SHALLOW GAS DEWATERING PUMP CONSORTIUM

SUMMARY OF ACTIVITIES (2009 – 2013)

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EXECUTIVE SUMMARY

On January 27, 2011, the Minister of Western Economic Diversification (WD) and the Petroleum Technology Alliance Canada (PTAC) entered into an agreement whereby WD would partially fund a project to review available technologies that claim to effectively and economically dewater natural gas wells. Under this arrangement, PTAC agreed to form a consortium of natural gas producers as well as representatives of the provincial governments of Alberta and Saskatchewan for the purpose of bench testing and field testing shallow natural gas well pumps from Canadian equipment vendors with a view to having a number of these vendors ensure their equipment was market ready, commercially available, and advertised to the upstream natural gas industry in general.

The consortium established a series of performance criteria required of an effective gas dewatering pump. These criteria were presented or sent to a general audience of small and medium enterprises (SMEs) requesting they propose a solution to the gas dewatering issue that would meet these criteria. In the end, 19 proposals from various SMEs were received and reviewed by the consortium. Six of these proposals were determined to be sufficiently advanced enough to warrant further investigation.

The consortium engaged C-FER Technologies (1999) Inc. (C-FER) to determine the operational functionality of the 6 candidates selected. C-FER was tasked to interview each pump manufacturer, design and build an appropriate bench testing apparatus, test the functionality of each pump, and report their results to the consortium. C-FER conducted bench tests on 5 of the 6 candidates selected. C-FER and the consortium observed the manufacturer’s test of the sixth pump and determined that an additional bench test by C-FER would be unnecessary. A brief summary of the results of these tests are included in this report.

Based on C-FER’s test results, the consortium selected 3 pumps for an extended controlled experimental field trial to confirm that observed laboratory bench test results could be duplicated with a full scale model. C-FER designed, planned, and executed the full scale model tests of 2 pumps, while Cenovus designed, planned, and executed the field test of the third pump. A brief summary of the results of these tests are also included in this report.

The program was completed on March 31, 2014 and concluded that of the 6 pumps bench tested by C-FER, the 2 that were selected for full scale testing by C-FER (the jet pump and the modified plunger pump) are functionally satisfactory and commercially available. At the time of the publication of this report, a “satisfaction evaluation” summary and wrap-up of the project with SME participants, corporate partners, and interested industry participants to fully conclude the project is scheduled to be held in June, 2014.

INTRODUCTION AND BACKGROUND

In mid-2009, Cenovus Energy Inc. (Cenovus) recognized a requirement for a more systematic method of discovering and testing affordable and reliable methods to dewater shallow gas wells. Although significant innovations had been made in shallow gas well dewatering technology, Cenovus realized that the new technology was poorly understood by natural gas producers, had negligible market penetration, and was being developed competitively rather than cooperatively. This approach resulted in abnormally high costs, repetitious mistakes, and high failure rates. As a result, affordable technology development in shallow gas dewatering, from both the manufacturers and users standpoints, was being seriously impeded.

As an alternative, in early 2010, Cenovus proposed to its industry counterparts that a consortium be formed to assist in gas dewatering research and development by setting standards and goals for pump equipment design, developing a mechanism to test equipment using controlled and standardized methods, and providing an avenue to allow innovations to obtain market exposure to all those interested in the technology.

To this end, on August 31, 2010, Cenovus Energy Inc., Encana Oil and Gas Partnership, Enerplus Corporation, Alberta Energy and the Petroleum Technology Alliance of Canada (PTAC) (the Consortium) entered into an agreement whereby the Consortium would fund and PTAC would facilitate and work with a steering committee composed of a representative of each of the Consortium members to develop a screening and testing process for dewatering natural gas wells. On January 27, 2011, the Minister of Western Economic Diversification (WD) and PTAC entered into an agreement whereby WD would provide additional funding to the project through PTAC to ensure the construction of the testing equipment and to facilitate the market penetration of the successful technology beyond the founding companies to the industry at large. At this time, the Consortium was joined by WD, C-FER and the Government of Saskatchewan.

CONSORTIUM OBJECTIVES

The Consortium’s two primary objectives were: to set standards and goals to assist SME’s in designing and developing technology for dewatering gas wells, and to determine the functionality of selected SME technological proposals, based on these standards and goals, before implementation of a full field installation and test by an operating company. Within the limits of the funding provided by the Consortium, the plan to accomplish these objectives was as follows:

1. Set goals or expectations for gas well dewatering pumps that would clearly define the design criteria required by operating companies to guide technological development by interested SME’s.
2. Publicly invite all interested SME’s to submit their proposals to meet these expectations.
3. Screen 18 to 20 proposals for technical merit and market readiness.
4. Based on the most promising technical merit and the most advanced market readiness, select 5 to 7 of these proposals for further investigation.
5. Establish standards and methodologies to bench test these 5 to 7 proposals for functionality in shallow gas production operations.
6. Construct the equipment required to perform the bench tests.
7. Based on test results, select 2 to 4 proposals for a controlled full scale field test.
8. Establish standards and methodologies to determine the functionality of the technology during the field test of these 2 to 4 proposals.
9. Obtain a wellbore that will allow for controlled testing of the selected pumps and perform the full scale field tests.

In addition to its primary objectives, the Consortium also desired to provide technical and business support to all applicants who submitted proposals. This was accomplished at individual meetings with each applicant who submitted a proposal. Representatives of the Consortium provided frank comments, criticism and advice to the applicant regarding their proposal. The result of these meetings was either a modification to, or a withdrawal of the original proposal. A table summarizing the objectives and results to date of the Consortium's efforts is shown below:

CONSORTIUM PERFORMANCE INDICATOR	ACTIVITY GOAL	ACTIVITY ACHIEVED
# of Technology Demonstrations	4	6
#of Technologies to Market	2 - 4	3
# SME's receiving a product evaluation	10	19
# SME's prototype bench tested	5	5
# "Satisfaction Evaluation" of SME and Corporate Partners	1	To be done, June 2014
# SME technical feedback and business support	18	19
# Alberta and Saskatchewan participants	18	19

Figure 1: Summary of Objective Goals and Achievements

PUMP PERFORMANCE EXPECTATIONS

By February, 2011, the Consortium had established a series of performance criteria required of an effective gas dewatering pump. These criteria were:

- Fluid production rates between 1 and 10 barrels per day.
- Gas production rates between 5 and 200 Mscfd.
- Manage up to 10% solids by volume.
- Minimum sandface pressure = 0 psig.
- Wellbore depth up to 1000 meters.
- Minimum casing size = 4.5 inches.
- Maximum turnkey installed price = $50,000. Desired turnkey installed price = $10,000.
- Must operate in the absence of on-site power.

These criteria were presented or sent to a general audience of SMEs requesting a proposed solution to the gas dewatering issue that would meet these criteria. In the end, 19 proposals from various SMEs were received and reviewed by the Consortium. After individual interviews with each applicant, 8 of these proposals were determined to be sufficiently advanced to warrant further investigation.

BENCH TESTS

On February 28, 2011, the Consortium engaged C-FER Technologies (1999) Inc. (C-FER) to determine the operational functionality of the 8 candidates selected. C-FER was tasked to interview each of these 8 pump manufacturers, design and build an appropriate bench testing apparatus, test the functionality of each pump, and report their results to the Consortium.

C-FER designed a flow loop to simulate the bottom of a well with the minimum casing size criteria of 4.5 inches, to insert and test the pumps in question. The flow loop was attached to pumps to introduce water and gas into the apparatus. Flow control and measurement equipment was also attached to measure the functionality of the pumps tested. A picture of the flow loop without the pumps and controls is shown below on Figure 2. A picture of the test equipment skid, which contained the flow control and measurement devices and was attached to the flow loop, is shown on Figure 3.

During C-FER's interview with the SME's selected for bench testing on the flow loop apparatus, two companies withdrew their proposals. In addition, C-FER and the Consortium observed a bench test performed by Lifteck International Inc. on their pump in their facilities. After this demonstration, both C-FER and the Consortium agreed that another bench test on this particular pump was not required. Thus, C-FER used their flow loop to test 5 of the 8 pumps selected. These pumps were as follows:

- A jet pump from Source Rock,
- A hydraulic piston pump from Hydro Pacific,
- An air chamber pump from Fluica,
- An electric submersible PCP from ERSI, and
- A modified rod pump from Samson.

Each of these pumps was tested for its ability to pump various combinations of water, air and solids against several discharge and suction pressure conditions. The pumps were also tested for their ability to restart after allowing 5 feet of solids to settle on top of the pump, and for their susceptibility to gas lock. A summary of the tests performed is shown on the test matrix designed by C-FER (Figure 4).

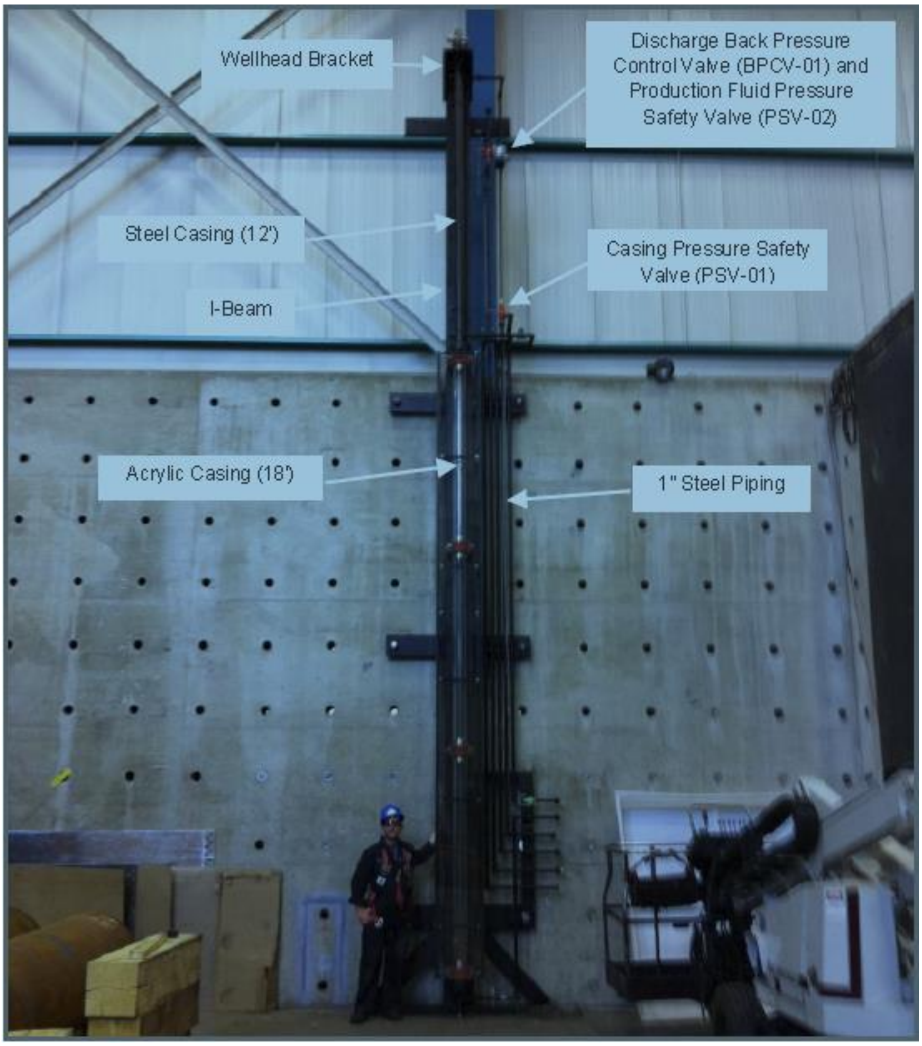


Figure 2: Casing Flow Loop Mounted on C-FER's Strong Wall ©C-FER 2012

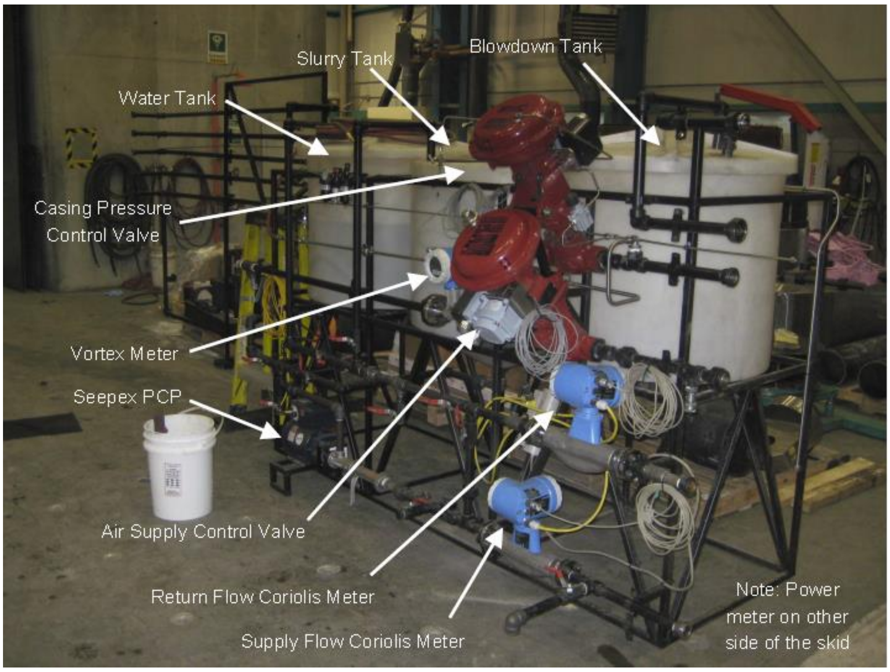
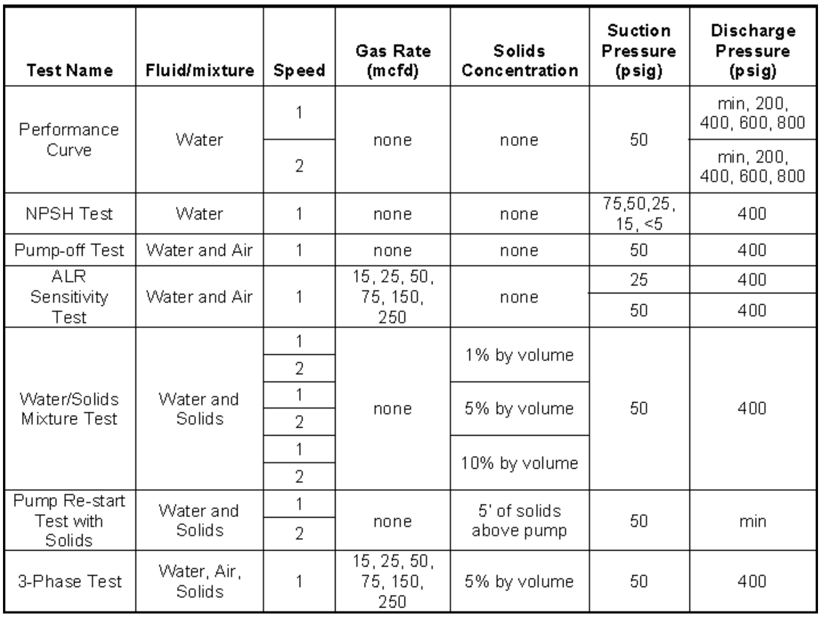


Figure 3: Test Equipment Skid ©C-FER 2012



Test Name	Fluid/mixture	Speed	Gas Rate (mcfd)	Solids Concentration	Suction Pressure (psig)	Discharge Pressure (psig)
Performance Curve	Water	1	none	none	50	min, 200, 400, 600, 800
		2				min, 200, 400, 600, 800
NPSH Test	Water	1	none	none	75,50,25, 15, <5	400
Pump-off Test	Water and Air	1	none	none	50	400
ALR Sensitivity Test	Water and Air	1	15, 25, 50, 75, 150, 250	none	25	400
					50	400
Water/Solids Mixture Test	Water and Solids	1	none	1% by volume	50	400
		2				
		1		5% by volume		
		2				
		1		10% by volume		
		2				
Pump Re-start Test with Solids	Water and Solids	1	none	5' of solids above pump	50	min
		2				
3-Phase Test	Water, Air, Solids	1	15, 25, 50, 75, 150, 250	5% by volume	50	400

Figure 4: Bench Test Matrix ©C-FER 2012

Figure 5: Bench Test of Lifteck's Gas Operated Piston Pump ©Lifteck International Inc 2012

FULL SCALE TESTS

Upon completion of the bench tests, the Consortium determined that 3 of the pumps showed the most promise with respect to performance, reliability, technical development and commercial availability. These pumps were the jet pump from Source Rock, the hydraulic piston pump from Hydro Pacific, and the gas operated piston pump from Lifteck. It was proposed that two of these pumps, the jet pump and the hydraulic piston pump, be placed in a full well bore and tested under controlled conditions to determine their respective performance with water and air, as well as to determine their respective ability to restart and operate after solids had settled over the pump discharge.

For the controlled test work, the Consortium obtained the use of test well facility owned by Enform and used for their training purposes. The Enform training well was modified by inserting 4.5 inch casing and installing a casing head donated by Weir Seaboard to simulate a producing shallow gas well (see Figure 6).

Upon fabrication of the test well, the jet pump and the hydraulic piston pump were to be tested to determine the system performance when pumping water, air and solids. A triplex pump was supplied by Cenovus to pump water into the well for testing. The Test Equipment Skid designed by C-FER for the bench test was utilized for flow and measurement purposes. The two pumps selected were subjected to the test matrix shown in Figure 7.

It was further proposed that the remaining pump, Lifteck's gas operated hydraulic piston pump, be tested on a proprietary Cenovus well. The Lifteck pump was installed on the selected well on October 10, 2013. Pressure gauges were incorporated into the pump installation design with the intention of having CFER analyse the data for the benefit of the consortium prior to its conclusion. However, upon installation, it was discovered that the wellbore configuration needed to be altered to properly test the pump and obtain reliable and usable test data. Unfortunately, conflicting Cenovus priorities and an unusually harsh 2013-2014 winter prevented the necessary wellbore alterations from being finalized, thus this test remains incomplete at the time of the publication of this report.

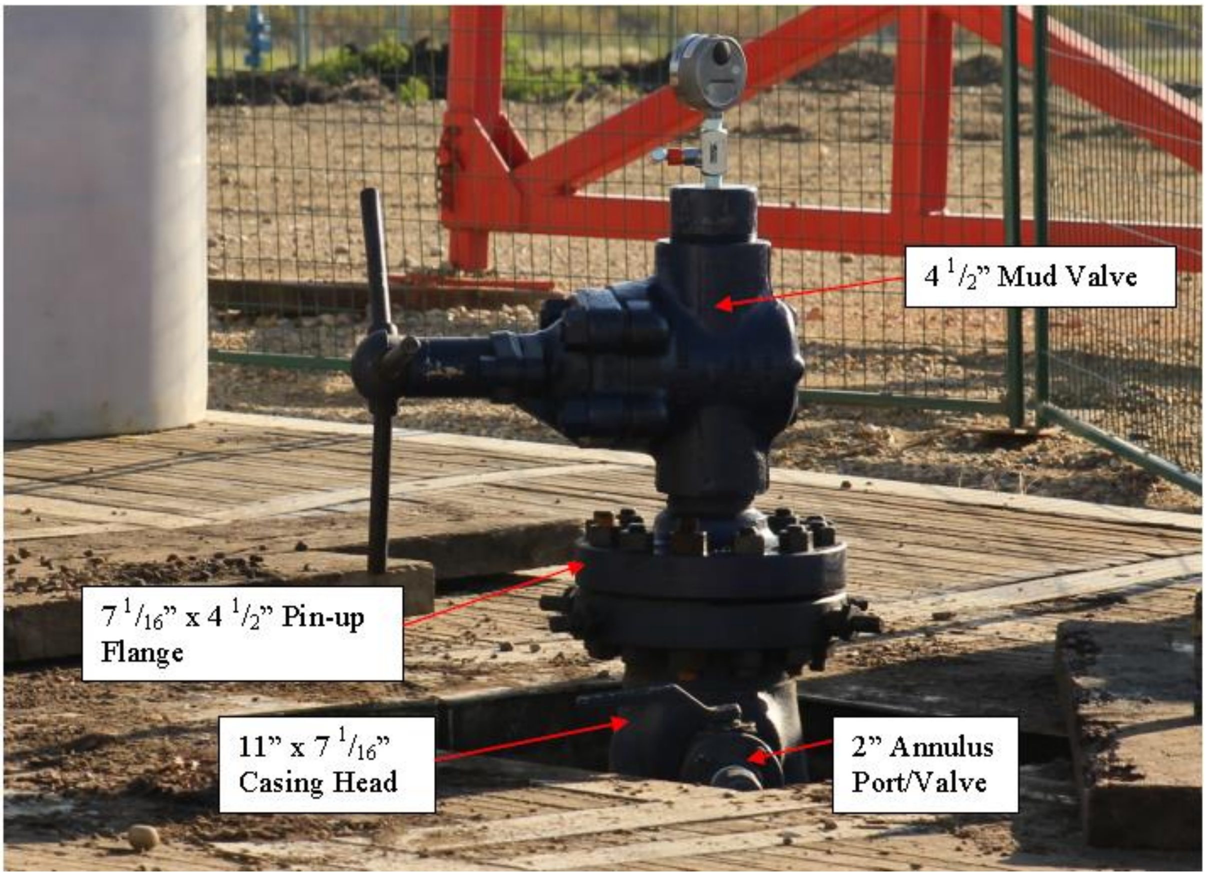
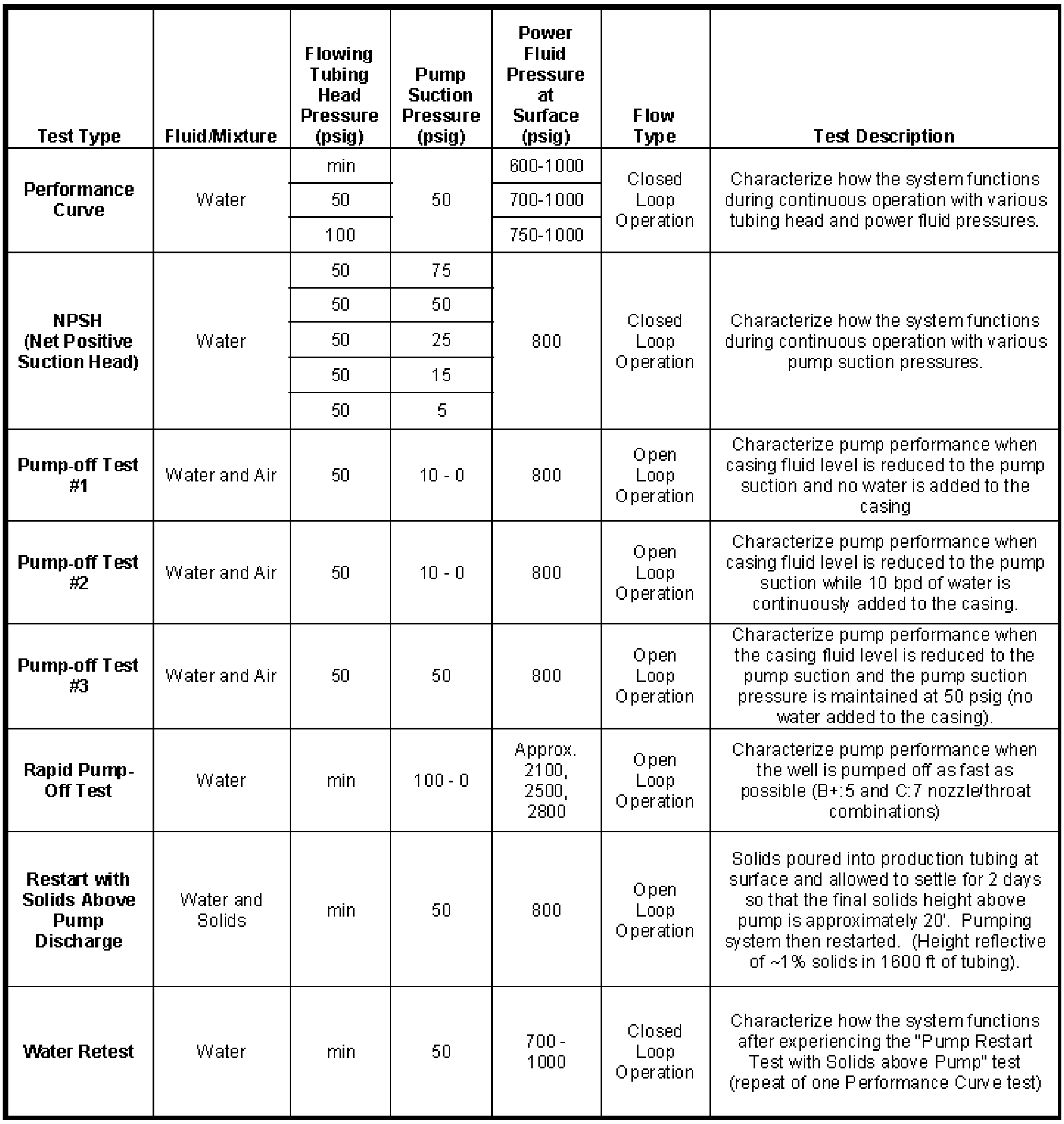


Figure 6: Test Well Casing Head ©C-FER 2012



Test Type	Fluid/Mixture	Flowing Tubing Head Pressure (psig)	Pump Suction Pressure (psig)	Power Fluid Pressure at Surface (psig)	Flow Type	Test Description
Performance Curve	Water	min	50	600-1000	Closed Loop Operation	Characterize how the system functions during continuous operation with various tubing head and power fluid pressures.
		50		700-1000		
		100		750-1000		
NPSH (Net Positive Suction Head)	Water	50	75	800	Closed Loop Operation	Characterize how the system functions during continuous operation with various pump suction pressures.
		50	50			
		50	25			
		50	15			
		50	5			
Pump-off Test #1	Water and Air	50	10 - 0	800	Open Loop Operation	Characterize pump performance when casing fluid level is reduced to the pump suction and no water is added to the casing
Pump-off Test #2	Water and Air	50	10 - 0	800	Open Loop Operation	Characterize pump performance when casing fluid level is reduced to the pump suction while 10 bpd of water is continuously added to the casing.
Pump-off Test #3	Water and Air	50	50	800	Open Loop Operation	Characterize pump performance when the casing fluid level is reduced to the pump suction and the pump suction pressure is maintained at 50 psig (no water added to the casing).
Rapid Pump-Off Test	Water	min	100 - 0	Approx. 2100, 2500, 2800	Open Loop Operation	Characterize pump performance when the well is pumped off as fast as possible (B+:5 and C:7 nozzle/throat combinations)
Restart with Solids Above Pump Discharge	Water and Solids	min	50	800	Open Loop Operation	Solids poured into production tubing at surface and allowed to settle for 2 days so that the final solids height above pump is approximately 20'. Pumping system then restarted. (Height reflective of ~1% solids in 1600 ft of tubing).
Water Retest	Water	min	50	700 - 1000	Closed Loop Operation	Characterize how the system functions after experiencing the "Pump Restart Test with Solids above Pump" test (repeat of one Performance Curve test)

Figure 7: Test Matrix for Full Scale Pump Test ©C-FER 2012

SUMMARY OF PUMP TEST RESULTS

1. Jet Pump by Source Rock

How it Works

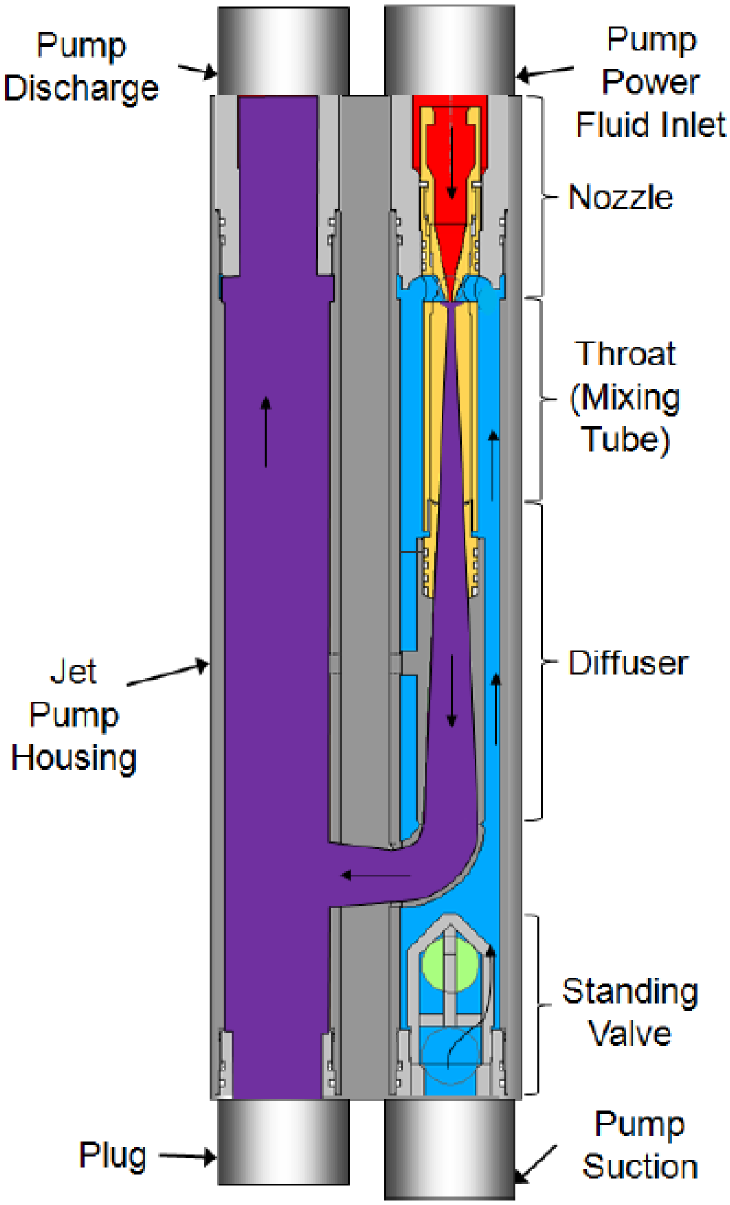


Figure 8. Schematic of Source Rock® Jet Pump System ©C-FER 2012

Jet pumps work by pumping a power fluid from surface at high pressure through a venturi tube mechanism at the bottom of the well. As the power fluid passes through the venturi tube system, it creates a vacuum that draws fluid from below the venturi mechanism into the power fluid stream. A common example of this type of pump would be a liquid lawn fertilizer bottle that attaches to a garden hose. Water from the garden hose is directed through the venturi system at the top of the fertilizer bottle at high pressure, creating a vacuum in the venturi mechanism. This vacuum sucks liquid fertilizer from the bottle through a tube that extends from the venturi system into the bottle of fertilizer. The fertilizer and water mix together allowing the fertilizer to be spread on the lawn with the water.

Advantages of the Source Rock® Jet Pumping System

1. They have no moving parts down hole.
2. They can handle very high fluid volumes.
3. They work well in deviated and horizontal wells.
4. They can handle large amounts of solids, corrosive fluids and gas.
5. They work very well with viscous fluids like heavy oil.
6. They are low maintenance and are easy to repair.
7. They can be operated continuously or intermittently.
8. Usually, jet pumps require specific bottom hole assemblies, thus are not flexible to changing down hole conditions. However, in the Source Rock® pump configuration, the carrier including the throat and nozzle can be circulated out of the well allowing it to be easily changeable and adaptable to a wide range of down hole conditions.

Disadvantages of Jet Pumping Systems

1. Jet pumps require expensive surface facilities such as pumps, high pressure lines, and separation equipment.
2. Jet pumps require a service rig for installation. If the well has tubing installed, a coiled tubing rig is required to install the pump.
3. Jet pumps are very inefficient compared to other artificial lift systems.

C-FER® Test Results on Source Rock Engineering Partners Inc.® Jet Pump

1. Flow test results were very comparable to theoretical curves from jet pump theory, although the required power fluid rates and pressures were slightly higher than predicted by the Source Rock design program.
2. The overall system efficiency was calculated at approximately 11%. This calculation was significantly affected by the triplex pump skid used to pump the power fluid during the test.
3. Pump cavitation occurred as predicted by theoretical equations in the literature.
4. Net Positive Suction Head (NPSH) tests showed that production at very low suction pressures was possible.
5. The water pump-off test revealed that the jet pump was able to operate with little to no available suction fluid and would even produce some casing gas along with the suction fluid.
6. The jet pump was able to produce fluids containing sand at concentrations as high as 10% by volume but required slightly higher power fluid pressure to produce at the same jet pump suction flow rate.
7. The jet pump was able to restart and perform as expected after approximately 5 feet of solids was allowed to settle on top of the pump.
8. Post-test measurements of the nozzle and throat mechanism showed that only minimal wear occurred after the solids delivery test.

Limitations of the C-FER® Test on Source Rock® Jet Pump System

1. By necessity, the bench test installation was a slightly scaled down version of a full field installation. As a result, some of the data collected may not be representative of the results obtained from a full field installation.
2. The test procedure altered the chemistry and thus the physical properties of the solids supplied by Enerplus for the test. Therefore, the results of the solids lifting experiments may not be able to be duplicated in actual field trials.
3. Test duration was insufficient to definitively determine the effect of solids production on the throat, nozzle, and valves of the pump mechanism.
4. The test utilized an improperly sized power supply to the power fluid pump, resulting in an erroneously low overall pump efficiency observation.
5. The test equipment was unable to deliver a gas-liquid mixture to the pump intake, thus a gas-liquid ratio sensitivity test and a three-phase flow test could not be performed.

C-FER® Test on Source Rock® Jet Pump System Conclusion

1. The test showed that the Source Rock® pump can effectively remove a wide range of water influx rates with a wide range of solids entrainment from shallow gas wells.
2. The tests revealed that the application for this type of system should be carefully chosen because of the poor overall efficiency of the equipment.
3. The pump satisfied all of the pump performance expectations established by the Consortium at the beginning of the project, except that it was estimated that the minimum installed turnkey price would most likely exceed $50,000.
4. The technology is field ready, thus it was recommended that this pump be tested on a full scale, controlled well test environment to confirm the bench test results.

Results of the Full Scale Test vs. the Bench Test on Source Rock® Jet Pump

1. The full scale performance test showed very similar results to the bench test of this pump.
2. The overall system efficiency was determined to be approximately 15% as compared to the calculated 11% during the bench test.
3. The NPSH test results from the full scale test were very similar to the bench test results.
4. The pump off results from the full scale test was also similar to the bench test results. An extra test was performed which showed that this pump could rapidly dewater a well by changing the throat and nozzle configurations. The benefit of this test was to demonstrate that once the well was dewatered to a pumped off condition, the pump could be shut down until dewatering was required once more. Thus, a well could be dewatered intermittently utilizing a pressure truck on a periodic basis and would not require the expensive surface equipment necessary to operate the pump on a continuous basis.
5. The pump was able to restart without incident after a 48 hour waiting period, which allowed solids to settle to approximately 20 feet above the pump intake.
6. Post-test measurements of the nozzle and throat mechanism showed that no detectable wear occurred after the test.

Project Participant Testing on Source Rock® Jet Pump

Cenovus Energy installed a jet pump system and its associated surface package supplied by Source Rock Energy Solutions into one of its wells to determine the following objectives:

1. Determine the potential for using a jet pump system as an alternative to the reciprocating rod, and PC pumps, in a typical horizontal well in this area.
2. Work through the installation process; review the production as compared to more conventional equipment.
3. Determine the cost of this equipment for installation and on-going operational costs.
4. Determine if this style of pump along with higher draw downs (early in the life of the well) is an effective way to gain incremental production.

At the time of writing of this report, Cenovus had not yet completed the test and no results are available for reporting.

2. HYGR PUMP by Hydro Pacific

How it Works:

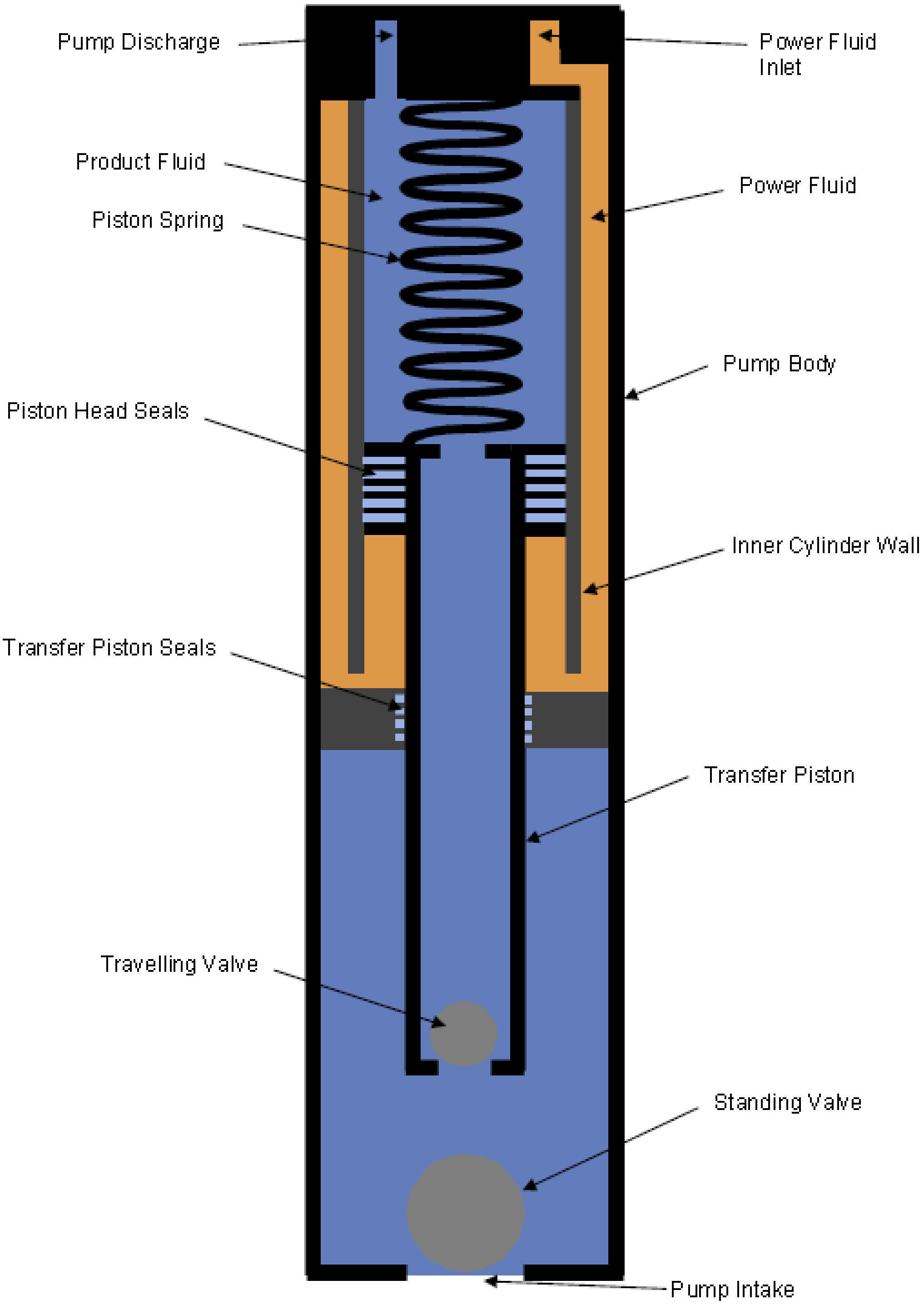


Figure 9: Schematic of Hydro Pacific HYGR® Piston Pump System ©C-FER 2012

The HYGR pump from Hydro Pacific operates like a typical plunger pump that consists of a barrel, a plunger, and a valve system to move the fluids from the bottom of the well to the surface. However, unlike the more common beam pumping systems, power to stroke the pump is performed with hydraulics rather than sucker rods attached to a beam pump at surface. When the power fluid pump at surface is activated, the power fluid is directed via a dedicated tubing string against the transfer piston seals, forcing the plunger to rise in the pump barrel. This action closes the travelling valve and opens the standing valve, allowing fluid to enter the barrel of the pump and push the fluid above the piston through the production string to surface. At the top of the stroke, the power fluid pump deactivates, relieving the pressure on the power fluid, thus the piston is forced downward by the piston spring and gravity. The power fluid recirculates back to the power fluid pump. This action closes the standing valve, and opens the travelling valve, allowing fluid to fill the plunger, awaiting transfer to the production string when the power fluid is activated again.

Advantages of Hydro Pacific's HYGR® Plunger Pumping System

1. The system is very flexible and can be used for a wide variety of depths and volumes
2. The system can pump almost any composition of oil and water mixtures.
3. Unlike other plunger pumping systems, the pump does not appear to be prone to gas locking.
4. Unlike a typical rod pump, this pump can operate in highly deviated or even horizontal applications.
5. The pump can be set with a coiled tubing rig.
6. Sucker rods and a pump jack are not required to operate the pump.

Disadvantages of Hydro Pacific's HYGR® Plunger Pumping Systems

1. The depth position of a HYGR pump is affected by the pressure capabilities of the power fluid apparatus.
2. The system must be carefully designed because the pump efficiency is sensitive to the activation and deactivation timing of the power fluid to ensure the piston able to complete its full stroke.
3. Like most plunger pumps this pump will have difficulty pumping highly viscous fluids because viscous fluids retard piston movement by gravity.
4. Plunger pumps have low overall efficiency.
5. Plunger pumps move fluid intermittently rather than continuously like PCP's or jet pumps, thus reducing its solids handling capabilities.

C-FER® Test Results on Hydro Pacific's HYGR® Piston Pump

1. Flow test results were very comparable to theoretical calculations for plunger pumps.
2. Net Positive Suction Head (NPSH) tests showed that production at very low suction pressures was possible.
3. The overall efficiency of the pump varied with the rate of volume pumped against discharge pressure, but averaged approximately 7.5% when pumping water at 10 bpd against a discharge pressure of 800 psig. The low overall efficiency was significantly affected by the improperly sized surface apparatus.
4. The water pump-off test revealed that the pump did not gas lock and was able to produce all the water supplied even though the water level was below the pump intake.
5. The plunger pump was able to produce fluids containing sand at concentrations as high as 10% by volume.
6. The pump was able to restart and perform as expected after approximately 5 feet of solids was allowed to settle on top of the pump.
7. Post-test measurements of the nozzle and throat mechanism showed no signs of wear were identified in the pump. However, it should be noted that upon re-test of the pump after the solids test, the net production flow rate had decreased under the same operating conditions. This would indicate that although the pump did not show any signs of wear, solids production does lower the pumping efficiency of the pump.

Limitations of the C-FER® Test on Hydro Pacific's HYGR® Piston Pump

1. The surface equipment could not be properly scaled down, thus was significantly oversized for the bench test equipment. This significantly affected the overall efficiency calculations for the pump.
2. The test procedure altered the chemistry and thus the physical properties of the solids supplied by Enerplus for the test. Therefore, the results of the solids lifting experiments may not be able to be duplicated in actual field trials.

3. Test duration was insufficient to definitively determine the effect of solids production on the pumping mechanism.
4. The test equipment was unable to deliver a gas-liquid mixture to the pump intake, thus a gas-liquid ratio sensitivity test and a three-phase flow test could not be performed.

Conclusion from C-FER® Test on Hydro Pacific's HYGR® Piston Pump

1. The HYGR® pump can effectively remove a wide range of water influx rates with a solids entrainment of up to 10% from shallow gas wells.
2. The pump has a very poor overall efficiency, thus the design for this type of system should be carefully planned to ensure that the piston stroke is fully completed to maximize the efficiency of the pump.
3. The pump's ability to handle a wide range of fluid influx, with an encouraging concentration of solids and minimal operational issues prompted a recommendation for further testing of this apparatus.

Results of the Full Scale Test vs. the Bench Test on Source Rock® Jet Pump

1. The full scale performance test showed very similar results to the bench test of this pump.
2. The overall system efficiency was determined to be approximately 15% as compared to the calculated 11% during the bench test.
3. The NPSH test results from the full scale test were very similar to the bench test results.
4. The pump off results from the full scale test was also similar to the bench test results. An extra test was performed which showed that this pump could rapidly dewater a well by changing the throat and nozzle configurations. The benefit of this test was to demonstrate that once the well was dewatered to a pumped off condition, the pump could be shut down until dewatering was required once more. Thus, a well could be dewatered intermittently utilizing a pressure truck on a periodic basis and would not require the expensive surface equipment necessary to operate the pump on a continuous basis.
5. The pump was able to restart without incident after a 48 hour waiting period, which allowed solids to settle to approximately 20 feet above the pump intake.
6. Post-test measurements of the nozzle and throat mechanism showed that no detectable wear occurred after the test.

Project Participant Testing on Hydro Pacific's HYGR® Piston Pump

At the time of writing of this report, none of the project's industry participants has undertaken further field testing on this pumping system.

3. SUBMERSIBLE PCP by Enhanced Recovery Services Inc. (ERSI)

How it Works:

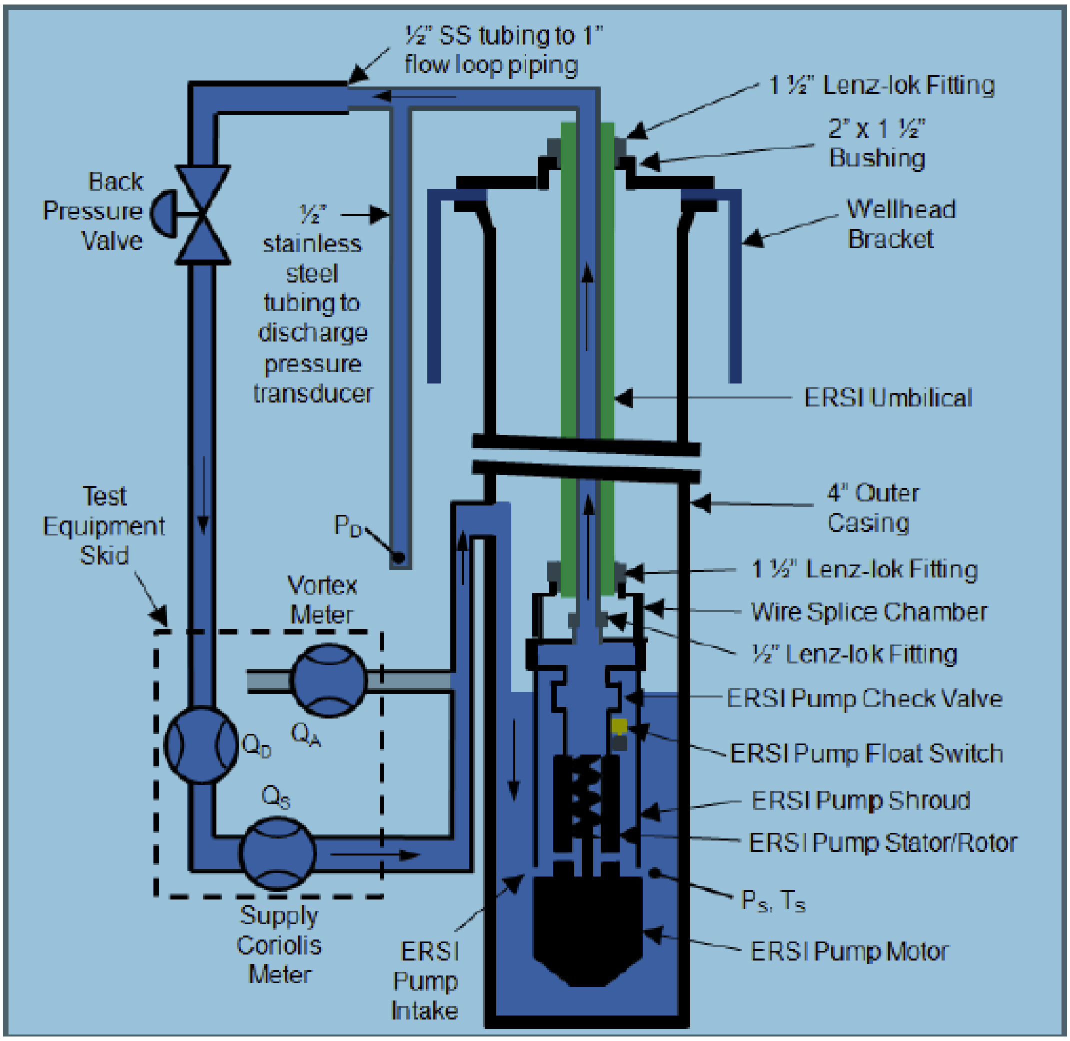


Figure 10: Schematic of ERSI Submersible PCP System ©C-FER 2012

Progressive cavity pumps (PCP) are often called screw pumps because they work by moving fluid through a sequence of small fixed shape discreet cavities by a spinning rotor. The action is much like an auger that pulls grain from the ground to the top of a storage building.

The system consists of a motor that is directly connected to a rotor which spins inside a specially designed and fit rubber frame called a stator. Most PCP rotors are driven from the surface, so the motor is connected from the wellhead to the subsurface rotor with rods. The ERSI system, however, contains a submersible electric motor that drives the rotor from below the pump.

Like any typical PCP, the ERSI rotor has a helix shape and the stator is designed to match the rotor's helix shape except that it is offset to allow a cavity to form when the rotor is sealed against one side of the rotor. Thus, there is a cavity offsetting the rotor helix that fills with fluid. The fluid is then transferred to the next cavity upward when the rotor spins. This action is shown on schematically on Figure 9.

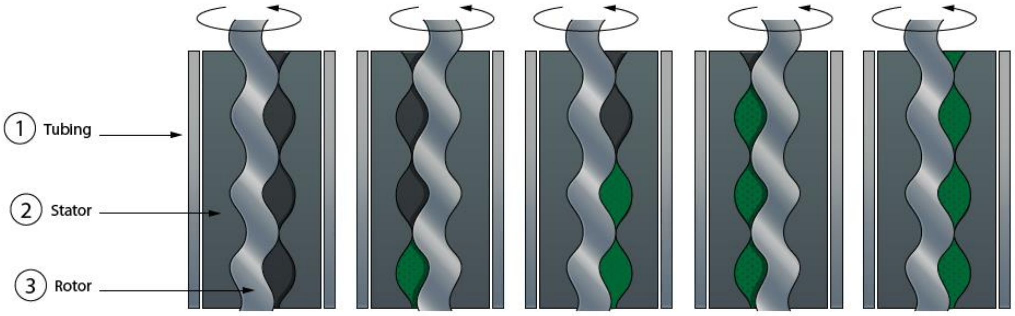


Figure 11: Schematic of PCP Pumping Operation ©**SAIT Polytechnic** 2012

A PCP's performance is dependent upon the following parameters:

- The length of the pump, because the length determines the number of cavities (or stages) available to push fluid.
- The pump rotational speed.
- The fluid viscosity.
- The fit between the rotor and stator at operating conditions (also called "slippage)
- The depth of the pump in the hole.

The design of the ERSI PCP dictates that the rotor of this pump spins of approximately 2500 rpm. Thus, especially for an ERSI pump, liquid within the pump is necessary to cool and lubricate the rotor and stator. Therefore, gas in the liquid being pumped is extremely dangerous to an ERSI pump. As a result, the pump is equipped with 3 devices design to shut down the unit so that the pump always remains submerged. The first is a paddle flow sensor in the production tubing that would detect low fluid rates and shut down the pump. The second is a float switch designed to shut the system down before the water level in the casing fell below the pump intake. The third device measures the current drawn by the submerged electric prime mover and was designed to shut down the system at unacceptably high current loads.

Advantages of ERSI® Submersible PCP Systems

1. The system has the ability to produce highly viscous fluids.
2. The system has relatively high energy efficiency.
3. The system can be installed without a service rig.
4. The system is unaffected by deviated holes.
5. The system has a constant energy demand.
6. The system has a small environmental footprint and a low noise level.

Disadvantages of ERSI® Submersible PCP Systems

1. The system must be very carefully designed as it is the least forgiving artificial lift system with respect to depth, volume, and fluid composition design parameters.
2. The system is unable to produce liquids containing gas.
3. The system currently has an unreliable low liquid level shutdown system.

C-FER® Test Results on the ERSI® PCP

1. The flow tests were as expected from theoretical equations, but the tests were not repeatable for two different pumps. C-FER speculated that this difference could have been the result of a variation of the power available on their test apparatus used to drive the electric submersible pump.
2. The low liquid level shutdown system did not operate reliably during the test. During the C-FER® test, only the float switch device worked reliably during repeated pump off tests.
3. Net Positive Suction Head (NPSH) tests showed that production at very low suction pressures was possible.

4. The pump was able to produce fluids containing solids at concentrations as high as 0.8% by volume. This was significantly less than the amount of solids that could be pumped by the other pumps tested.
5. The pump was able to restart without incident after solids were allowed to settle over the pump intake. The ERSI® pump is equipped with a self-draining check valve designed to open on pump shutdown to allow fluid to drain from the production tubing through the check valve, thus limiting the amount of solids that can collect above the pump intake. The C-FER bench test apparatus was insufficiently sized to activate the check valve with hydrostatic pressure, so C-FER tested the activation of this valve by adding pressure to the production tubing to simulate the hydrostatic pressure that would normally be present at field operating conditions. It should be noted that during the solids pumping tests, the drain valve failed to operate properly, indicating that it was fouled with solids.
6. Overall pump efficiency is a function of suction and discharge pressure, but at a constant differential pressure (discharge minus suction), the overall pump efficiency was approximately 37%.
7. Post-test measurements of the rotor and stator showed light abrasive wear on the leading edge of each lobe of the rotor and minimal damage to the stator. The stator was not cut open, so only surface damage could be observed on the stator.

Limitations of the C-FER® Test on ERSI PCP®

1. The test procedure altered the chemistry and thus the physical properties of the solids material supplied by Enerplus for the test. Therefore, the results of the solids lifting experiments may not be able to be duplicated in actual field trials.
2. Test duration was insufficient to definitively determine the effect of solids production on the working parts of the pump mechanism.
3. The test equipment was improperly sized to properly test the self-draining check valve.
4. The test utilized an improperly sized power supply to power the submersible prime mover resulting in inconsistent results for different pumps.
5. The test equipment was unable to deliver a gas-liquid mixture to the pump intake, thus a gas-liquid ratio sensitivity test and a three-phase flow test could not be performed.

Conclusion from C-FER® Test on ERSI PCP®

C-FER's bench test of the ERSI PCP indicated that the pump had insufficient solids handling capability and an unreliable low fluid level shutdown so a more extensive field test or a full scale test was not carried out.

Project Participant Testing on ERSI PCP®

At the time of writing of this report, ERSI is working on re-designing the low liquid level shut down controls. None of the project's industry participants has undertaken further field testing on this pumping system.

4. Nojak Pumping System by Fluica

How it Works:

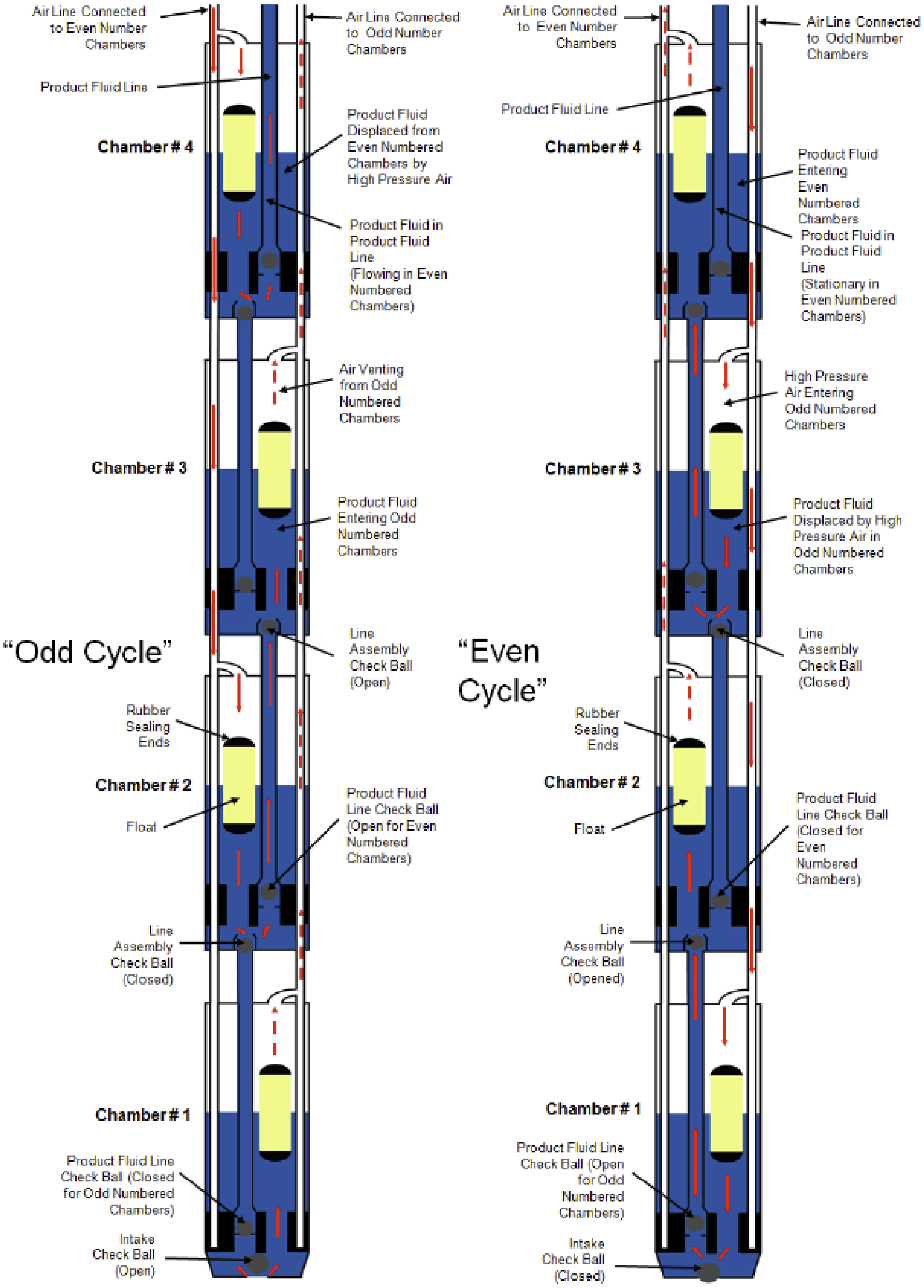


Figure 12: Schematic of Fluica's Nojack® Pumping System ©C-FER 2012

The Nojack® pumping system is a chamber lift system whereby fluid is drawn into a chamber, then moved to the surface by continually transferring the fluid to the next chamber stacked above it until the fluid reaches the surface. Fluid is introduced into the bottom (first) chamber by reducing the pressure in the cylinder. This causes fluid from the well to enter the chamber past the standing valve and causes a float to rise in the chamber. When the float reaches the top of the chamber, pressurized gas (usually air) is pumped into the chamber, forcing the float downward and displacing the fluid in the chamber into a pipe connected to the chamber above. When the float seats back into the bottom of the chamber, the air is vented reducing the pressure in the chamber, which allows fluid to enter the chamber and causes the float to once more rise in the chamber. A ball check valve in the connecting pipe prevents fluid from draining from the chamber above into the bottom chamber, thus allowing only well fluid to enter the bottom chamber.

The Nojack system alternates the filling and draining of the individual chambers by simultaneously activating the filling of the odd numbered chambers with the draining of the even numbered chambers. When the sequence is reversed (drain the odd numbered chambers, fill the even numbered ones), fluid moves through the entire length of the pump by switching the compressed air stream from the odd numbered to the even numbered chambers.

Advantages of Chamber Pumping Systems

1. The system can operate without a large footprint or conspicuous heavy machinery.
2. The system can be installed without utilizing a service rig.
3. The system can pump almost any composition of oil and water mixtures.
4. The system will not gas lock because incoming gases mix with the pressurized gas used to drive the float and is vented on the “chamber fill” stroke. However, care must be taken to ensure that the incoming gases will not create an explosive mixture with the gas (usually air) used to power the float piston.
5. The pump can handle up to 10% solids content by volume in the produced fluid because produced solids will fall only to the chamber below and not to the bottom of the well.
6. Since each chamber pumps only to the chamber above, each chamber, with the exception of the bottom chamber, can be designed to handle relatively low pressures. The bottom chamber must be designed to be capable of withstanding the shut in bottom hole pressure of the well.

Disadvantages of Chamber Pumping Systems

1. The pump must be carefully designed to ensure the “on” and “off” cycle times for the pressurized gas are sufficient to allow the chambers to properly fill and drain with fluid.
2. The surface air compressor required to drive the pump must be carefully designed to optimize the pressure and volume of pressurized gas required for the operation of the pump.
3. Produced gases from the reservoir, especially methane, carbon dioxide and hydrogen sulphide would have to be captured and treated or incinerated during the pump vent cycle. This could significantly complicate the surface equipment required to operate the pump.
4. The pump is not easily installed into a well as the chambers and their associated support cables and air hoses must be assembled singly and individually as the pump is lowered into the well.
5. The overall pump efficiency is very low.
6. The pump system requires a specialized wellhead adaptor.
7. Depending on the number of chambers required, the pump is expensive to install and repair because all the chambers are linked together, thus a failure in one chamber will affect the whole system.

C-FER® Test Results on the Fluica Nojak® Pump

1. Flow test results were showed the pump performance is significantly affected by time required to fill and empty the bottom chamber with reservoir fluids, the density of the float within each chamber relative to the density of the fluids produced, the pressure of the air supply required to force the fluids from the individual chamber and the discharge pressure of the pump.
2. The overall pump efficiency was measured at approximately 4.25%, and is considerably affected by the efficiency of the compressor supplying the pressurized gas to operate the pump.
3. Net Positive Suction Head (NPSH) tests showed that production at very low suction pressures was possible.
4. The water pump-off test revealed that the pump did not gas lock and was able to produce all the water supplied even though the water level was below the pump intake.

5. The pump was able to produce fluids containing sand at concentrations as high as 10% by volume with very little change in system performance.
6. Post-test measurements of all parts of the pump exposed to solids showed no signs of abrasion.

Limitations of the C-FER® Test on the Fluica Nojak® Pump

1. The bench test was limited to a single chamber operation. It is probable that pump efficiencies and pressurized gas volumes and pressures measured by the bench test are not indicative of a multiple chamber field application of this pump.
2. The test procedure altered the chemistry and thus the physical properties of the solids supplied by Enerplus for the test. Therefore, the results of the solids lifting experiments may not be able to be duplicated in actual field trials.
3. Test duration was insufficient to definitively determine the effect of solids production on the pumping mechanism.
4. The test equipment was unable to deliver a gas-liquid mixture to the pump intake, thus a gas-liquid ratio sensitivity test and a three-phase flow test could not be performed.

Conclusion from C-FER® Test on the Fluica Nojak® Pump

1. The Nojak® pump can effectively remove a wide range of water influx rates with a solids entrainment of up to 10% from shallow gas wells.
2. The pump has a very poor overall efficiency, thus this type of system must be carefully designed to optimize the cycle times, float densities, and pressurized gas volumes and pressures to maximize the efficiency of the pump.
3. The pump's ability to handle a wide range of fluid influx, with a promising concentration of solids and minimal operational issues was encouraging, but a lack of a procedure to install this unit into a live gas well discouraged further testing on this pump.

Project Participant Testing on the Fluica Nojak® Pump

At the time of writing of this report, none of the project's industry participants has undertaken further field testing on this pumping system.

5. Sampson Pump by Unico Canada

How it Works:

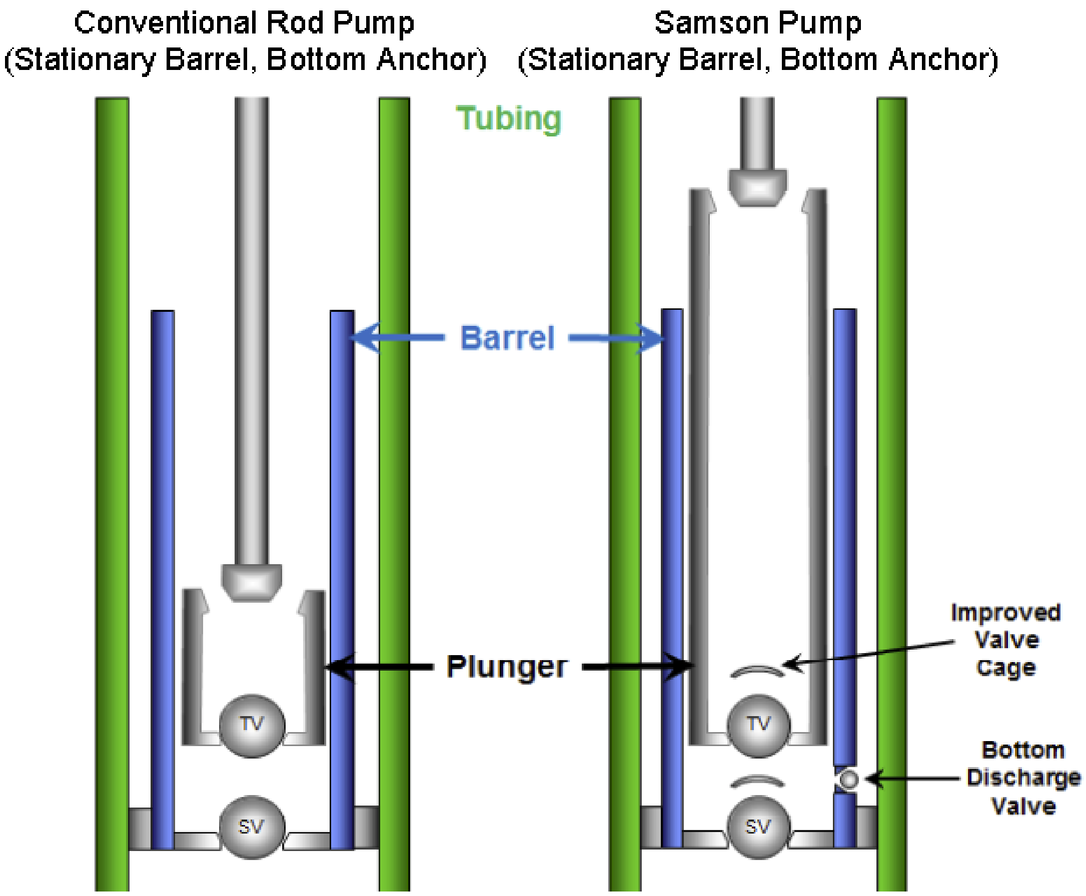


Figure 13: Schematic of Unico Canada's Sampson® Pumping System ©C-FER 2012

The Sampson® pumping system incorporates two modifications to the standard plunger pump, which allows the plunger pump to move fluids containing high solids content (see Figure 6). In all other aspects, the pump operates as a typical sucker rod activated bottom hold down plunger pump. Specifically, the Sampson® pump modifications are:

1. The plunger is designed so that its top is always above the top of the barrel. This limits the amount of solids that could become trapped between the plunger and barrel annulus, which results in less abrasive wear than that which could be expected from a conventional plunger pump system.
2. The Sampson® pump contains a bottom discharge valve. During the down stroke, as the travelling valve is open and the plunger is filling with fluid, some liquid is forced through the bottom discharge valve. Theoretically, this movement of fluid helps prevent solids from settling within the annulus between the pump barrel and the tubing, and allows the pump to be more easily pulled from the seating nipple in the event of a pump replacement operation.

Advantages of Unico Sampson® Pumping System

1. The system is very flexible and can be used for a wide variety of depths and volumes.
2. The system can pump almost any composition of oil and water mixtures.
3. The system has high net lift, but a relatively low overall pump efficiency.
4. The system has low operating costs relative to other pumping systems.
5. The plunger pumping system has been in use for a long time and is thus familiar to field operators.

Disadvantages of Unico Sampson® Pumping System

1. Plunger pumps have difficulty pumping fluids with a high gas to liquid ratio.
2. Plunger pumps struggle to pump highly viscous fluids because viscous fluids retard the gravitational movement of the piston.
3. Plunger pumps have low overall efficiency.
4. Operational ease and cost effectiveness of piston pumps decreases rapidly with hole deviation.
5. Plunger pumps move fluid intermittently rather than continuously like PCP's or jet pumps, thus reducing its solids handling capabilities.

C-FER® Test Results on the Unico Sampson® Pump

1. During the performance test, the pump behaved predictably over a wide range of flow rates and differential pressures.
2. The pump experienced increased leakage rates with increasing discharge pressures and stroke rates. The leakage rates were not as predictable at higher differential pressures and stroke rates although the leakage rates appeared to be minimal up to a stroke rate of 2.5 spm.
3. The maximum overall pump efficiency was measured at approximately 9% over a wide range of differential pressures and stroke rates.
4. Net Positive Suction Head (NPSH) tests showed that the pump would continue to move fluid as long as the pump inlet was submerged.
5. The water pump-off test revealed that the pump is prone to gas locking, although C-FER concluded that this phenomenon occurred because of the modifications made to the pump to allow it to fit the bench test apparatus. C-FER determined that theoretically, the pump should not gas lock in a typical field installation.
6. The pump was able to produce fluids containing sand at concentrations as high as 10% by volume with very little change in system performance, although the pump performance was noticeably degraded at lower stroking rates and higher solids contents.
7. The pump immediately restarted after being submersed under a solids column of approximately 5 feet. However, the production rate after restart was approximately 50% of the rate determined during the water-only performance test.
8. Post-test measurements of all parts of the pump exposed to solids showed the effects of solids production in the following manner:
    a. The finish on the outside of the plunger was dulled.
    b. The inside of the plunger above the travelling valve was partially blocked with solids.
    c. The travelling valve and seat contained solid residue.
    d. The bottom discharge valve was fouled with solids and would not seat properly.
    e. The barrel and standing valve were unaffected by the solids production.

Limitations of the C-FER® Test on the Unico Sampson® Pump

1. The plunger length, barrel length, and stroke length were reduced to allow the pump operation to fit the bench test equipment.
2. The bench test measurement equipment was affected by the polish rod displacing fluid from the production tubing on the down stroke.
3. The test procedure altered the chemistry and thus the physical properties of the solids supplied by Enerplus for the test. Therefore, the results of the solids lifting experiments may not be able to be duplicated in actual field trials.
4. The test equipment was unable to deliver a gas-liquid mixture to the pump intake, thus a gas-liquid ratio sensitivity test and a three-phase flow test could not be performed.

Conclusions from the C-FER® Test on the Unico Sampson® Pump

1. The Sampson® pump can effectively remove a wide range of water influx rates with a solids entrainment of up to 10% from shallow gas wells.
2. Under the bench test conditions, the pump is prone to gas locking if the fluid level falls below the pump intake.

3. After the pump restart with solids test, the pump produced at a significantly lower flow rate under the same operating conditions as the water-only performance test.
4. The results of the pump teardown after the bench test showed the pump mechanism was partially blocked with solids.
5. A field trial was recommended to determine the performance differences that might result from a full field installation of the pump, and to quantify the long-term effects of solids on the pump mechanism. However, this field trial was not carried out.

Project Participant Testing on the Unico Sampson® Pump

At the time of writing of this report, none of the project's industry participants has undertaken further field testing on this pumping system.

6. Gas Operated Piston Pump by Lifteck International Inc.

How it Works:

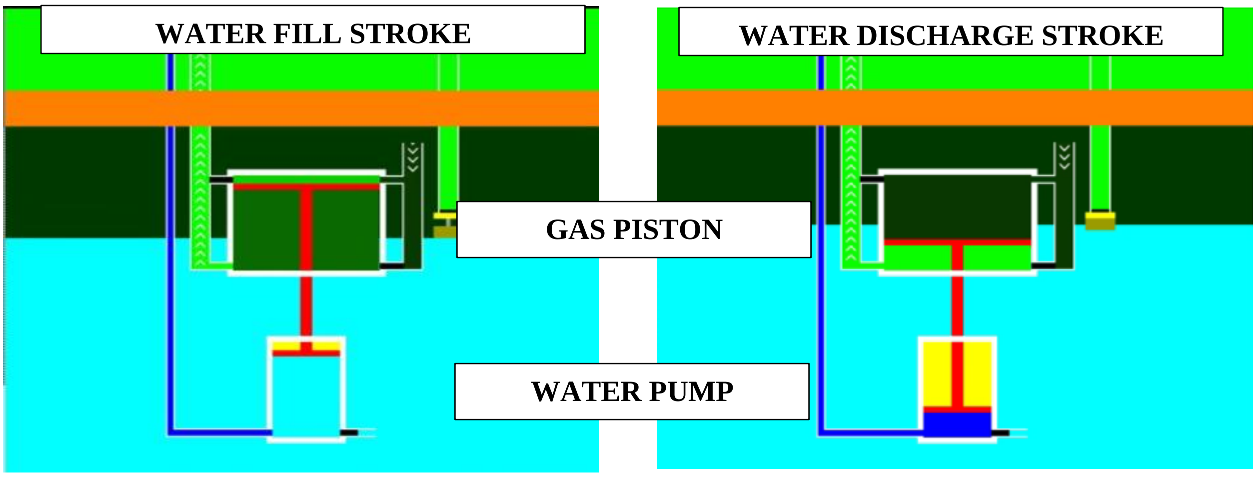


Figure 14: Schematic of Lifteck's Gas Operated® Pumping System ©Lifteck International Inc. 2012

The Lifteck® pumping system utilizes a gas operated piston to drive a plunger-style pump to remove water from a wellbore. Gas is produced up the annulus of the well and the pump remains inactive until water entering the wellbore reaches a predetermined level in the casing. At this time, the gas in the annulus above the water is diverted into the gas piston, driving the piston downwards, triggering the water pump to discharge water from the well into the production tubing. Gas below the piston is diverted into the annulus of the well. When the gas piston reaches the limit of its downward travel, valves switch the gas entering the gas piston from the top of the piston to the bottom, driving the piston upwards, thus initiating the fill cycle on the water pump. Gas above the piston is vented back to the annulus. This process is repeated until the water pump lowers the water level in the wellbore to the intake of the water pump. The pump then deactivates to prevent cavitation and gas locking of the water pump and reactivates when water entering the wellbore reaches a predetermined level in the casing once again.

Advantages of Lifteck's Pumping System®

1. The pump is powered by reservoir gas pressure, so no external power source is required.
2. The pump will function at any angle so it can be inserted into highly deviated wells.
3. The pump requires very little maintenance.
4. The pump can be installed on coiled tubing.
5. The pump has a wide pumping range from 0.01 to 40 bbl/d and is self-activating, thus pump design for specific applications is simplified.

Disadvantages of Lifteck's Pumping System®

1. The pump cannot handle large quantities of solids.
2. The pump requires a minimum reservoir pressure to operate.
3. The system requires a packer to be set in the casing to allow gas to be discharged in the annulus above the pump. If water enters the wellbore above the packer, the pump will not operate efficiently, if at all.

C-FER® Test Results on the Lifteck® Pump

This pump was not tested by C-FER but was field tested by Cenovus on a proprietary well. The test is incomplete, so no rest results are available at the time of the publication of this report.