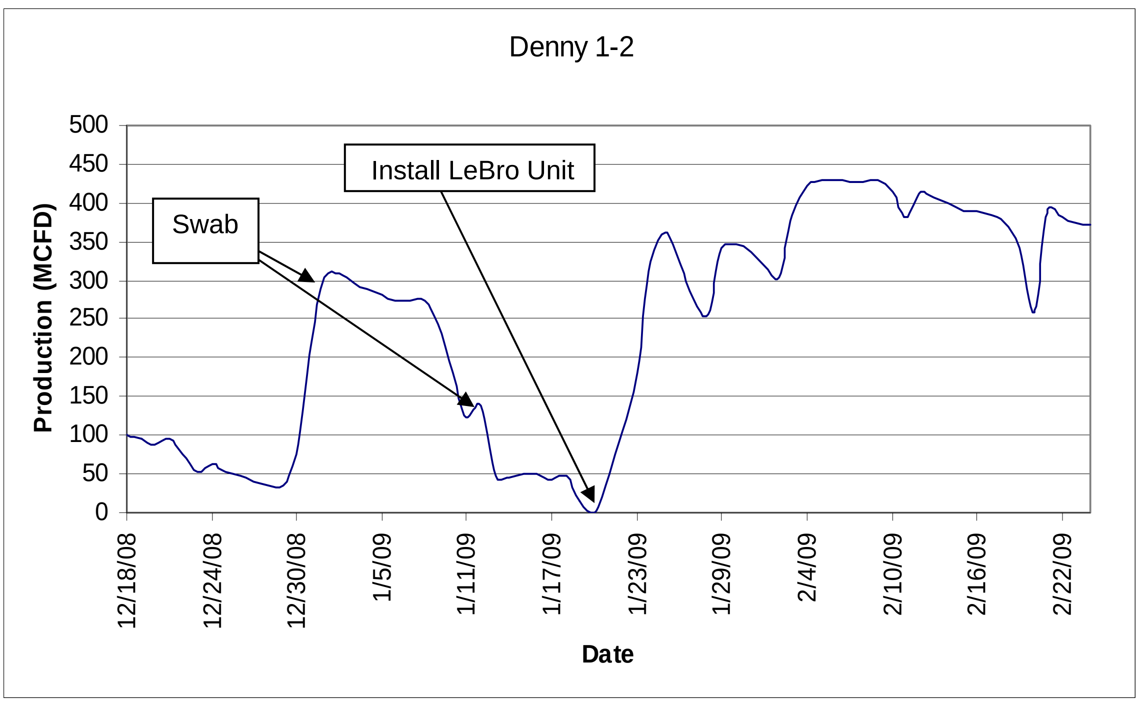

Figure 8 - Denny 1-2 production curve illustrating the installation of the LeBro Pump System.