IMPROVED PUMPING CAPACITY AND DEPTH OF AIRLIFT SYSTEMS PUMP

FINAL REPORT

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ABSTRACT

The current Airlift Services International pumping system is capable of moving up to 60 bbls/day at a depth of 1000 feet. This pumping capacity and pumping depth significantly limit the market potential for this technology. Market research indicates that the available market for this system would grow by 300% if the system were capable of producing 100 bbls/day at a depth of 3000 feet.

The purpose of this grant, from the Stripper Well Consortium, was to improve the pumping capacity and depth of the existing pumping system. The target pumping capacity is 100 bbls/day at 3000 feet. The design of the pump allows for the variation of major system parameters that alter the pumping capacity. This grant project determines the optimum setting of these parameters to deliver the maximum pumping capacity.

Since the cost to build many systems with varying design parameters is beyond the scope of this project a commercial simulation program was employed. This simulation software evaluates pumping performance vs. design parameter. An optimization technique determines the best setting for each of the design parameters to achieve the maximum pumping capacity. To limit some of the design parameters the simulation focused on a 1000 foot well.

The simulation program requires validation with actual field test data prior to performing system optimization. Validation requires the development of pump level sensing tools and actual in well testing. The development of the sensing tools was also a part of this grant project. Actual field data was used to correlate to the simulation program. Successful validation of this tool cooul allow Airlift Services International to simulate well conditions in actual customer's wells and to develop a pumping system tuned for the wells characteristics.

The results of the work on this grant have provided a tool for use in evaluating various design parameters along with the prediction of a significant increase in the system pumping capacity. The model indicates that a 114% pumping capacity increase can be realized by increasing the length and number of fluid chambers and increasing the size of the air lines.

EXECUTIVE SUMMARY

This intent of this project was to improve the pumping capacity and depth of an existing Airlift Services pump design. The goal is to achieve 100 barrels per day pumping capacity at a depth of 3000'. The current system performance is in the range of 60 barrels per day at a depth of 1200 feet.

This report details the steps taken to achieve the goal. The project included 3 major phases. The first phase of the project was to identify a method for determining the optimum system performance. The design of this pumping system allows for the variation of a number of system parameters without creating a major redesign. For this reason the best method for selecting the system with the optimum performance is to use a computer modeling system to evaluate numerous design alternatives. The second phase of the project was to validate the computer model. Validation of the computer model included developing a module to record system operating parameters in the test well. Actual well data can then be compared to the computer predicted performance. The final phase of the project was to use the computer simulation to predict the optimum performance of the system and to build a prototype of that system and measure the performance in an operating well.

To better understand the results of this grant project requires an understanding the operation of the pumping system. The current technology uses compressed gas as the driving force to move fluid from the well to the surface. The major components of the system are an in hole pump along with a compressor on the surface. The in hole pump consists of a series of fluid chambers connected by line assemblies. The chambers are connected in series with the line assemblies at a spacing of approximately 250 feet. The line assemblies consist of a fluid product line and two gas lines. The two gas lines deliver gas pressure to each of the chambers. The fluid chamber includes a float to control fluid and gas pressure shut off and a number of check valves to control fluid flow. The pump is placed in the well such that the bottom chamber is below the static fluid level of the well. The operation of the pump begins with the well fluid filling the bottom chamber. Gas pressure is then applied to the chamber to force the fluid from the bottom of the chamber. The check valve forces the fluid to flow into the line assembly and ultimately into the fluid chamber that is directly above. After the fluid fills the upper chamber the gas pressure is applied to this chamber to force the fluid to the next higher chamber. This process continues until the fluid is raised to the surface. In the system operation, all of the even chambers are pressurized at the same time driving the fluid to the odd chambers. All of the odd chambers are then pressurized to drive the fluid to the even chambers.

Phase 1 of this project was to identify a method for determining the optimum system performance. The system design allows for variation of the factors listed in the table below without creating a major redesign whose costs would be outside of the scope of this grant.

SYSTEM PARAMETER	MINIMUM SETTING	MAXIMUM SETTING
Air Line Diameter	0.375 in	0.625 in
Length of Fluid Chamber	10 ft	20 ft
Number of Fluid Chambers	4	12
Fluid Line Diameter	1 ⅜"	1 ½"
System Operating Pressure	125 psi	175 psi

Evaluating all of the parameters listed above at their extreme points would require building and testing 32 different designs. The most effective way to evaluate these parameters is to use a simulation model to predict the performance of the various designs. The AMEsim computer software program was selected to perform this task.

When using any simulation tools to predict performance of actual hardware a validation of the tool is required. This validation of the computer modeling software was accomplished in phase 2 of the project. To validate the computer model certain system performance characteristics are measured in physical system operation and compared to those same characteristics predicted by the program. The characteristics to be measured were:

1. Chamber gas pressure
2. Chamber fluid pressure

These measurements must be performed at the chamber within the well. This necessitated the development of a data recording module that could be incorporated in the pumping system. The measurement system used pressure transducers for the fluid and gas pressures. The recording module was mounted between the top manifold of the chamber and the transition adaptor. The comparison of the computer model to the actual test data showed a strong correlation on the exhaust side of the air cycle and a weaker correlation on the pressure side. The error is due to the inability of the computer to model supersonic flow. The initial flow of air from the compressor on the surface is supersonic. This error can be accounted for in the exhaust model but can not be addressed in the pressure side of the model. The fluid flow correlation could also be improved by adding significant detail to the model. This amount of work is beyond the scope of this project. Although the model does not exactly match the test data it has shown to be accurate enough to evaluate design alternatives and predict relative improvement.

The optimum system performance is predicted by setting the various design parameters at the levels listed in the table below.

SYSTEM PARAMETER	CURRENT SETTING	OPTIMUM SETTING
Air Line Diameter	⅜"	⅝"
Chamber Length	10 ft	20 ft
Number of Chambers	4	12
Fluid Line Diameter	1 ¼"	NA
System Operating Pressure	150 psi	175 psi

The predicted performance of this system is a 114% increase in pumping capacity.

The final phase of the project was to build and test the optimized system. For a number of reasons the optimum system tested was not the system defined by the computer model. The factors affecting the decision on the pumping system to build included:

1. Inability to make connections to chambers using ⅝" air lines.
2. Market viability of a system with 12 chambers for 1000'
3. Costs associated with building prototype chambers and line assemblies.

While attempting to design the prototype using the ⅝" air lines it was determined that a major redesign of the transition adaptor and transition shell would be required. In evaluating the total system cost it was determined that a 12 chamber design would increase the cost to the point that the system could not be sold. An evaluation of the system cost vs. system performance increase determined that the most cost effective system to test would be one that utilized 6 chambers and ½" air lines. This system did achieve a 50% improvement in pumping capacity.

During the test of the optimized system a data logger was used to measure the energy usage. The energy comparison showed a 24% improvement in energy usage for the higher volume pumping system. This is due to the lower number of cycles needed to generate the higher pumping capacity along with the lower frictional losses associated with the larger air lines.

EXPERIMENTAL

This study is performed using the AMEsim software. This commercial software performs a system run simulation based on a model developed by the user. The model is assembled by defining the system components. The computer uses the underlying differential equations to come to an iterative solution at each time step. The computer system also has the capability of performing an optimization based on providing variable parameters for system components.

The data recording module is a two piece construction made of brass and an acrylic cover. A picture of the module is shown in figure 1. The module will be located at the top of the chamber as shown in figure 2.

The data acquisition system will also be housed in the recording module. The data acquisition system will consist of the following components:

1. Embedded microcontroller – Parallax basic stamp 2p module
2. Mass storage – Rogue Robotics uMMC serial data module
3. Power system – Lithium polymer batteries with regulated voltage
4. Communication system – MaxStream Xbee-Pro 802.15.4 OEM RF module for wireless communication
5. Timing – DS1302 timekeeping chip
6. Data conversion – Maxim multirange 8-channel serial 12 bit a/d converter

Energy measurements were recorded using an Amprobe DM-2 Pro Data logger.

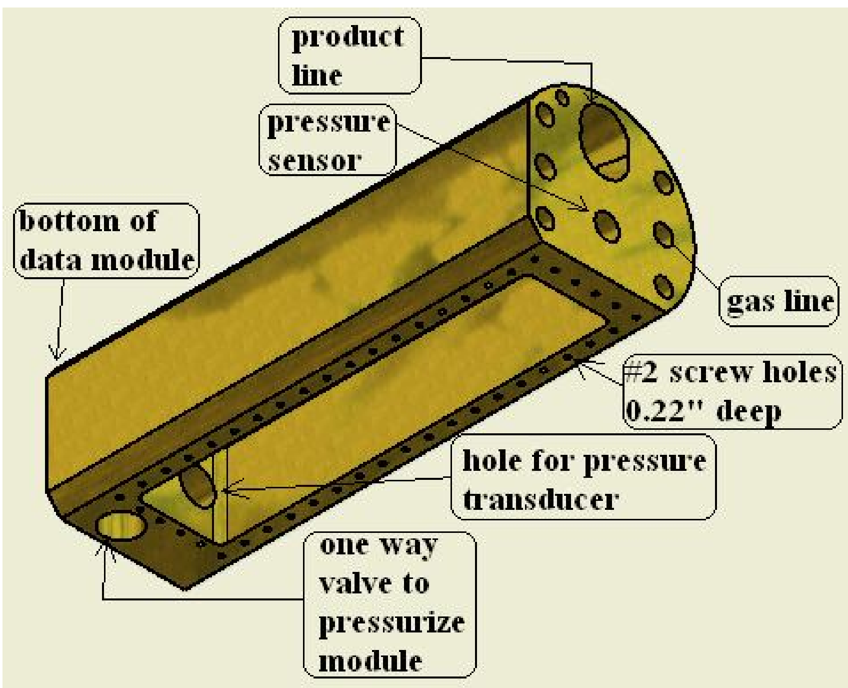

Figure 1 – data module

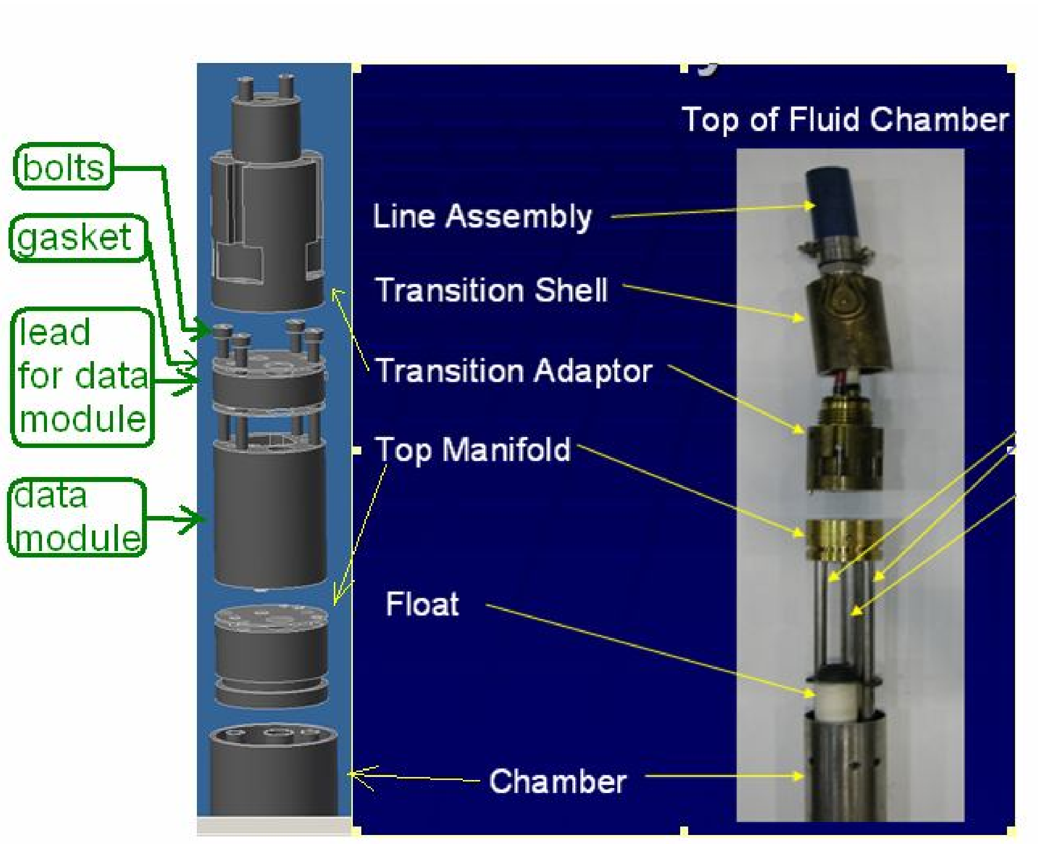

Figure 2 – Location of data module in pump

RESULTS

System Model

The phase 1 portion of this project was to use a computer simulation model to predict the performance of a pumping system for a 1000' well. The current system configuration would utilize four pumping chambers for this system. The system would have to following design parameters:

DESIGN PARAMETER	SETTING
Air Line Size	⅜"
Fluid Line Size	1 ¼"
Chamber Length	10'
Number of Chambers	4
Distance Between Chambers	240'
Operating Pressure	150 psi

The computer simulation predicted the performance to be 57 barrels of fluid per day.

Actual field performance for this system has been in the range of 45 to 60 Bbls per day. The field performance is typically degraded from the predicted performance due to the presence of gas in the fluid that is released from the fluid as it is pumped to the surface.

Model Validation

The correlation of the model data to the field test data is shown in figures 3 and 4. The 2 chambers that are shown are the bottom chamber (chamber 4) and the second from the bottom chamber (chamber 3). The data shows excellent correlation between the model and the test data for the exhaust portion of the cycle. This correlation is shown by comparing the gas pressure curves. The gas pressure curve marked as HAL is the field test data. A comparison of the pressure side of the curve shows that there is a difference in the fill rate. The fill rate for the model is approximately 5 psi/sec while the test data shows a fill rate of 13.5 psi/sec. The fill rate difference is due to the fact that in the field test the initial fill rate is controlled by supersonic air flow. The model is not capable of modeling that flow. In the exhaust side of the cycle the supersonic flow is modeled by using a large orifice size. This yields adequate results due to the fact that the system is exhausting into atmospheric pressure. This can not be accomplished with the fill side of the cycle. The data also shows that computer predicts that the fluid will flow at a lower pressure differential between the chambers. This is due to the fact that the model does not include the inertia required for the fluid to unseat the check balls. The overall time for the fluid to move between the chambers is within 10% between the model and the test data.

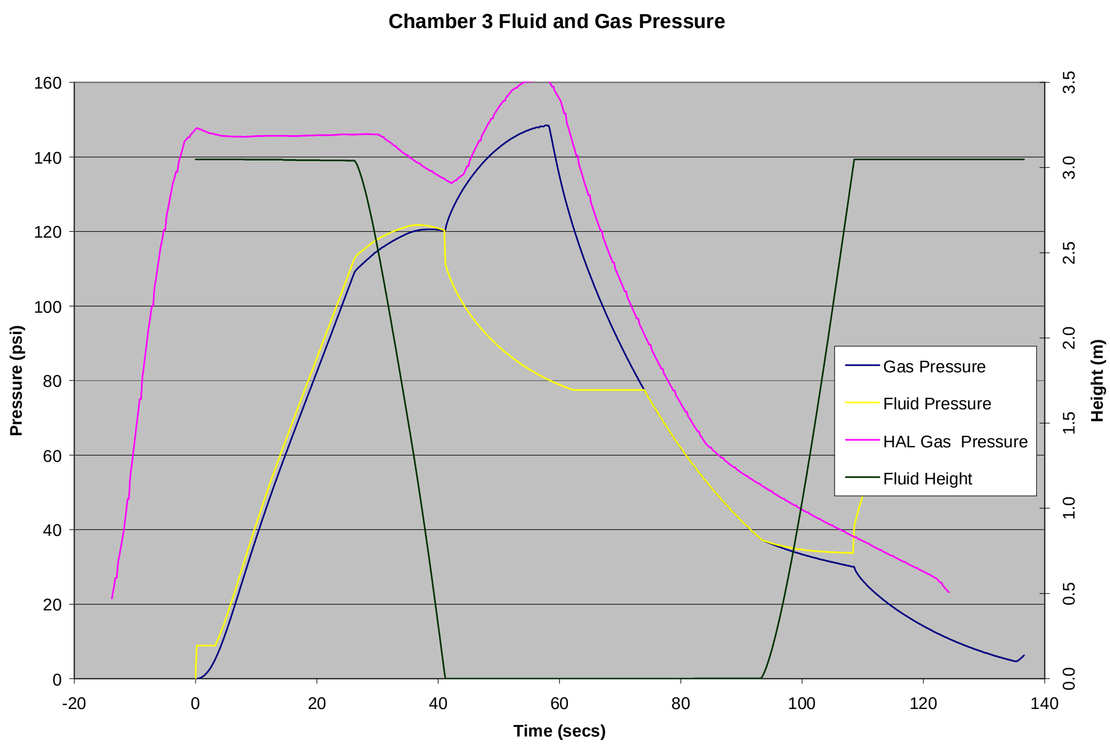

Figure 3 – Computer simulation vs. field test data for chamber 3

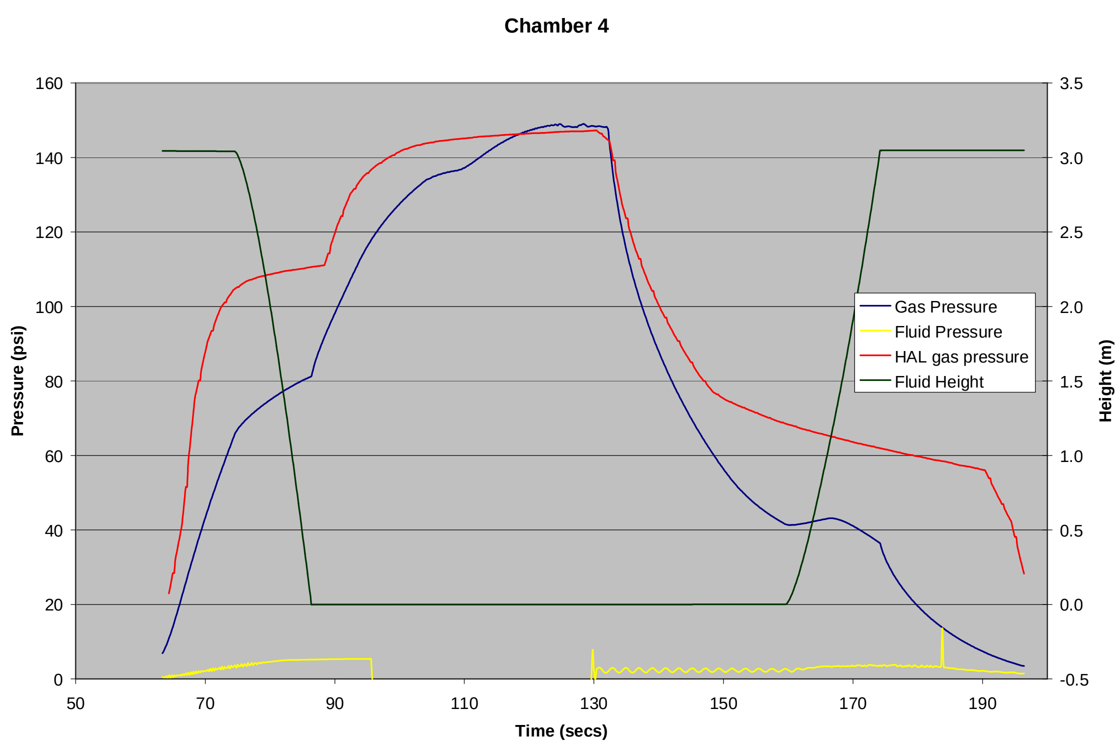

Figure 4 – Computer simulation vs. field test data for chamber 4

Optimization

The goal of the optimization study was to determine the best setting for the chosen system parameters to achieve the maximum pumping capacity. Several experiments were run to determine the significance of the various design parameters. The design parameters are listed below in their order of importance.

1. Air line diameter
2. Length of fluid chambers
3. Number of fluid chambers
4. Operation pressure
5. Fluid line size

Some initial modeling indicated that the fluid line size had no significant effect on the pumping capacity. The remaining factors were studied in a full factorial experiment. In these simulations the factors were set at either their minimum or maximum values.

The optimum system taken from the full factorial experiment is shown in the following table.

SYSTEM PARAMETER	BASE SYSTEM	OPTIMIZED SYSTEM
Air Line Diameter	0.375 in	0.625 in
Length of Fluid Chamber	10 ft	20 ft
Number of Fluid Chambers	4	12
Distance Between Chambers	230 feet	63 feet
Operating Pressure	150 psi	175 psi

The optimized system predicts a maximum fluid capacity of 121.5 Bbls per day. This value is a 114% increase from the performance predicted for the base design.

Due to factors such as design limitation and system economics the system with maximum performance was not tested in the final test. The final test consisted of a system that has a much higher commercial viability. The results of this test in the Energy Inc.'s wells yielded a pumping capacity of 91 bbls/day. This is a 50% increase over the current system.

Energy Measurements

Due to the operator concerns over energy usage with the system, the energy usage was measured during the testing for the system validation and the optimum design. The results of the energy measurement showed an energy usage reduction for the higher output pumping system. The current pumping system required 2.48 kwh/bbl compared to a 1.89 kwh/bbl for the optimized system. The actual energy measurements are shown in figures 5 and 6.

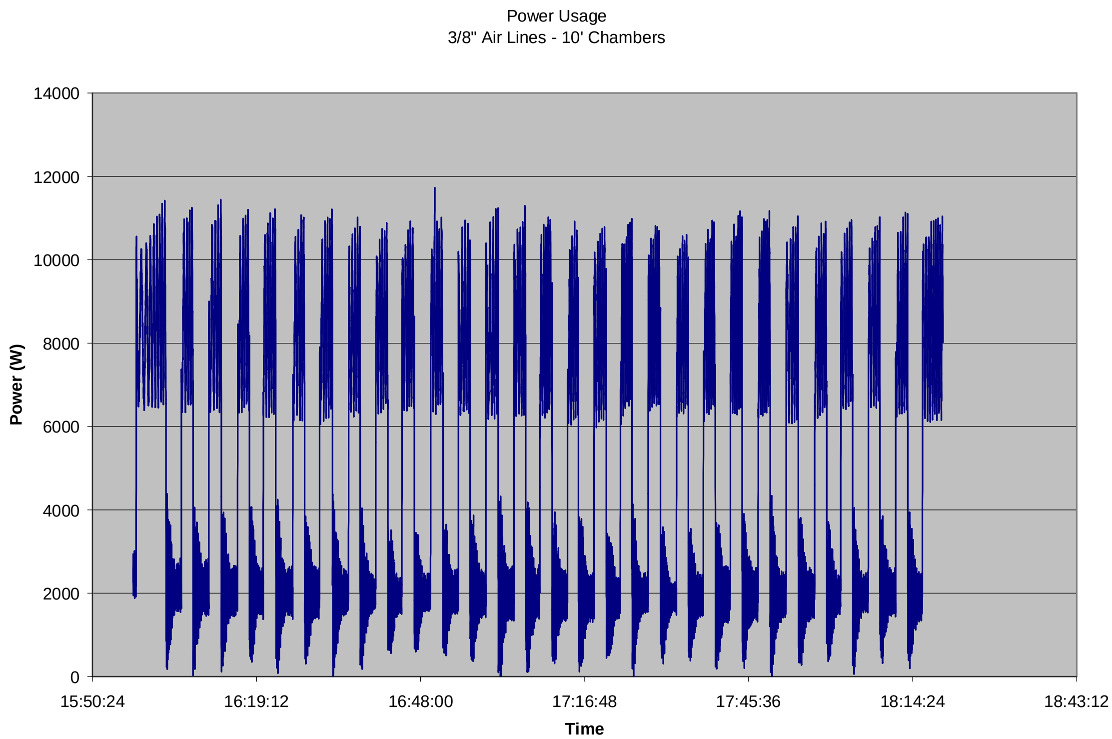

Figure 5 – Power vs. time curve for current system

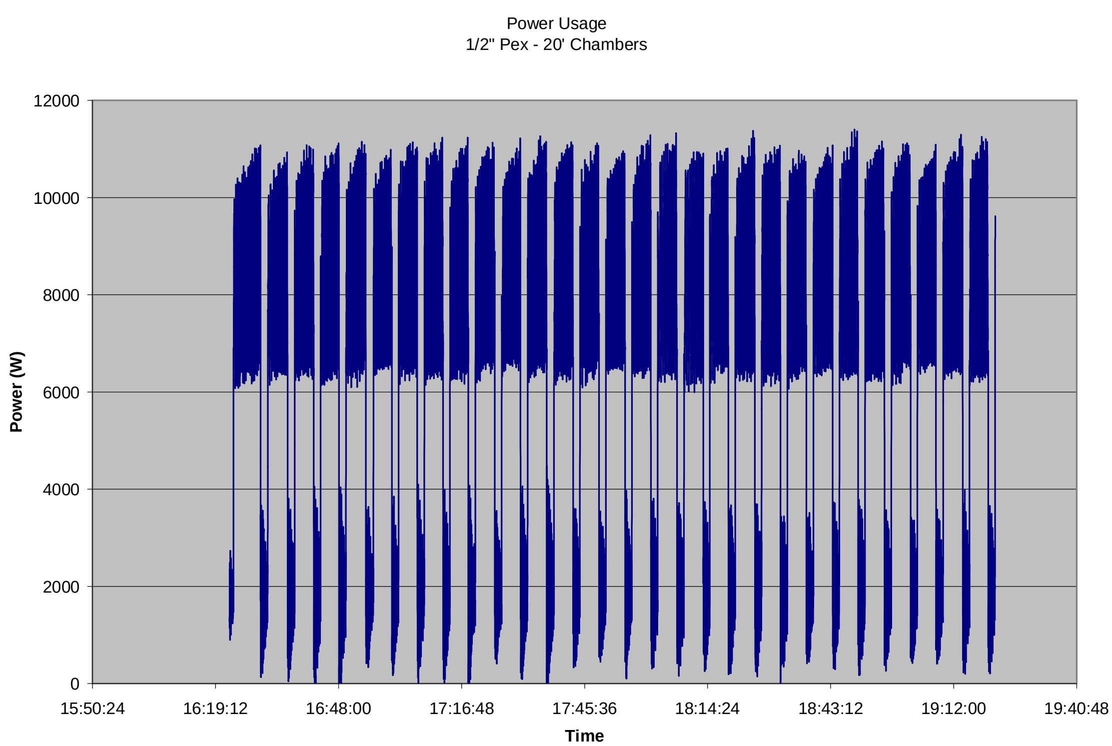

Figure 6 – Power vs. time curve for optimized system

CONCLUSIONS

Although the stated goal of achieving 100 bbls/day pumping capacity at a depth of 3000' were not achieved due to design limitations and economic viability the results of this grant still provided a 50% increase in pumping capacity. This increase in capacity will allow the market for this product to grow by 75%. The lowered energy usage while generating higher pumping capacity will also add to the sales potential of the product.

The results of the computer modeling show that there is a potential to achieve a 114% increase in pumping capacity by increasing the number of chambers from 4 to 12 in a 1000' system. At the current cost for the system that would result in a 200% increase in sales price to the customer. Considerable effort must be made in reducing the system cost so that this potential could be achieved. The optimum system that was tested will increase the system sales price by 20%. The short term plans for cost reductions should allow this system to be offered at the current system price within 6 months.

The final analysis indicates that the computer modeling system can be effective at evaluating design alternatives prior to building prototype samples. Additional detail in the model are required if it is desired to use the model to accurately predict the final performance of a given system design.

The results of this grant project have also provided a direction for future designs of the existing product. Increasing the size of air lines and length of fluid chambers offers the potential for significant increases in pumping capacity. These changes would require a major redesign of the pumping system. These design changes are beyond the scope of this grant.

REFERENCES

None