Successful Implementation of the Low Maintenance Airlift Pump to Extend the Life of Stripper Wells

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Abstract

This report summarizes the evolution and testing results of the Airlift pumping system. System development has passed through four versions: Gen 1, Gen 2, Gen 3, and 3.1. The DOE grant only funded the development and testing of the Gen 2 version, but the Gen 2 unit was a crucial design bridge between the primitive Gen 1 unit and the sophisticated Gen 3 unit. The DOE grant covered the years 2000 to 2002, but this report analyzes the data collected from testing on all four versions across the years 1998 through 2003. A variety of Airlift units were tested in twelve wells. The overall reliability of the Airlift versus traditional pump jack technology was compared.

Although neither the Gen 2 nor Gen 3 demonstrated a reliable pumping system, the Gen 3.1 was designed to correct the flaws in these systems. Currently undergoing testing, the Gen 3.1 is operating with a reliability four times better and two-and-a-half times better in the time it requires to repair than standard pump jack technology. The high reliability and low maintenance required to operate the Airlift Gen 3.1 will make the Airlift the natural and economical choice to replace pump jacks on stripper wells.

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1.0 Introduction

As the primary oil reserves have played out in the old Trenton Oil field in the Midwest U.S., and other regions, small independent oil producing companies in the U.S. have difficulty producing oil using the traditional technology of pump jacks, down hole steel rods, steel tubing, and cups. Shallow stripper well production is generally uneconomic for several reasons:

- the low oil output of stripper wells (<10 barrels a day) provides less funding to pay labor costs for normal pump-jack maintenance
- pump jack equipment experiences significant wear-and-tear, leading to low reliability and significant downtime for repairs
- the corrosive chemical environment (including salt water and acids) of the shallow wells destroys the equipment

Even though a well may still be producing small quantities of oil, the well is capped because the cost to operate such wells has proven to be non-productive.

Starting in 1997, Energy, Inc. began development of a new oil pumping system. Called Airlift, the new pump featured off-the-shelf PVC construction and virtually no moving parts. It relied on pressurized air to force oil through a series of stages until reaching the surface. The design of the unit has solved the problems facing traditional pump-jack equipment, namely reliability and corrosion. As added benefits, the design was safer, environmentally friendly, and required less maintenance. Potentially, the Airlift unit would allow thousands of old abandoned stripper wells to become economically feasible again due to low operating costs.

The first version of the Airlift, later referred to as Gen 1, was tested from 1997 to 2000 in a few stripper wells. These earlier tests of the first version indicated the concept was sound, hence the current DOE grant was received in 2000 to take the technology to the next stage of success.

2.0 Executive Summary

The primary goal of the DOE grant was to retrofit standard oil wells with Airlift pumps to create an extensive test-bed of the technology. During the DOE grant period, Airlift units were tested in seven wells. Two versions of the Airlift were tested: Gen 1 and Gen 2. Knowledge gained during the DOE grant period led to the non-DOE funded development of the Gen 3. After the DOE grant period, testing started on the Gen 3 in two wells. The Gen 2 and Gen 3 were successively more sophisticated and introduced a series of technology improvements. These designs also introduced a series of unexpected problems, which were corrected in the Gen 3.1.

Testing focused on the reliability of the Airlift units. Logs were recorded of maintenance issues and downtime. These logs were compared to logs from traditional pump jack operation on the same leases. In this manner, the overall reliability of the Airlift versus the pump jack was compared. The summary results were as follows:

Table 1: Summary Results

Pumping System	Cumulative Days Tested	% Downtime	Avg. # Days Between Failures	Avg. Length of Failure
Pump Jack	8465	6.9%	90	6.2
Airlift Gen 1	1856	1.2%	265	3.3
Airlift Gen 2	1472	4.9%	113	5.5
Airlift Gen 3	1097	7.4%	78	5.8
Airlift Gen 3.1	583	1.7%	146	2.5

While the Gen 2 and Gen 3 versions were not successful in demonstrating a highly reliable pumping system, they were no less reliable than existing pumping technology. More importantly, the Gen 3.1 are operating with a reliability four times better (when comparing downtime percentage) and two-and-a-half times better in the time it requires to repair (when comparing average number of days down per failure) than standard pump jack technology.

The high reliability and low maintenance required to operate the Airlift Gen 3.1 will make the Airlift the natural and economical choice to replace pump jacks on stripper wells. As a result, stripper well lifetimes will be extended, unlocking more of the nation's oil reserves for production. Plus, the low surface profile and environmentally friendly design of the Airlift system will encourage more landowners to accept operating wells on their property.

Picture 1: An Airlift Gen 3 quietly operating at a test site.

3.0 Experimental

3.1 Goals

Primary: Retrofit oil wells with Airlift pumps to create an extensive test-bed of the technology.

Secondary:

- Install bottom stage sensors to indicate when the bottom stage is full or empty to optimize cycle operation.
- Create new installation equipment customized for Airlift pump installation.

3.2 Test Period

Originally, this grant was for a one-year period. It quickly became apparent that one year was not sufficient, so the grant period was extended to cover the two years from 5/17/00 to 5/17/02. All DOE funds were expended within this period and the DOE portion of the project officially ended 5/17/02.

In reality, directly related development and testing started before the DOE grant period and has continued beyond this period. In many cases, Airlift Gen 1 units that were already in operation were allowed to continue during the DOE grant period, and Airlift Gen 2 units that were already operating at the conclusion of the DOE grant period were allowed to continue.

This final report focuses on the two years of the DOE grant period, but also includes prior data from pump jack operation as early as 10/30/95, Airlift Gen 1 testing from 11/20/98 to 5/17/00, and subsequent data on Airlift Gen 2, Gen 3, and Gen 3.1 testing from 5/17/02 to 1/31/04. The cost of this additional research has been born solely by Energy, Inc.

See the timeline in Appendix A for a graphical overview of the wells tested, the test time periods, and the Airlift versions tested.

3.4 Location

During the DOE grant period of 5/17/00 to 5/17/02, Airlift units were tested on three oil lease sites: Stone, Lahr, and Wilson (see Table 2 and Figures 1, 2, and 3). (A fourth site named Ralston was considered, but eventually rejected because of the field's poor performance characteristics.)

Table 2: Testing Sites

Lease Name	Acres	Location	Wells Tested*
Stone	254	SW1/4, Sec. 14, T27N, R5E & NW1/4, Sec. 23, T27N, R5E Rich Valley Oil Field Wabash County, IN	#1
Lahr	159.8	NE1/4, Sec. 2, T26N, R9E Mt. Etna Oil Field Huntington County, IN	#3, #8, #9, #12
Wilson	80	E1/2, Sec. 14, T27N, R5E Rich Valley Oil Field Wabash County, IN	#1, #4, #5, #7

*Wells specifically under testing within the DOE grant period of 5/17/00 to 5/17/02. Data collected before and after the DOE grant period includes wells Stone #3, Lahr #5, and Lahr #6.

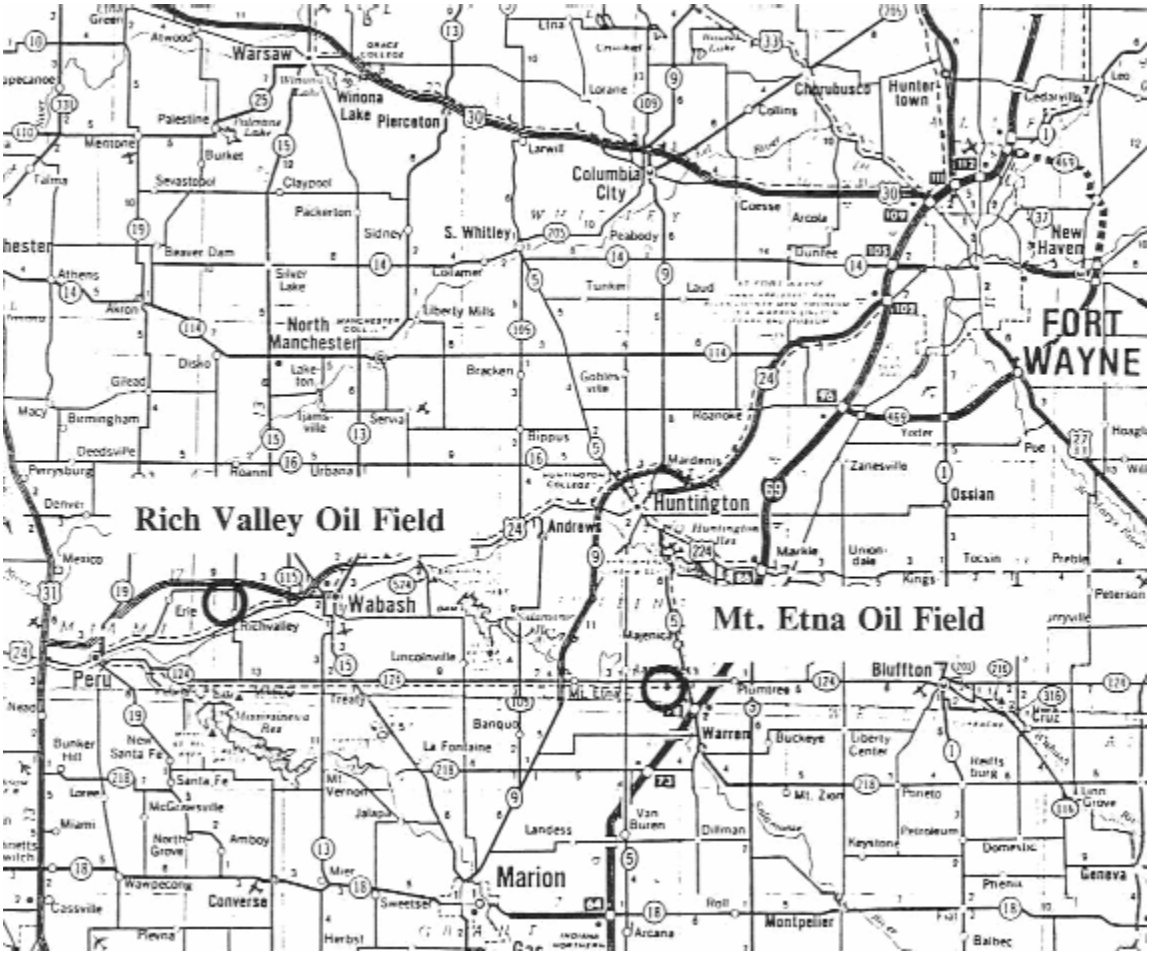
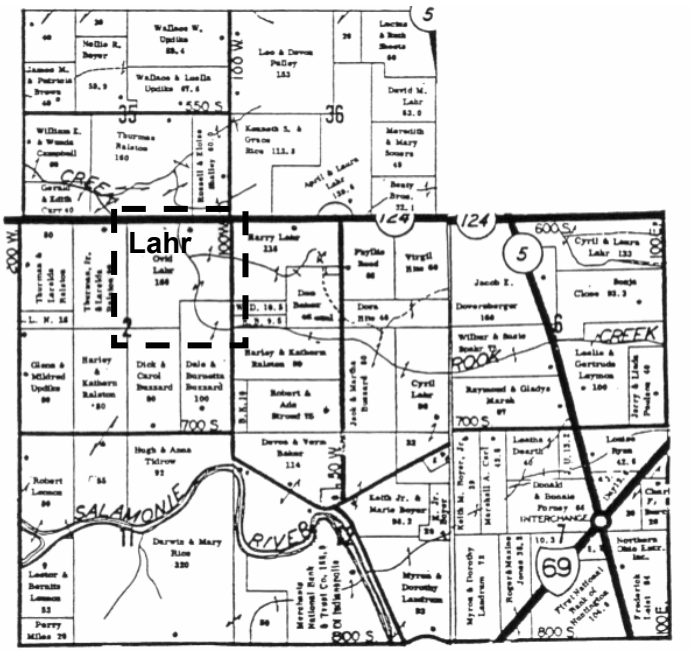


Figure 1: Location of the Rich Valley Oil Field (containing the Stone and Wilson leases) and the Mt. Etna Oil Field (containing the Lahr lease).



Figures 2: Map Showing Lahr Lease

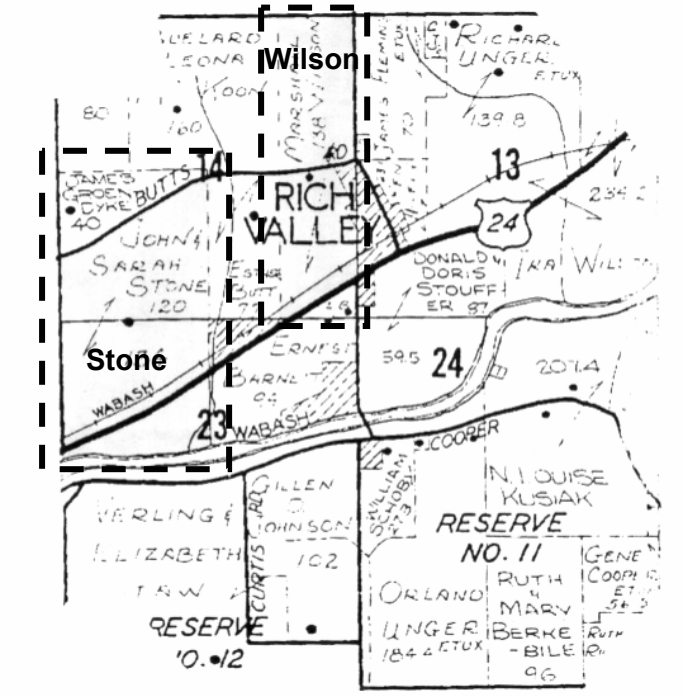


Figure 3: Map Showing Stone and Wilson Leases

All the wells have similar characteristics, hence they provide similar testing environments for all of the Airlift units. All of the wells were between 800 and 900 feet deep and accessed Trenton Formation oil at the interface of the Kankakee and Cincinnati Arch's. All wells were shallow stripper wells well past their prime, with the average well producing less than 1 barrel oil and several barrels of water a day. Originally, all of the wells were outfitted with traditional pump

jack equipment (see Picture 2). Each lease site includes a shared oil/water separation tank and oil storage tank. The surrounding environment is primarily farmland with a scattering of forest.

Picture 2: Pump Jack on Wilson #5

3.5 Procedure

3.5.1 Primary Goal: Test Bed of Airlifts

The primary goal of the DOE grant was to retrofit standard oil wells with Airlift pumps to create an extensive test-bed of the technology. During the DOE grant period, the Gen 2 version was developed and both the Gen 1 and Gen 2 were tested in seven wells. Independently of DOE grant funding, the Gen 3 and Gen 3.1 units were developed. Subsequent to the grant period, the Gen 3 and Gen 3.1 were tested in four wells.

Each oil well retrofitted followed a similar procedure:

- Remove downhole steel production equipment and pump jack
- Install air lines from the air compressor station
- Install well head control panels to operate the Airlift
- Install Airlift production equipment
- Start well production and adjust controls until reaching optimal production
- Monitor producing Airlifts several times weekly
- Maintain records on operation

Originally, the success criteria for monitoring were to be measurement of the oil output from individual, retrofitted wells. It was hoped that the wells with Airlifts would produce more oil and less water than the same wells when they had traditional pump jacks. Unfortunately, the oil outputs of all the individual wells on a lease combined into one holding tank, so prior data on pump jack output for individual wells was not available for comparison. Furthermore, the cost of installing a separate holding tank for each well was cost prohibitive, so no data was collected on individual oil output from Airlifts in each well.

Instead of measuring output, the success criteria was changed to focus on reliability of the Airlift units. Logs were recorded of maintenance issues and downtime (see Appendices B, C, and D for log records). These logs were compared to logs from traditional pump jack operation on the same leases. In this manner, the overall reliability of the Airlift versus the pump jack was compared.

3.5.2 Secondary Goals

The secondary goals of the project were not accomplished during the DOE grant period. The primary goal required more funding and effort than originally thought. An attempt to include sensors in the bottom stage of the Airlift units was abandoned after the electrical lines to the sensors kept snapping upon installation of the Airlift into the well.

During the grant period, an existing truck was reworked in an unsuccessful attempt to both enhance Airlift installation and remove conventional equipment, primarily through a provision to handle the Airlift support cable and adjustments in its boom. This initial attempt was found less time effective than existing methods. A second truck had minor modifications made, and was more efficient to use, but still did not deal with the Airlift tubing assemblies effectively. An attempt to design a more effective installation truck was delayed until after the conclusion of the DOE grant period because of the high cost. In August 2003, a custom designed installation truck was delivered, so the Airlift units can now be installed and removed with proper equipment. This truck is has been successfully installing and removing Airlifts, although rework is in process to extend its capability. No DOE funding supported the purchase of the new customized installation truck.

3.6 Device Setup

An Airlift stage is comprised of manifolds, airlines, product lines, and reservoir housing. The manifold is the point where all lines and valves interface. The airlines carry the compressed air. The product lines carry the well fluids. Finally, the reservoir housing stores the fluids.

Approximately 250 feet separate each stage. In a four stage installation, the stages are numbered from one to four with the bottom stage being #1 and the top stage being #4. Fluid enters the Stage #1 through the screen. Compressed air is routed to Stages #1 and #3, which forces the crude oil in Stage #1 to Stage #2 and the oil in Stage #3 to Stage #4. Next, compressed air is routed to Stages #2 and #4,

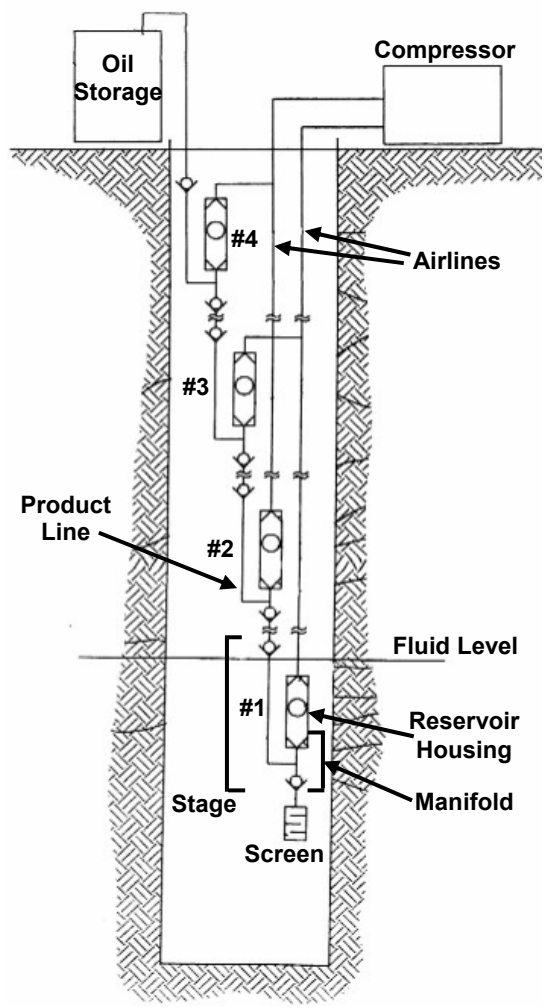
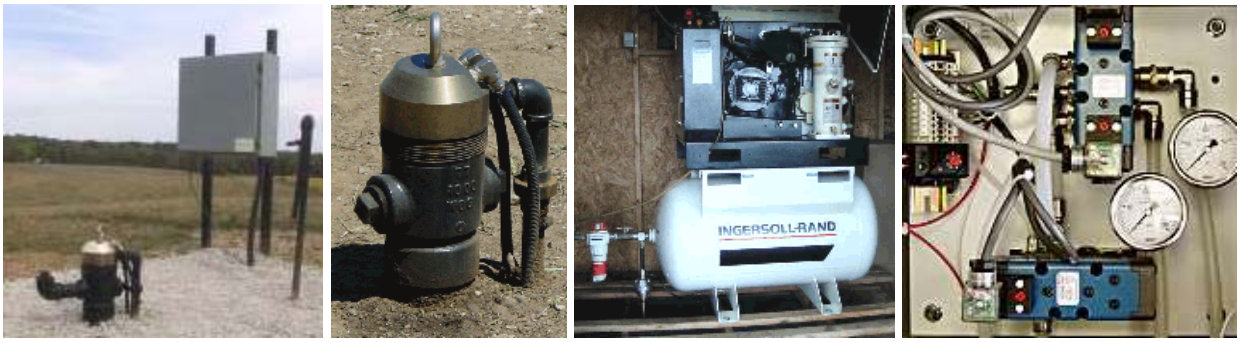


Figure 4: Diagram of Setup

which forces the crude oil in Stage #2 to Stage #3 and the oil in Stage #4 to the storage tank. While the compressed air is routed to Stages #2 and #4, Stage #1 fills with crude. The paired stages are alternately supplied compressed air. A control panel manages the cycle time.



Pictures 3, 4, 5, and 6: *(from left to right)* An Airlift Gen 3 in the well next to the control panel. A close-up of the Gen 3 unit in the well. A compressor used to run several Airlift units. The interior of the control panel.

3.7 Evolution of the Airlift

The predominate amount of the time and money spent during the DOE grant period was on the design, fabrication, and testing of Airlift units. During the DOE period, the Airlift Gen 2 was developed, fabricated, and tested. The later Gen 3 was more sophisticated than the Gen 2.

Table 3: Evolutionary Relationship to the DOE Grant

Airlift Version	Development	Testing
Gen 1	Developed and tested before DOE grant period.	Testing continued throughout DOE grant period.
Gen 2	Development before and during the DOE grant period.	Testing started and continued throughout DOE grant period and 1 year beyond.
Gen 3	Developed independently of DOE funding toward the end of the DOE grant period.	Testing started at the end of the DOE grant period and continued for 1.5 years beyond.
Gen 3.1	Developed after the DOE grant period.	Testing started 1 year beyond DOE grant period.

3.7.1 Airlift Gen Version 1 (Pre-DOE Grant)

The Airlift Gen Version 1 is the original prototype of the Airlift concept. It was constructed from off-the-shelf PVC parts that were glued together (see Figure 5). The airlines/product lines were exterior to the reservoir housing. Before the DOE grant was awarded, the Gen 1 unit had been operated in a variety of wells from 1997 through 2000. Information from several of these trial runs is included in the data. The Gen 1 continued to be tested throughout the DOE grant

period, with the longest running Gen 1 lasting over three years. By the end of the period, the Gen 1 was essentially phased out of operation.

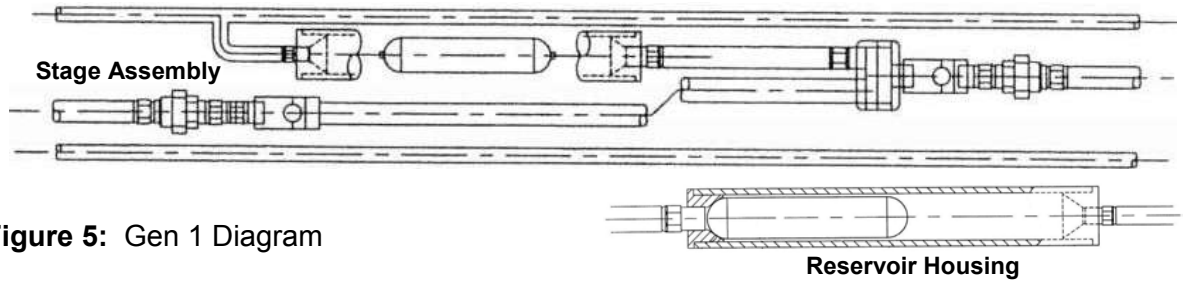


Figure 5: Gen 1 Diagram

3.7.2 Airlift Gen Version 2 (During DOE Grant)

The DOE grant provided funds necessary to advance the Gen 1 design beyond off-the-shelf parts. Plastic blocks were designed and machined to be the manifolds on either end of the unit, providing a more integrated system. The airlines/product lines were still exterior to the reservoir housing (see Figure 6). The Gen 2 was tried for short periods (<3 months) the first year and then tested for longer periods (1+ year) the second year of the DOE grant. The Gen 2 continued to be tested in several wells the year after the DOE grant, but it was also phased out of service.

Figure 6: Gen 2 Diagram

Midway through the DOE grant, results from the Gen 2 tests indicated a more robust Airlift was required. The plastic blocks would easily crack and the exterior airlines would cause the unit to become stuck upon removal from the well. The glue used on the Gen 2 could not survive long-term contact with the well environment.

3.7.3 Airlift Gen Version 3 (Independent of DOE Grant Funding)

To correct the Gen 2 problems, a completely integrated metal unit was designed and machined. The airlines/product lines were moved to the interior of the reservoir housing (see Figure 7). Stainless steel and brass were used because of their corrosion resistant properties. The first Gen 3 units began testing at the end of the DOE grant period. These two units continued operation for about 1.5 years, but then were retired from service. No DOE funding supported the design, fabrication, or testing of the Gen 3 units.

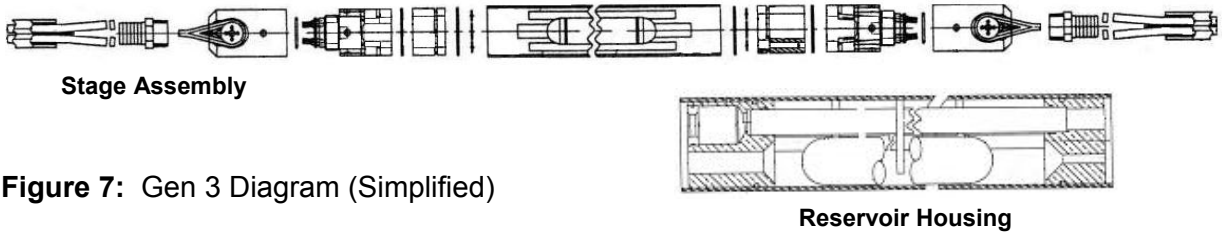


Figure 7: Gen 3 Diagram (Simplified)

Even though the Gen 3 was made of stainless steel, it began to suffer serious corrosion of the internal airlines/product tubes, pitting of the reservoir housing, and corrosion near washers. The chlorine ion present in the well fluids seems to have been the major factor causing the corrosion of the stainless steel. Chlorine ions enhance localized attacks (see Picture 7).

Picture 7: Localized attack on a Gen 3 stainless steel product line resulting from the presence of Cl^-.

3.7.4 Airlift Gen Version 3.1 (Post-DOE Grant)

The Gen 3.1 was similar in design to the Gen 3, except for several significant improvements. The Gen 3.1 was upgraded to another type of stainless steel with better corrosion resistant properties. The Gen 3.1 was also designed to be easier to manufacture. Four wells currently contain Gen 3.1 units for ongoing testing. So far, the Gen 3.1 units are performing exceptionally well and not suffering significant corrosion. No DOE funding supported the design, fabrication, or testing of the Gen 3.1 units.

4.0 Results and Discussion

4.1 Reliability Data Results

The data set for this study was a collection of maintenance logs recorded during the operation of pump jack, Gen 1, Gen 2, Gen 3, and Gen 3.1 pumping units. Complete records of these logs and the data from the individual well tests are available in Appendices B, C, and D. Appendix A contains a timeline that graphically displays the wells tested, the test time periods, and the Airlift versions tested. The data set is summarized and averaged in Table 4 to compare downtime among the various pumping units:

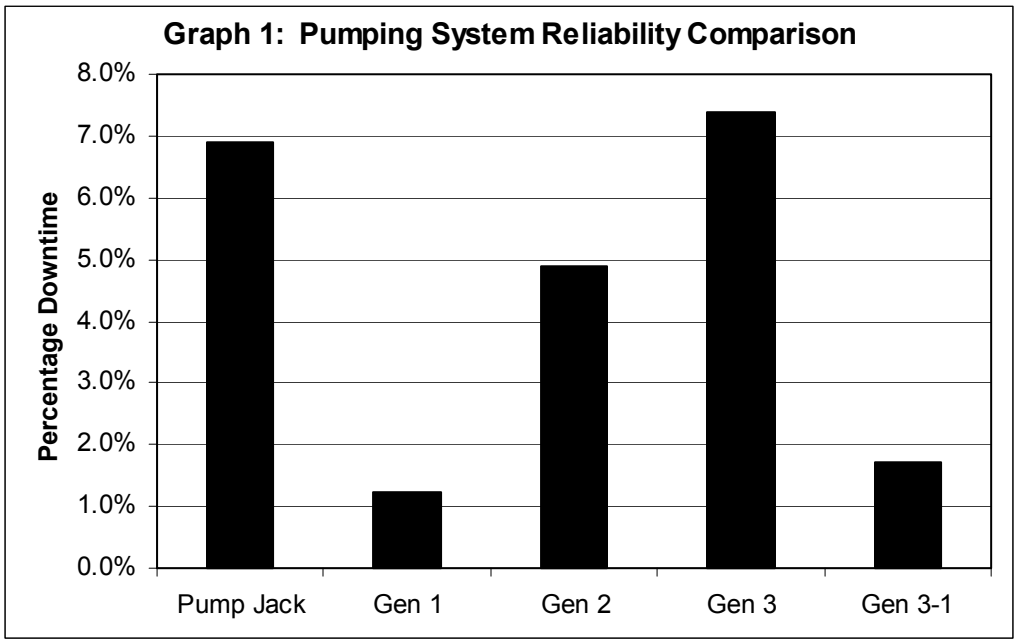
Table 4: Data Grouped to Compare Different Pumping Systems

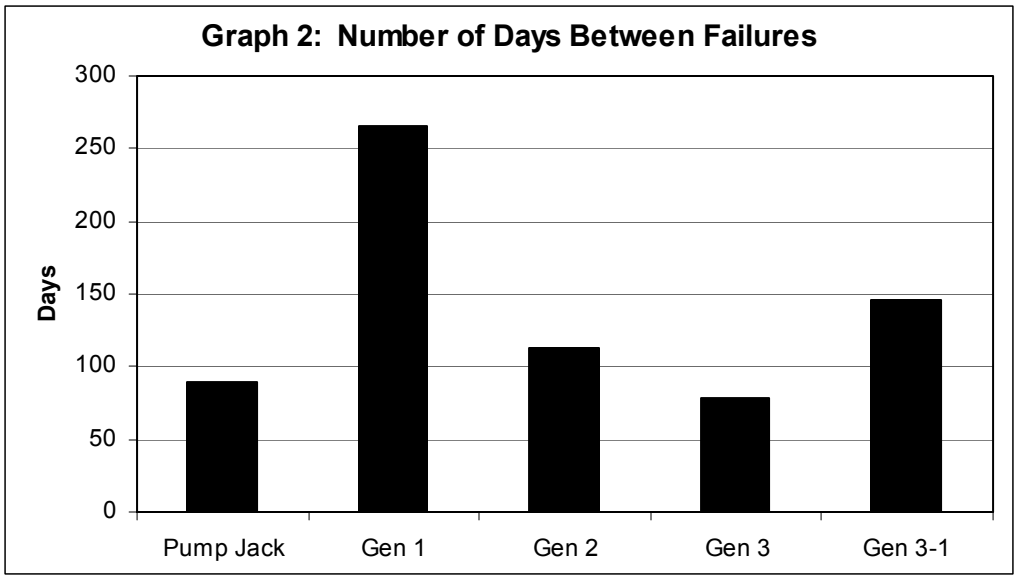
Well Name	System	Test Period (days)	Downtime (days)	% Downtime	# of Failures	Avg. # Days Between Failures	Avg. Length of Failure
Stone #3	Pump Jack	343	27	7.9%	5	69	5.4
Lahr #3	Pump Jack	1273	57	4.5%	14	91	4.1
Lahr #8	Pump Jack	1076	120	11.2%	15	72	8.0
Lahr #12	Pump Jack	540	78	14.4%	11	49	7.1
Wilson #1	Pump Jack	1838	53	2.9%	12	153	4.4
Wilson #4	Pump Jack	885	85	9.6%	14	63	6.1
Wilson #5	Pump Jack	1692	91	5.4%	16	106	5.7
Wilson #7	Pump Jack	818	73	8.9%	7	117	10.4
	Results:	**8465**	**584**	**6.9%**	**94**	**90**	**6.2**
Lahr #3	Gen 1	125	2	1.6%	2	63	1.0
Lahr #7	Gen 1	84	9	10.7%	2	42	4.5
Lahr #8	Gen 1	648	1	0.2%	1	648	1.0
Lahr #12	Gen 1	739	1	0.1%	1	739	1.0
Wilson #4	Gen 1	260	10	3.8%	1	260	10.0
	Results:	**1856**	**23**	**1.2%**	**7**	**265**	**3.3**
Lahr #9	Gen 2	68	4	5.9%	2	34	2.0
Wilson #4	Gen 2	601	27	4.5%	5	120	5.4
Wilson #7	Gen 2	71	3	4.2%	2	36	1.5
Wilson #7	Gen 2	732	38	5.2%	4	183	9.5
	Results:	**1472**	**72**	**4.9%**	**13**	**113**	**5.5**
Wilson #1	Gen 3	515	34	6.6%	6	86	5.7
Wilson #5	Gen 3	582	47	8.1%	8	73	5.9
	Results:	**1097**	**81**	**7.4%**	**14**	**78**	**5.8**
Stone #1	Gen 3-1	159	1	0.6%	1	159	1.0
Wilson #1	Gen 3-1	127	0	0.0%	0	127	0.0
Wilson #5	Gen 3-1	94	5	5.3%	2	47	2.5
Wilson #7	Gen 3-1	203	4	2.0%	1	203	4.0
	Results:	**583**	**10**	**1.7%**	**4**	**146**	**2.5**

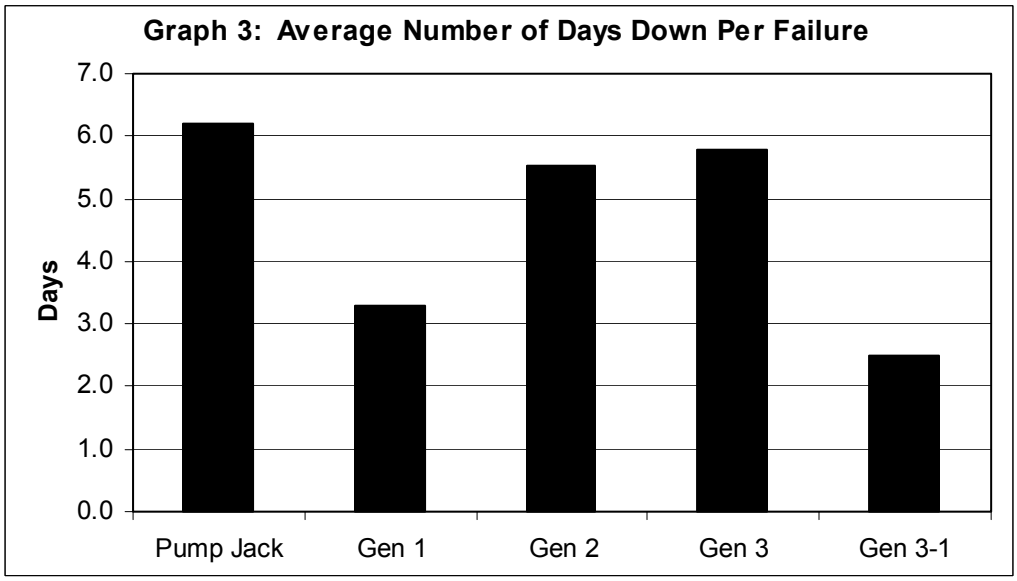
A description of the various headings in Table 4 is as follows:

Well Name – lease name followed by well number.
System – pumping unit used.
Test Period – the number of days the system was in the well. During this period, it is assumed the system was pumping continuously unless expressly noted as downtime in the logs.
Downtime – the number of days the system was not operational because of pumping problems, maintenance, and repairs. Generally, the initial time required to install an airlift and make it operational was not counted as downtime.
% Downtime – the percentage of the test period that the system was not functioning properly because of pumping problems, maintenance, and repairs.
# of Failures – the number of separate times the system failed during the test period.
Average # of Days Between Failures – the length of the test period divided by the number of failures.
Average Length of Failure – the average amount of days it required to repair the system after a failure.

The Results line after each system grouping is the cumulative results for each system. The similarity of the wells used for the tests permits the grouping of the data from various wells to compare the various pumping systems studied. (Restricting the data set to group data collected from only Wilson lease wells provides similar results.) The most relevant results are compared in Graphs 1, 2, and 3.







4.2 Discussion

The data provides a clear comparison of the reliability of the various Airlift versions with traditional pump jack technology. An examination of the pump jacks used on these leases reveals a downtime of 6.9%. In contrast, the Gen 1 had a downtime of only 1.2%. Unfortunately, the downtime for Gen 2 and Gen 3 jumped significantly, with the Gen 3 comparing with the pump jacks in reliability.

The poorer performance of the Gen 2 and Gen 3 is easily explained: The Gen 2 and Gen 3 were successively more sophisticated and introduced a series of new technology improvements. These designs also introduced a series of new and unexpected problems. In the case of the Gen 2, the plastic units were too brittle and did not survive long-term use. In the case of the Gen 3,

the metal units were not able to withstand the corrosion of the well environment. They suffered significant corrosion related failures that required weeks to repair.

The Gen 3.1 units incorporated the lessons learned about the Gen 3. Although the Gen 3.1 units have not yet had the same amount of testing time as earlier versions, their performance has been closer to the Gen 1 with a downtime of only 1.7%. The number of days down to repair each Gen 3.1 failure (2.5 days) has actually been lower than the Gen 1 (3.3 days) and significantly lower than the pump jack (6.2 days). If the Gen 3.1 continues to perform well and resists the corrosive effects that impacted the Gen 3, its statistics will improve further.

4.3 Other Significant Achievements

4.3.1 Multiples Wells on One Compressor (Post-DOE Grant)

The capability to run several Airlifts using one compressor would offer an energy and cost saving technique. This was technique was demonstrated on the Wilson lease, with both wells #1 and #5 connected to a single, 10 HP air compressor. Sharing the air compressor worked well.

4.3.2 Extended Well Depth (Post-DOE Grant)

The capability to add additional stages to the Airlift system would allow the unit to function in greater well depths. The capability has now been demonstrated in 1600 feet deep wells using six Airlift Gen 3.1 stages. The systems were installed January of 2004 in two wells located in southern Illinois and are undergoing testing. The depths of these wells include unique challenges and the Airlift Gen 3.1 units may need additional design improvements to continue long-term operation.

5.0 Conclusion and Relevance

5.1 Conclusion

The DOE grant enabled development and testing of the Airlift Gen 2 pumping system. Knowledge gained during the DOE grant period led to the creation of the more sophisticated Gen 3. While the Gen 2 and Gen 3 versions were not successful in demonstrating a highly reliable pumping system, they were no less reliable than existing pumping technology. More importantly, the new version Gen 3.1 is operating with a reliability four times better (when comparing downtime percentage) and two-and-a-half times better in the time it requires to repair (when comparing average number of days down per failure) than standard pump jack technology.

Accomplishments resulting from the DOE grant include:

- Development and testing of the Gen 2 Airlift version
- Airlift Gen 1 and Gen 2 testing in seven wells (with data analyzed from twelve wells)

Accomplishments made independent of the DOE grant include:

- Conversion of the Airlift from a plastic based design to a rugged metal design
- Fabrication and testing of two Gen 3 units and four Gen 3.1 units
- Use of one compressor to operate multiple Airlift units
- Design and purchase of a customized Airlift installation truck

5.2 Relevance

Through this research, the Airlift pumping system has been refined into practical technology that will impact the oil industry in several ways:

1. **Making Stripper Wells Economical:** Through the Airlift disruptive technology, stripper wells producing less than 10 barrels of day can be operated with little labor and few repair costs, making the stripper wells more economic. The high reliability and low maintenance required to operate Gen 3.1 will make the Airlift the natural choice to replace pump jacks on stripper wells.

2. **Making Older Wells Open for Use:** Many older stripper wells have been capped because the owner's could not afford the maintenance costs. With the Airlift Gen 3.1, these wells can be opened and made useful again. Stripper well lifetimes will be extended, unlocking more of the nation's oil reserves for production.

3. **Making Wells Environmentally Friendly:** The low surface profile of the Airlift Gen 3.1 is pleasing to the eye and environmentally friendly. It is safer than traditional pump jack technology because it has no moving parts. People that would normally prohibit oil production on their land because of the "ugly" look of traditional pump jacks will be willing to use the Airlift pumping system.

5.3 For Further Study

Airlift Services International, Inc. (ASI) has been formed to continue development and begin market the Airlift pumping system. The DOE grant brought the Airlift technology through the Gen 2 version, providing ASI with the foundation to move to the Gen 3 and Gen 3.1 stages of development. Now, ASI is raising funding to conduct a large scale testing for 10 sites spread throughout Louisiana, Illinois, Kansas, Ohio, West Virginia, and Pennsylvania. This large scale testing will provide dating on the Airlift Gen 3.1 operation in a variety of well environments at a variety of well depths. Testing at a site in southern Illinois has already started as of January, 2004.

Now that a customized installation truck has already been designed, outfitted, and delivered (as of 8/25/03), Airlift installation methods are becoming more refined and require less time. For the next technological improvement, ASI intends to develop sensor technology for the Airlift stages and create remote monitoring capability for each well.

6.0 References

No references.

Final Technical Report Appendices

Reporting Period
5/17/00 to 5/17/02

Report Date
March 2004

DOE Grant No. DE-FG26-00BC15261

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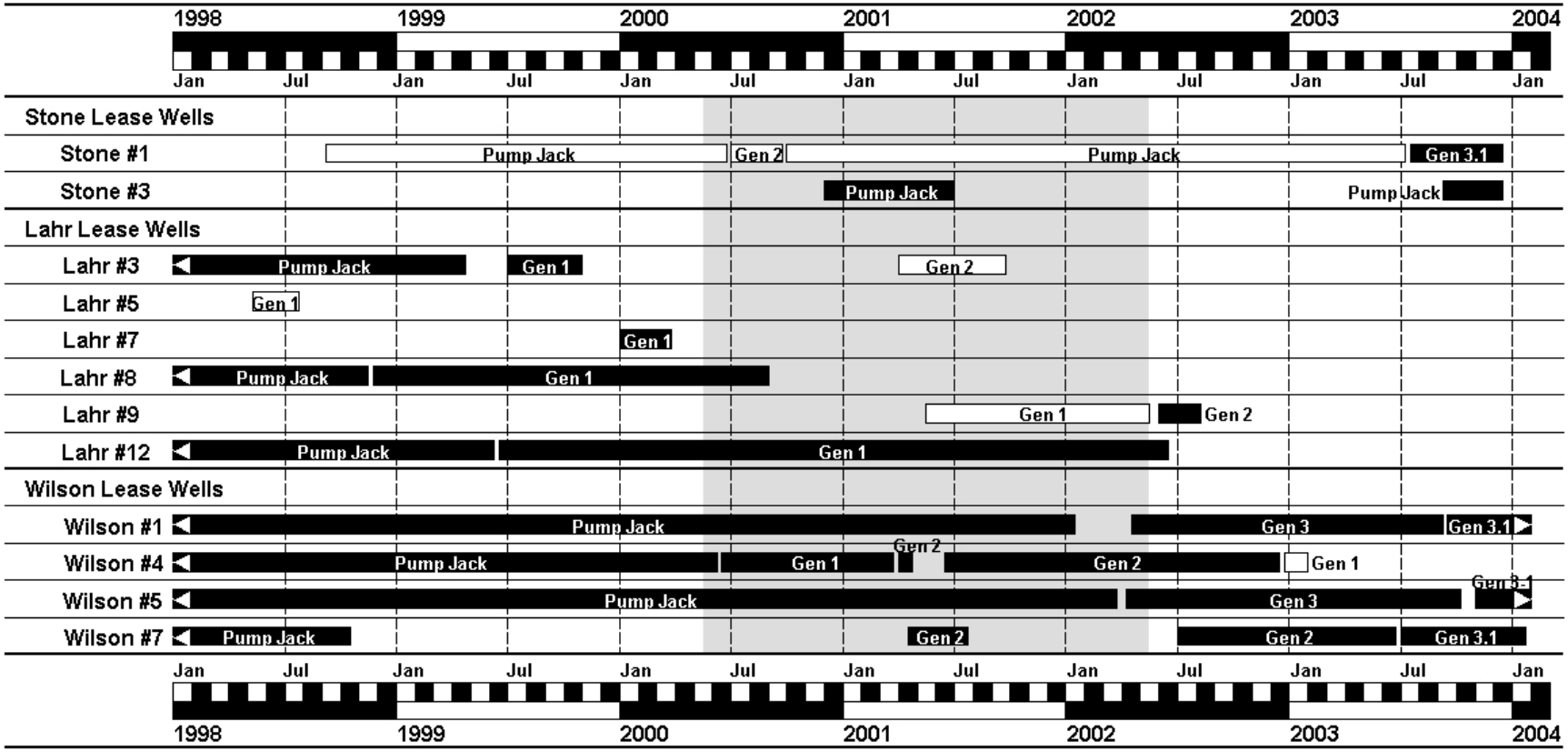
Appendix A: Reliability Testing Timeline (Jan.1998 through Jan. 2004)

1/29/04



Black bar is testing period for reliability with valid data. Data for these periods is tabulated to compare the various pumping systems.

White bar is testing period for reliability with insufficient or questionable data. Data for these periods is not included in comparison tabulations.

Shading highlights the two-year Department of Energy grant period (5/17/2000 to 5/17/2002).

Appendix B: Stone Lease Oil Pump Reliability Data

Stone #1 Data

Traditional Pump Jack (insufficient/questionable data)

Summary

Test Period: 9/4/1998 to ~6/21/2000

Days Recorded: ~687
Days Operating: 0
Days Downtime: 0
0.0% of days recorded were downtime

Number of Failures: 0
Avg. Failure Rate: na
Avg. Failure Length: na

Failure/Maintenance Log

Date	*Downtime*	*Reason*
9/4/98	10	Dropped tubing; fished out tubing, replaced barrel, 2 set balls and seats, 1 working valve, 1 seating valve, 7 joints tubing, 6 cups

Airlift Gen 2 (insufficient/questionable data)

Summary

Test Period: ~6/22/2000 to 9/22/2000

Days Recorded: ~92
Days Operating: na
Days Downtime: na
0.0% of days recorded were downtime

Number of Failures: na
Avg. Failure Rate: na
Avg. Failure Length: na

Failure/Maintenance Log

Date	*Downtime*	*Reason*
8/24/00	7	Well sanded-up; striped sand out of well.
?/??/??	?	Had problem with glue in stages. In and out of well about 4 times.

Traditional Pump Jack (insufficient/questionable data)

Summary

Test Period: 10/1/2000 to 7/9/2003

Days Recorded: 1012
Days Operating: na
Days Downtime: na

Number of Failures: na
Avg. Failure Rate: na
Avg. Failure Length: na

Failure/Maintenance Log

Date	*Downtime*	*Reason*
11/20/00	15	Acidized and swabbed well.

Airlift Gen 3-1

Summary

Test Period: 7/10/2003 to 12/15/2003

Days Recorded: 159
Days Operating: 158
Days Downtime: 1
0.6% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 159 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
8/21/03	1	Inspected stage #2 check ball, was enlarged two times its normal size; replaced check ball.

Stone #3 Data

Traditional Pump Jack

Summary

Test Period Recorded: 12/2/2000 to 6/30/01
8/9/2003 to 12/18/2003

Days Recorded: 343
Days Operating: 316
Days Downtime: 27
7.9% of days recorded were downtime

Number of Failures: 5
Avg. Failure Rate: 1 every 69 days
Avg. Failure Length: 5.4 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
12/2/00	7	Broken rods; replaced rods and 4 cups.
6/26/01	5	Broken rods, stuck in barrel; replaced 1 rod and 4 cups. Became stuck in barrel again. Packer stuck. Sat idle for 2 years, 1 month, 12 days.
7/30/03	10	Trouble setting packer.
9/30/03	1	Replaced pumping unit.
12/15/03	4	Broken rods; removed rods but cups and barrel bad.

Appendix C: Lahr Lease Oil Pump Reliability Data

Lahr #3 Data

Traditional Pump Jack

Summary

Test Period: 10/30/1995 to 4/24/1999 (slight discrepancy)

Days Recorded: 1273
Days Operating: 1216
Days Downtime: 57
4.5% of days recorded were downtime

Number of Failures: 14
Avg. Failure Rate: 1 every 91 days
Avg. Failure Length: 4.1 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
10/30/95	4	Replaced 4 cups
2/2/96	3	Hole in tubing; replaced 1 joint tubing, 4 cups
3/1/96	6	Hole in tubing; replaced 1 joint tubing, 4 cups
7/11/96	2	Gas locked; replaced 4 cups
10/12/96	3	Replaced 4 cups
1/7/97	2	Replaced 4 cups
4/14/97	4	Hole in tubing; replaced 1 joint tubing, 4 cups
7/2/97	3	Replaced 4 cups
10/4/97	1	Gas locked
1/8/98	5	Hole in tubing; replaced 1 joint tubing, 4 cups
4/9/98	3	Replaced 4 cups
8/12/98	6	Replaced 4 cups
11/2/98	7	Hole in tubing; replaced 1 joint tubing, 4 cups
4/1/99	8	Replaced 4 cups

Airlift Gen 1

Summary

Test Period: 6/30/1999 to 11/1/1999

Days Recorded: 125

Days Operating: 123
Days Downtime: 2
1.6% of days recorded were downtime

Number of Failures: 2
Avg. Failure Rate: 1 every 63 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
7/8/99	1	Fluids not flowing; raised system 20 feet and flushed back and forth.
11/1/99	1	System stuck in hole during removal process.

Airlift Gen 2 (insufficient/questionable data)

Summary

Test Period: 3/28/2001 to 9/21/2001 (estimated length of time)

Days Recorded: 178
Days Operating: 177
Days Downtime: 1
0.6% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 178 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
4/2/01	1	Leaking down hole, stage #2 block leaking, air line leak; repaired.

Lahr #5 Data

Airlift Gen 1 (insufficient/questionable data)

Summary

Test Period: 5/7/1998 to 7/24/1998 (discrepancy)

Days Recorded: 79

Days Operating: 78
Days Downtime: 1
1.3% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 79 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
7/24/98	1	Would not pump.

Lahr #7 Data

Airlift Gen 1

Summary

Test Period: 12/30/1999 to 3/22/2000

Days Recorded: 84
Days Operating: 75
Days Downtime: 9
10.7% of days recorded were downtime

Number of Failures: 2
Avg. Failure Rate: 1 every 42 days
Avg. Failure Length: 4.5 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
3/7/00	6	Air leaking down hole, glue came apart in bottom stage.
3/20/00	3	Ran packer, air leak, system became stuck during removal process.

Lahr #8 Data

Traditional Pump Jack

Summary

Test Period: 12/10/1995 to 11/19/1998

Days Recorded: 1076
Days Operating: 956
Days Downtime: 120
11.2% of days recorded were downtime

Number of Failures: 15
Avg. Failure Rate: 1 every 72 days
Avg. Failure Length: 8.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
12/10/95	17	Hole in tubing; replaced 1 joint tubing, 4 cups, 1 set brass valves, 2 sets ball and seats, 1 new barrel
1/12/96	5	Replaced 4 cups
2/20/96	9	Hole in tubing; replaced 1 joint tubing, 4 cups
4/28/96	10	Hole in tubing; replaced 1 joint tubing, 4 cups
6/10/96	7	Replaced 4 cups
7/8/96	9	Hole in tubing; replaced 2 joints tubing, 4 cups
9/16/96	11	Hole in tubing; replaced 1 joint tubing, 4 cups
11/17/96	4	Replaced 4 cups
12/25/96	7	Hole in tubing; replaced 1 joint tubing, 4 cups
2/8/97	11	Valves stuck in barrel; stripped out, replaced 16 rods, 6 cups
3/18/97	1	Replaced 3 HP motor
5/1/97	4	Replaced 4 cups
5/21/97	6	Hole in tubing; replaced 1 joint tubing, 4 cups
7/28/97	9	Hole in tubing; replaced 1 joint tubing, 4 cups
9/26/97	10	Hole in tubing; replaced 2 joints tubing, 4 cups

Airlift Gen 1

Summary

Test Period: 11/20/1998 (slight discrepancy) to 8/28/2000

Days Recorded: 648
Days Operating: 647
Days Downtime: 1
0.2% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 648 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
8/28/00	1	Stopped pumping, air line in bottom stage became soft and ruptured; all future air lines were changed to pex lines.

Lahr #9 Data

Airlift Gen 1 (insufficient/questionable data)

Summary

Test Period: ~5/14/2001 to 5/17/2002

Days Recorded: ~369
Days Operating: na
Days Downtime: na

Number of Failures: na
Avg. Failure Rate: na
Avg. Failure Length: na

Failure/Maintenance Log

Date	*Downtime*	*Reason*

Airlift Gen 2

Summary

Test Period: 6/3/2002 to 8/10/2002

Days Recorded: 68
Days Operating: 64
Days Downtime: 4
5.9% of days recorded were downtime

Number of Failures: 2
Avg. Failure Rate: 1 every 34 days
Avg. Failure Length: 2.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
6/17/02	3	Float filled with fluid in bottom #1 stage. During system removal, part of the pex lines caught and were destroyed.
8/10/02	1	Leaking air down hole, glue failed in stages #1, #2, and #3. During system removal, portions of air lines were destroyed.

Lahr #12 Data

Traditional Pump Jack

Summary

Test Period: 7/12/1997 to 6/4/1999

Days Recorded: 540
Days Operating: 462
Days Downtime: 78
14.4% of days recorded were downtime

Number of Failures: 11
Avg. Failure Rate: 1 every 49 days
Avg. Failure Length: 7.1 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
10/17/97	4	Replaced 4 cups
12/10/97	6	Hole in tubing; replaced 1 joint tubing, 4 cups
2/8/97	3	Replaced 4 cups
4/9/98	5	Replaced 4 cups
6/17/98	8	Hole in tubing; replaced 1 joint tubing, 4 cups
9/5/98	7	Replaced 4 cups
11/15/98	9	Replaced 4 cups
11/28/98	8	Replaced 1 new barrel, 2 set ball and seat, 4 cups
1/12/99	5	Hole in tubing; replaced 2 joints tubing, 4 cups
3/3/99	12	Hole in tubing; replaced 1 joint tubing, 4 cups
5/1/99	11	Replaced 4 cups

Airlift Gen 1

Summary

Test Period: 6/10/1999 to 6/17/2002

Days Recorded: 739
Days Operating: 738
Days Downtime: 1
0.1% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 739 days
Avg. Failure Length: 1.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
6/17/02	1	Leaking air down hole, air line was full of fluid, air lines enlarged and caused problems during removal, bottom stage float filled with fluid, o-rings leaking between air line and production line, glue problems on two stages.

Appendix D: Wilson Lease Oil Pump Reliability Data

Wilson #1 Data

Traditional Pump Jack

Summary

Test Period: 1/4/1997 to 1/15/2002

Days Recorded: 1838
Days Operating: 1785
Days Downtime: 53
2.9% of days recorded were downtime

Number of Failures: 12
Avg. Failure Rate: 1 every 153 days
Avg. Failure Length: 4.4 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
1/4/97	2	Hole in tubing
1/25/97	4	Hole in tubing; replaced 1 joint tubing, 4 cups
2/1/97	6	Stuck in barrel; stripped out, replaced 1 joint tubing, 4 cups
3/17/97	2	Replaced 1 joint tubing, 4 cups
5/10/97	3	Pulled rods and tubing
5/15/97	5	Sump pump would not work
8/21/97	3	Hole in tubing
9/8/97	12	Hole in tubing; dropped down well
6/18/98	4	Hole in tubing; replaced 1 joint tubing, 4 cups
8/14/98	5	Hole in tubing; replaced 3 joints tubing, 4 cups
10/2/2000	3	Trouble running rods, caved joint tubing
6/18/2001	4	Hole in tubing; replaced 2 joints tubing, 4 cups, 1 ball and seat

Airlift Gen 3

Summary

Test Period: 4/14/2002 to 9/10/2003

Days Recorded: 515
Days Operating: 481
Days Downtime: 34

6.6% of days recorded were downtime

Number of Failures: 6
Avg. Failure Rate: 1 every 86 days
Avg. Failure Length: 5.7 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
5/17/02	5	Float not working, pex lines grew and stopped float; replaced air lines inside stages with stainless steel lines.
5/22/02	1	Stage #2 gasket leaking.
10/30/02	21	System inspection. Air leak in bottom stage, top stage has leak in gasket. Pex line clamps badly corroded, bottom stage stainless steel pitted at o-ring seats, two hole in stainless steel air lines. Took to Marion Engineering for rebuilding and improvements. Changed stage #3 production lines to improved stainless steel. Added Teflon coated float seats to bottom stage #1. Replaced all stainless steel clamps on air lines with copper rings and replaced all air lines clamps inside of 1 ¼" charter plastic. Cleaned well.
12/2/02	1	Air lines frozen; thawed lines.
12/6/02	4	Wilson 10 HP air compressor failure, leaking oil bad at air filter, relay valve bad; Capital Machinery serviced machine and replaced relay valve. (Note: this single compressor operates both Wilson #1 and #5.)
9/9/03	2	Stopped pumping, pulled for inspection. Stage #1: Teflon coated seats not worn. The ¾" production line has six holes in the stainless steel. Inside 3" stainless steel slightly pitted. Stage #2: Brass in good shape. Stainless steel production lines pitted badly and has one hole. Stage #3: Stainless steel production lines in good shape. Teflon float seats in perfect shape. 3" stainless steel stage pitted around o-ring seat. Stage #4: Pressed brass with UHMW is in good shape. 3" stainless steel stage pitted around o-ring seat.

Airlift Gen 3-1

Summary

Test Period: 9/25/2003 to 1/29/2004 (latest data available, still in operation)

Days Recorded: 127
Days Operating: 127
Days Downtime: 0
0.0% of days recorded were downtime

Number of Failures: 0
Avg. Failure Rate: 0 every 127 days
Avg. Failure Length: 0.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
None	None	None

Wilson #4 Data

Traditional Pump Jack

Summary

Test Period: 1/5/1997 to 6/7/2000 (slight discrepancy)

Days Recorded: 885
Days Operating: 800
Days Downtime: 85
9.6% of days recorded were downtime

Number of Failures: 14
Avg. Failure Rate: 1 every 63 days
Avg. Failure Length: 6.1 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
1/5/97	5	Hole in tubing; replaced 1 joint tubing, 4 cups
1/20/97	7	Replaced 4 cups
2/28/97	6	Hole in tubing; replaced 1 joint tubing, 4 cups, 1 set ball and seat
3/8/97	3	Hole in tubing; replaced 2 joints tubing, 4 cups
5/20/97	10	Replaced 4 cups
11/17/97	7	Hole in tubing; replaced 3 joints tubing, 4 cups
3/27/98	6	Hole in tubing; replaced 1 joint tubing, 4 cups
6/10/98	6	Hole in tubing; replaced 2 joints tubing, 4 cups
9/26/98	4	Hole in tubing; replaced 1 joint tubing, 4 cups, 2 belts
3/31/99	9	Hole in tubing; replaced 2 joints tubing, 4 cups
4/2/99	5	Hole in tubing; replaced 2 joints tubing, 4 cups, 1 set ball and seat
7/19/99	4	Hole in tubing; replaced 1 joint tubing, 4 cups, 3 HP motor
7/31/99	8	Hole in tubing; replaced 2 joints tubing, 4 cups
4/29/00	5	Hole in tubing; replaced 1 joint tubing, 4 cups

Airlift Gen 1

Summary

Test Period: 6/13/2000 to 2/27/2001

Days Recorded: 260
Days Operating: 250
Days Downtime: 10
3.8% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 260 days
Avg. Failure Length: 10.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
6/13/2000	10	Control panel not functioning properly.

Airlift Gen 2

Summary

Test Period: 3/1/2001 to 3/25/2001
5/16/2001 to 12/12/2002

Days Recorded: 601
Days Operating: 590
Days Downtime: 27
4.5% of days recorded were downtime

Number of Failures: 5
Avg. Failure Rate: 1 every 120 days
Avg. Failure Length: 5.4 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
3/25/01	1	Trouble removing system from well, air lines folded over, pex air lines grew about 5 to 7 inches in length, one block cracked from age.
5/18/01	15	Leaking air down hole, two clamps leaking, block cracked, cable broke and system fell down hole; fished system out, repaired, sand pumped

		well. Ran system back into hole. Began leaking at stage #3 because block cracked; replaced and ran system back into hole.
11/4/01	5	Not functioning properly, air lines leaking, stage #1 block cracked and leaking, stage #2 PVC loose and leaking, anchor plugged with paraffin and iron sulfite.
7/10/02	4	Stage #4 float full of fluid, air leaking about 10 ft. above stage #2, Mac valve not working.
12/11/02	2	More than half the blocks were cracked and leaking.

Traditional Pump Jack (insufficient/questionable data)

Summary

Test Period: 12/13/2002 to ?/?/????

Days Recorded: na
Days Operating: na
Days Downtime: na

Number of Failures: na
Avg. Failure Rate: na

Failure/Maintenance Log

Date	*Downtime*	*Reason*

Wilson #5 Data

Traditional Pump Jack

Summary

Test Period: 12/5/1996 to 2/25/2002 (slight discrepancy)

Days Recorded: 1692
Days Operating: 1601
Days Downtime: 91
5.4% of days recorded were downtime

Number of Failures: 16
Avg. Failure Rate: 1 every 106 days

Avg. Failure Length: 5.7 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
12/5/96	6	Hole in tubing; replaced 2 joint tubing, 4 cups
3/7/97	12	Wrong type of tubing received
3/28/97	3	Hole in tubing; replaced 2 joint tubing, 4 cups
8/20/97	7	Hole in tubing; replaced 1 joint tubing, 4 cups
11/25/97	4	Hole in tubing; replaced 1 joint tubing, 4 cups, 2 belts
2/26/98	3	Hole in tubing; replaced 1 joint tubing, 4 cups
5/26/98	7	Hole in tubing; replaced 1 joint tubing, 4 cups, 1 ball/seat
9/12/98	6	Hole in tubing; replaced 1 joint tubing, 4 cups
4/14/99	4	Stuck in barrel, stripped out
5/2/2000	8	Cutting oil, replaced 6 cups, 2 balls/seats
7/29/2000	9	Hole in tubing
10/27/2000	6	Hole in tubing; replaced 1 joint tubing, 4 cups
11/5/2000	5	Hole in tubing; replaced 1 joint tubing, 4 cups
11/16/2000	5	Hole in tubing; replaced 1 joint tubing, 4 cups
5/8/2001	3	Hole in tubing; replaced 1 joint tubing, 4 cups, 1 3HP motor
9/28/2001	3	Replaced 4 cups

Airlift Gen 3

Summary

Test Period: 3/5/2002 to 10/7/2003

Days Recorded: 582
Days Operating: 535
Days Downtime: 47
8.1% of days recorded were downtime

Number of Failures: 8
Avg. Failure Rate: 1 every 73 days
Avg. Failure Length: 5.9 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
5/7/02	1	Was not pumping, lines going bad; replaced air lines in all stages with stainless steel.
7/14/02	1	Pump cutting oil; changed air pressure from odd to even sides rapidly for about five minutes. Let set for two hours.
7/29/02	1	Fuse blew in control panel; replaced fuse.

8/24/02	1	Parker valve not working in control panel; cleaned hard build-up in-side of plunger area.
9/27/02	28	Pump cutting oil, leaking air internally but no external leaks. Pex clamps rusted into stainless steel clamps, all clamps were bad in bottom stage #1 pex clamps. Stainless steel stage eaten and pitted bad inside at o-rings. Stage #1 ¾" production line stainless steel has hole eaten thru it. Each end of ¾" production stainless steel line was pitted bad in stages #1 and #2. Potential cause of failure: too deep in well, laying in bottom sludge and iron sulfite. Sand pumped well, removed 48+ gallons of heavy sludge, solids, and hard iron sulfite. Gained 6'+ in well depth. Checked and cleaned all stainless steel and brass. Took to Marion Engineering for rebuilding. Changed production lines to improved stainless steel and clamps. New o-rings and Teflon float seats on stages #1 and #3. Plastic UHMW new float seat on stages #2 and #4. Kept pump about 20 feet of bottom.
11/04/02	5	Pump cutting oil, vibrating, float not seating properly; raised pump and then lower pump, flushed out check valve or float seats.
12/6/02	4	Wilson 10 HP air compressor failure, leaking oil bad at air filter, relay valve bad; Capital Machinery serviced machine and replaced relay valve. (Note: this single compressor operates both Wilson #1 and #5.)
9/30/03	7	Oil leaking back through air line on odd side of pump; pulled airlift, but cable came loose and system dropped down hole, had to be fished out.

Airlift Gen 3-1

Summary

Test Period: 10/28/2003 to 1/29/2004 (latest data available, still in operation)

Days Recorded: 94
Days Operating: 89
Days Downtime: 5
5.3% of days recorded were downtime

Number of Failures: 2
Avg. Failure Rate: 1 every 47 days
Avg. Failure Length: 2.5 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
11/11/03	3	Charter plastic 1 ¼" production line pulled off of the brass bark on top of stage; replaced brass bark with stainless steel barb.
11/19/03	2	Pump working only part of the time, found piece of rubber blocking

		flow of air in stage #3. Piece from former Gen 3 system lodged into the reused 1 ¼" charter plaster production lines. Removed rubber. No damage to Gen 3-1 system.

Wilson #7 Data

Traditional Pump Jack

Summary

Test Period: 7/17/1996 to 10/12/1998 (some discrepancy)

Days Recorded: 818
Days Operating: 745
Days Downtime: 73
8.9% of days recorded were downtime

Number of Failures: 7
Avg. Failure Rate: 1 every 117 days
Avg. Failure Length: 10.4 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
7/17/96	20	Hole in tubing; replaced 1 joint tubing, 4 cups
5/21/97	7	Replaced 4 cups
6/11/97	17	Hole in tubing; swabbed entire well and replaced all tubing
1/9/98	7	Hole in tubing; replaced 1 joint tubing, 4 cups
1/19/98	4	Hole in tubing; replaced 1 joint tubing, 4 cups
7/14/98	8	Hole in tubing; replaced 1 joint tubing, 4 cups
10/2/98	10	Hole in tubing; replaced 2 joints tubing, 4 cups

Airlift Gen 2

Summary

Test Period: 4/17/2001 to 6/26/2001

Days Recorded: 71
Days Operating: 68
Days Downtime: 3
4.2% of days recorded were downtime

Number of Failures: 2
Avg. Failure Rate: 1 every 36 days
Avg. Failure Length: 1.5 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
4/17/01	2	Leaking down hole, stage #1 and #3 blocks leaking, all blocks have cracks, o-rings in stage #1 and #1 leaking; repaired all stages.
6/26/01	1	Leaking in stage #1, o-rings leaking badly.

Airlift Gen 2

Summary

Test Period: 6/27/2002 to 6/29/2003

Days Recorded: 732
Days Operating: 694
Days Downtime: 38
5.2% of days recorded were downtime

Number of Failures: 4
Avg. Failure Rate: 1 every 183 days
Avg. Failure Length: 9.5 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
7/13/02	27	Parker valve not operating properly. Attempted to remove pump system, became stuck. Bottom stage block leaking, pex lines grew bad. Glue not holding. Repaired. Replaced Parker valve with Mac valve. Glued stages #1 and #3.
12/12/02	3	Leaking air and fluid down-hole, gasket leaking; repaired.
6/13/03	2	Not pumping, became stuck during removal process; repaired.
6/24/03	6	Not pumping, became stuck during removal process.

Airlift Gen 3-1

Summary

Test Period: 6/30/2003 to 1/18/2004

Days Recorded: 203
Days Operating: 199
Days Downtime: 4
2.0% of days recorded were downtime

Number of Failures: 1
Avg. Failure Rate: 1 every 203 days
Avg. Failure Length: 4.0 days

Failure/Maintenance Log

Date	*Downtime*	*Reason*
7/12/03	4	Cutting oil, leaking air at stage #2 gasket; repaired.