

A PILOT PLANT FOR ARTIFICIAL OIL LIFT STUDIES

Pablo Javier Alsina, pablo@dca.ufrn.br
Diego Antonio de Moura Fonsêca, diegomoura@dca.ufrn.br
Universidade Federal Rio Grande do Norte, Campus Universitário, CEP: 59072970, RN, Brasil

Osmar de Araújo Dourado Jr., osmar@ifal.edu.br
Instituto Federal de Alagoas, Rua Mizael Domingues 75, Poço, CEP: 57020-600, AL, Brasil

Abstract. *In this paper a pilot plant for study and research of plunger lift oil wells is presented. In this plant diverse types of plungers can be tested. Measurements will be realized and the collected data will be used in the improvement of the existing dynamic models. This will make possible to refine the computational modeling of the plunger dynamics and to improve a real time numerical simulator for wells with plunger lift. The well is constituted by a 20m high column of two concentric tubes, that is, tubing and casing. They extend vertically from the base, on the ground. For visualization purposes of the cyclical phenomena in the bottom of the well, a section of 4m with transparent tubes is used and the other section of 16m is made in galvanized steel. The fluid production in the bottom of the well is physically emulated by an air feeder deriving from a compressor and by a line of pressurized liquid through a hydraulic pump. A PLC (programmable logic controller) receives data from the field instruments that allow acquisition of the values of the pressures in the top, casing and inside the tubing, arrival sensor, as well as the flow measurements of both liquid and air lines that feed the well. These data are monitored numerical and graphically by supervisory software which allows changing some parameters of the process, such as set points and controller gains.*

Keywords*: pilot plant, plunger lift, reservoir performance, computational modeling.*

1. INTRODUCTION

Plunger lift is an artificial lift method that uses a piston that moves cyclically up and down inside the column production (Lea, 1981). The piston, which acts as a mechanical interface between the liquid and produced gas (Beauregard and Ferguson, 1982), uses the energy released by expansion of the gas for its upward movement (Lea, 1981). The piston causes an increasing in the efficiency of lifting liquids, because it prevents the passage of gas through the liquid (Gasbarri, 1996), significantly reducing the liquid returning through the gas, a phenomenon known as fallback. However, the plunger lift is a complex process so that its analysis and modeling may be difficult (Maggard, and Wattenbarger, 2000).

During the production cycle, the fluid produced in the reservoir will be transported to the well so that the gas will accumulate in the annular space while the liquid will be moved into the production column so forming on the piston the liquid column to be produced - or liquid slug. During the time that the fluid is draining into the well, the control valve or motor cycle valve remains closed valve remains closed causing an increasing pressure inside the well, characterizing the step of build up or shut-in. Upon reaching the pressure value preset in the casing on the surface or after an elapsed pre fixed time, the motor valve opens so the piston starts to rise. When opened, the motor valve connects the tubing string to the sales line causing a sharply pressure decreasing on the liquid slug, so the liquid starts to rise. The gas stored in the annulus expands and moves to the column of production, providing the energy to take the piston and the column of liquid to the surface. When the piston nears the surface, the liquid column starts to be produced on the production line (Gasbarri, 1996). At the moment the piston reaches the surface, the motor valve is closed, and the build up restarts and the piston drops to the bottom starting a new cycle (Gasbarri, 1996). However, there are cases where the production line remains open after the piston reaches the surface. During this interval, also known as afterflow, will be produced gas and some liquid dragged by the gas. Then the motor valve closes and the cycle begins again.

During the production cycle control valve is initially closed while the gas produced by the reservoir is stored in the annular space casing- production column and the liquid is stored in the tubing, thus characterizing the increasing pressure period.

A pilot plant for studies of plunger lift wells was installed at the Federal University of Rio Grande do Norte dependencies in order to make a more detailed study of the plunger lift process, and capture data on its behavior. These data will serve to develop an improved dynamic mathematical model. Based on this model will be implemented in a computational simulator for wells with plunger lift that, interfaced by a dedicated hardware, will communicate with the programmable logic controller currently used to control wells of these types. This set, PLC plus simulator, will be used to develop controllers that aim to increase the production potential of the reservoir, thus maximizing the financial return of project production. Finally, the controllers developed will be tested and validated in the pilot plant.

1.1 . Literature review

Computer modeling has allowed the development of dynamic models more useful for the processes of Plunger Lift. One of the first dynamic models was developed by Lea (1981) for the plunger rise phase. In this paper, it was shown that the piston speed increases as it rises from the wellbore. It was also presented an analysis, by coupling a gas well reservoir which is discharging the fluid accumulated in the bottom of the column through a time control of the Plunger Lift. Rosina (1983) presented a dynamic model for conventional Plunger Lift. In this work, a rigorous model for annular gas expansion into the tubing, the rise of gas bubbles at the same speed as the plunger, and plunger through a slug of liquid in accordance with experimental data resulted in a set of differential equations. Chacín and Doty (1994) presented a mechanistic design of plunger lift assisted intermittent gas lift installations. The dynamic numerical simulator presented incorporates experimental data, such as plunger velocity, so that fallback can be estimated. The model presented can be used to obtain an optimum for new installations, considering both gas consumption costs and crude recovery. The paper (Wiggins et al. (1999)) discusses plunger lift and the dynamic interaction of the mechanical plunger lift system coupled with the reservoir behavior. The dynamic simulator presented is used to investigate various operating scenarios for both oil and gas wells. Maggard et al. (2000) presented a study of the application of plunger lift to the problem of water removal from tight gas wells. It was developed a model which includes gas flow in the reservoir, wellbore/annulus effects and dynamic plunger lift cycles. The transient reservoir performance was also included in the model. Gasbarri and Wiggins (2001) developed a dynamic model for Plunger Lift in gas wells that includes the transient, single-phase gas flow in the tubing above the piston and slug. The delay for the pressure in the tubing above the slug decline in the beginning of the plunger rise resulting in an acceleration of the piston significantly lower than that observed in work (Lea (1981)), although all the speeds were similar. The paper (McCoy et al. (2003)) is a field case that show how the plunger position monitoring can be applied to optimize plunger lift operation. The plunger position can be tracked from the surface by monitoring the acoustic signals generated as it falls down the tubing. When the plunger passes a tubing collar recess, an acoustic pulse is generated that travels up the gas within the tubing and can be monitored at the surface by a microphone or a sensitive pressure transducer. The paper (Chava et al. (2008)) provides an overview of the various plunger lift available in the public domain and proposes a new approach to plunger lift modeling. Because the availability of pressure and temperature data provided by smart plungers, these data are coupled with the fundamental conservation equations of mass, momentum and energy that govern the dynamics of plunger lift. Chava et al. (2010) present um updated model that take accounts for pressure drop only due to gravitation, but satisfactorily reproduces the dynamics of a field installation in East Texas, USA. A comparison of the predictions from the new model and the corresponding results from some earlier plunger lift models available in the public domain.

All of those models and simulators have some common features such as: perfect sealant piston during its upward movement, so without fall back occurrence; possible liquid accumulation during build up; accumulation of the liquid produced by the reservoir only at the end of the tubing, and without liquid carriage by the gas coming from both reservoir and annulus, while production line is kept open.

2. PILOT PLANT

The pilot plant for studies of plunger lift wells basically consists of 2 parts, an instrumented well and a laboratory.

The well is formed basically of two concentric pipes (column production and casing) extending up from the soil to a depth of 20 meters, 16 meters of which are galvanized steel and 4 meters of transparent acrylic to visualize the moments of departure and arrival of the piston to the bottom of it. The internal diameters of tubing and casing are 2" ⅜ and 5 " ½, respectively. The sales line is formed by an upwelling pipe from 2" galvanized steel that connects the wellhead to the fluid reservoir located in the laboratory. The pilot plant well, as well as plunger lift wells, has surface and sub-surface equipments, but as it comes from a well at small scales some of the equipment as wellhead and the set tubing stop and bumper spring were adapted. Because it is a well on the surface it was necessary to use some structure to support it. In this case, we used a column of an elevated water storage tank height compatible with the well. Figure 1 presents some equipments of the well and the structure that support it.

Figure 1. Pilot Plant's well overview.

The laboratory is divided into two compartments: the powerhouse and control room. In the powerhouse are the equipments that simulate the geological formation of fluids to be produced by the well, i.e., liquids and gas. The emulation of the flow of oil to the bottom is being made through the injection of water, contained in a tank of 500 liters, for a positive displacement hydraulic pump of one stage helicoidal type of 1 hp, operating at flow rates up to 20 m³ / day and maximum discharge pressure of 71,12 psi. Natural gas injected into the bottom is emulated by compressed air coming from a 50 HP air compressor rotary screw type, effective flow of 7545.6 cubic meters per day and a maximum working pressure of 174,05 psi. However, the compressor was pre-tuned to work at a pressure of 58,02 psi which is a sufficient and safe operation for the pilot plant. In the control room are installed the PLC, three pressure transmitters to measure the casing pressure, surface pressure and separator pressure, and the flow indicators / totalizers of air and water that go into the well. Outside the laboratory are located two flow meters, with a magnetic liquid and a gas turbine, two globe valves and electro-pneumatic positioner to regulate these flows.

The operating range for the pilot plant are shown in Table 1. Such values were estimated from simulation tests based on the model developed by Baruzzi (1994).

Table 1. Operating range for the pilot plant

GLR*	30 – 70
After flow (s)	5 – 10
P_{rev} (psi)	15 – 55
Q_{MAXwat} (m3/d)	20
Q_{air} (m3/d)	600 – 1400

* GLR – Gas-liquid-ratio.

The powerhouse of the laboratory, that emulates the geological formation, is connected to the well cannonades through two parallel lines in 2-inch galvanized steel, which will be transferred by the liquid and air. The pump sucks water from the reservoir of liquid and moves to the entrance at the bottom. The flow control, which must be permanently 10m³/ day, is accomplished through a globe valve with electro-pneumatic positioner. For this, a magnetic flow meter was installed on a straight section after the valve. When reading the flow, the meter sends a current signal (4-20 mA) proportional to the value read to the PLC which, after processing this signal, generates a control signal (output) which is sent to the actuator control valve also in the form of current (4-20 mA). Natural gas, represented by the flow of air from the compressor, is injected through the other line, in another entry of the well. The control of air flow, which should be in steady state of 7,000 m³/day is held in the same way that control of water flow, or a meter, which in this case is a turbine meter, reads the flow, it sends a signal of 4-20 mA current to the PLC that processes this signal and generates a control output which is sent to the valve.

During the production process, the gas produced by the compressor is stored in the annular space while the liquid coming from the water pump will accumulate in the tubing, with some gas mass accumulated over the liquid slug. During this period, also called a step increase in pressure, the engine valve surface is kept closed. After a preset time or when the pressure in the casing reaches an appropriate value, the engine valve opens, thus beginning the production process. The gas over liquid slug expands, creating a differential pressure at which the liquid slug is submitted. Due to the high pressure gas stored in the casing expands into the tubing and raises the piston with the liquid column to start the process of ascent of the piston. As the piston nears the surface, the liquid slug is produced at the production line. When the piston reaches the surface, the production line can be kept open for a specified period of time or otherwise, be closed. By remaining open will be produced gas and any liquid that has been brought about by this gas, beginning the period of gas production. After the afterflow period, the motor valve is closed, the buildup step starts again and the piston drops to the bottom, starting a new cycle.

Because the production line being connected to the reservoir from the powerhouse, the separation between the liquid and gas phases is done in the reservoir, where the liquid is retained and the gas is released into the atmosphere. This separation procedure ensures 100% of the reuse of the process liquid.

The production process of the pilot plant is shown in the schematic of figure 2.

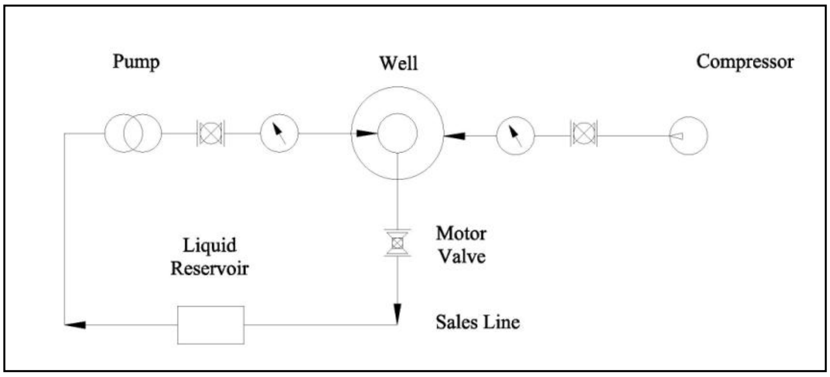

Figure 2. Schematic diagram of the pilot plant.

3. SUPERVISORY SYSTEM

The systems of supervision and control, also known as SCADA (Supervisory Control and Data Acquisition), should be able to get the process information, format them and make them available to users of the system. Such systems are designed to function as man-machine interface stations, local supervision of industrial processes, according to Santos (2007). Daneels and Salter (2000) explained that supervisory software allows information to be monitored and tracked from a production process or a physical installation.

• Physical process: production of liquid and gas (air) by means of artificial lift plunger lift.

• Hardware: responsible for controlling the process. It consists of pressure and flow rate sensors, flow control valves, actuators and PLC.

• Supervision software: Also known as supervisory, communicates with field devices in order to get access to the process data.

• Networking: responsible for information traffic and is used by software supervision during the data acquisition process. Communication with the PLC is done via a serial cable directly connecting the computer's serial channels and the controller.

3.1. Architecture

As this is a relatively simple process, in which the computer connects directly to the PLC (peer to peer) to control the production process of a single well, the architecture used in this work is based on a monolithic architecture, i.e., only one station (stand alone) is responsible for acquiring data from the PLC and present them to the user. The figure 3 shows the schematic SCADA using a PLC.

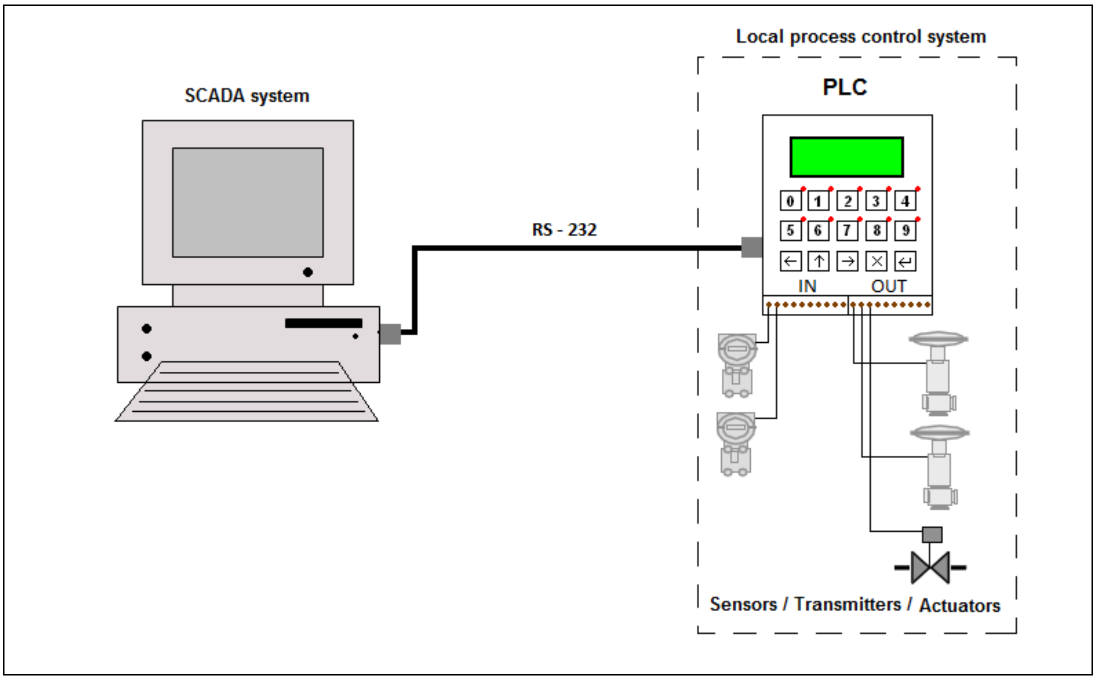

Figure 3: schematic SCADA using a PLC.

3.2. Supervisory software

Despite being on the same workstation as seen in the architecture of the project, the complexity of data exchange between the station and the PLC is transparent to system users. The software is responsible for monitoring user interaction with the process, allowing them to monitor and control the behavior of the production process.

Figure 4 represents a specific supervision screen of the automated well. In this window you can get more specific information from the well, in addition to developing an overview of the installation of the plant. In this example, dynamic informations such as: casing pressure, wellhead pressure, sales line pressure, values of the flow of fluids, GLR, stage of the process and speed of the piston can be observed. Also in the supervisory screen, the user can make adjustments in process parameters such as, type of cycle control (manual, pressure or time), enabling or disabling the production of gas, adjustment of the PID controllers of the flow control valves or adjusting the percentage of opening of these valves if not use the controllers to control them.

Another feature of supervisory is the automatic information storage of flows and pressures involved in the process to monitor his behavior. The monitoring of unusual occurrences during the production cycles, such as errors in sensor arrival of the piston, pressure above a certain threshold, communication error, etc., is done through specific messages that are reported in a portion of the supervisory screen used for this purpose.

3.3. Pilot Plant instrumentation

The instrumentation for Plunger Lift Pilot Plant is based on the ACOS 205 module (HIT, 2006), for control and acquisition for petroleum industry. This module is set for plunger lift, and the only digital input required is the piston arrive sensor. There is only one digital output too, for the trip/close signal of the motor valve.

The following measurements take part of analogic input:

- Casing pressure
- Wellhead pressure
- Sales line Pressure

ACOS 205 has three transmitters configured for the pressure range 0-16kgf/cm². However, some of the original features were modified in accordance to the needs of the Pilot Plant, such as

- Liquid flow measurement from the reservoir to the bottom of the well through magnetic flow meter
- Air flow measurement from the reservoir to the bottom of the well through turbine flow meter

For these measurements, were added two new flow transmitters. Originally only one flow measurement is enabled: the gas flow input for assisted plunger lift. So, to make possible the liquid and air flow measurements, was needed to use two new backup entries of the analogic inputs.

The analogic output that originally is used for the control flow valve for plunger lift assisted method is modified for another purpose. This output is used to control an air flow valve at the output end of the compressor. The backup analogic output is used to the water control flow valve at the output end of the hydraulic pump. These control valves allow to control the air flow and water flow into the well. This is an important feature, because the operator can define a given RGL (gas is substituted by air) and then make the tests with known parameters.

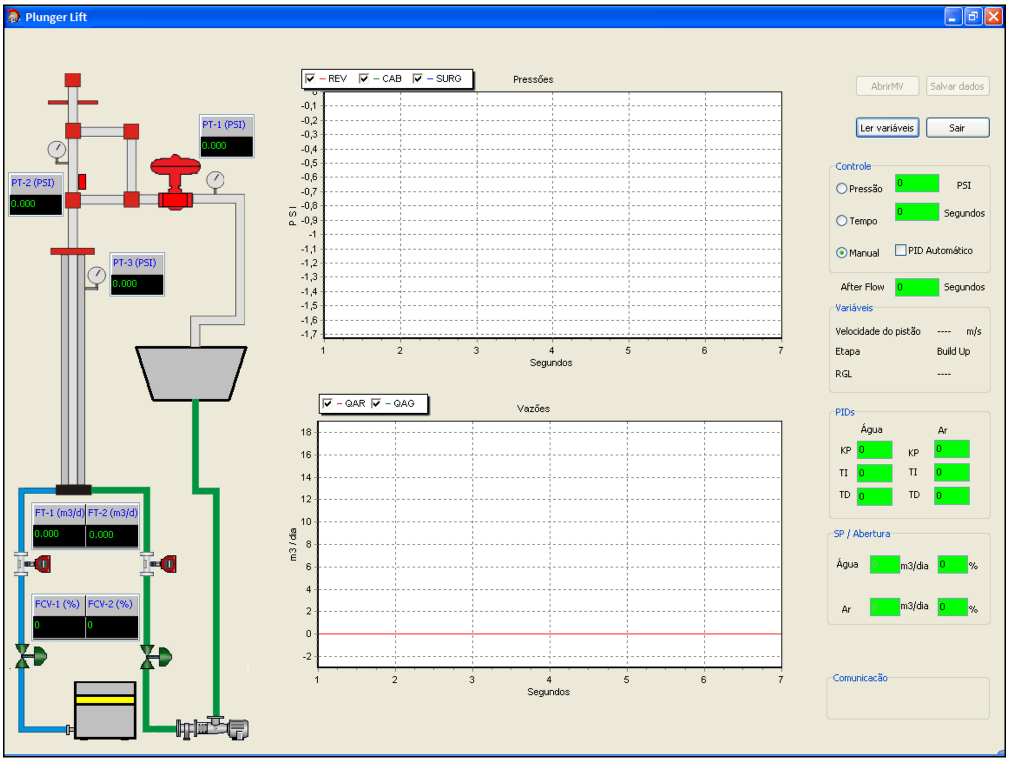

Figure 4: Supervisory screen.

4. RESULTS

In this section are presented results coming from both tests performed with pilot plant and computational simulation.

4.1. Tests with pilot plant

The values of the plant parameters were adjusted according to Table 2.

Table 2. Test parameters

Shut-in time	90s and 60s
After flow	10 second
Air flow	0 a 700 m³/d
Water flow	19,047m³/d
RGL	~ 30,0

As indicated in Table 2, for the test in particular, the control of the cycle is done from shut-in time. The test lasted approximately 1,500 second. During first half, (approximatelly 750s) shut in time was 90s, and during the other half this time was readjusted to 60s. Figure 5 (a) shows the the pressure evolution at wellhead, top of the casing and separator. From the time instant 0 up to approximately 250 second process is in the transitional regime, characterized by the peak pressure on the casing and at the sales line. The value for pressure at the sales line remains almost constant with mild elevations in the instant pressure drop at surface. The discharge values are reported in Figure 5 (b). The air flow has values very oscillatory, this is due to the pressure control of the compressor, or as it is pre-tuned to work in a pressure range considered safe, so it constantly changes its flow as a way to keep this the pressure as constant as possible. With respect to the flow of water, this is due to the constant problem shows that there has been measured with magnetic flow. Thus it was set a value for flow rate of approximately 20 m³/d, which was the value observed in tests when the meter worked perfectly and is the maximum pump output. Given this variability in the value of airflow rate, the value of SMR is calculated as the average flow of air entering the well in each cycle.

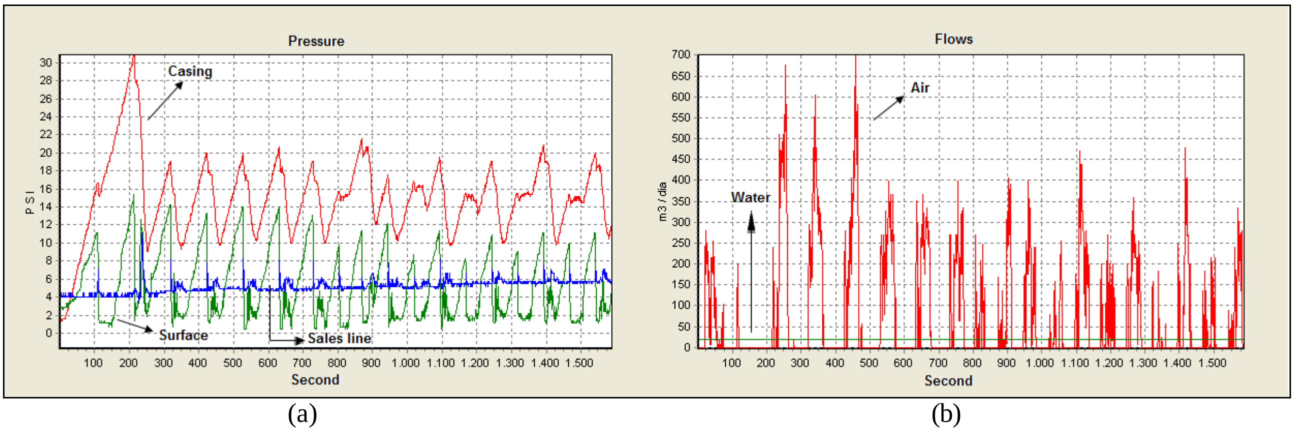

Figure 5: (a) pressures on the well head, casing and sales line, (b) flow of air and water at the well entrance.

4.2. Computational simulator

The Plunger Lift simulator developed is based on a simplified model. Upon completion of the Pilot Plant is expected to include nonlinear dynamics not modeled in order to make it more precise.

The processing of the simulator in Figure 6 displays the parameters of pressure on the top of the column input and the top of the casing, these parameters are measured in the field for a some Plunger Lift cycles.

Comparing Figure 5 (a), measurement curves, to Figure 6, curves of simulation, one can observe similar behavior and magnitude of the casing pressure on the surface and for the wellhead too, from the second cycle. One can note in Figure 5 that a peak pressure during the first cycle of the test plant. This occurrence was due to the plant is in the transitional period, and the steady state reached in the second cycle. It can be seen that the simulation presents a steady state behavior. This is due to the control of the plunger rise velocity, an optimization present in the simulator. The simulator requires some physical parameters in the pilot plant that are unavailable, and therefore had to be freely given, though with a commitment not to be very different from those which would be for the plant. This explains certain differences between these two Figures.

For a given cycle, the curves for the first step of pressure at the wellhead begin with high values and since then, as slug and piston move toward the top of the column, the pressures decrease. In the second stage occurs the afterflow and the motor-valve remains open after the arrival of the piston. At that moment occurs at the first discontinuity in the curves that the values of top pressure in the tubing reaches higher values.

After ending time afterflow, motor-valve is closed and the pressure casing increases in value in a linear behavior until the motor-valve is opened again and a new cycle begins. This simulator will be connected directly with the pilot plant and improved according to the observations and results obtained.

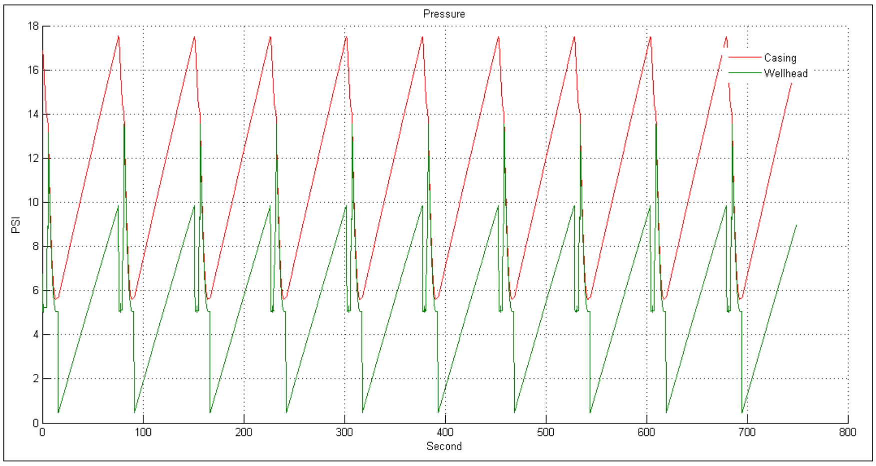

Figure 6: Simulation results.

5. CONCLUSIONS

Overall the pilot plant serves as a tool for advanced studies of wells equipped with Plunger Lift. About the model, it will be possible through the development of parts of the Plunger Lift cycle that are neglected by mathematical models, which consider them as simplifications. The validation of models is another activity that can be exploited through the plant with regard to modeling. In terms of control process, it is plausible to study the operation of the plant in order to increase production of oil and gas through the optimization of existing control strategies and the development of new techniques such as neural control or reinforcement learning.

Future work:

- Measurements on the fall speed of the piston by image processing through the transparent portion;
- Measure the speed of fall of the piston through inductive or optical sensors;
- Testing at the pilot plant with different types of pistons for evaluating the performance of each one in the production.

6. ACKNOWLEDGEMENTS

The authors would like to acknowledge financial support conceded by Petrobrás and technical support by Edson Henrique Bolonhini.

7. REFERENCES

Baruzzi, J.O.A., 1994. “Modelagem do Plunger Lift Convencional”. Master Thesis, State University of Campinas, Campinas, São Paulo, 1994.

Beauregard, E. and Ferguson, P.L., 1982. “Introduction to Plunger Lift: Applications, Advantages and Limitations”. SPE 10882, presented at the 1982 SPE Annual Technical Conference and Exhibition, Billings, MT, May 19-21, 1982.

Becker, D.J., McCoy, J., Rowlan, L., Podio, A., 2006. “Plunger Lift Optimization by Monitoring and Analyzing Wellbore Acoustic Signals and Tubing and Casing Pressures”. SPE 104594, presented at the 2006 SPE Eastern Regional Meeting, Canton, Ohio, October 11–13.

Chacin, J., Doty, D., 1992. “Modeling and Optimization of Plunger Lift Assisted Intermittent Gas Lift Installations”. SPE 23683, presented at the Second Latin American Petroleum Engineering Conference, Caracas, Venezuela, March 8-12, 1992.

Chava, G., Falcone, G., Teodorio, C., 2010. “Plunger-Lift Modeling Toward Efficient Liquid Unloading in Gas Wells”. SPE-124515-PA, SPE Project, Facilities & Construction, New Orleans, Louisiana, March.

Chava, G., Falcone, G., Teodorio, C., 2008. “Development of a New Plunger-Lift Model Using Smart Plunger Data”. SPE-124515-PA, SPE Annual Technical Conference and Exhibition, Denver, Colorado, September 21-24.

Wiggins, M.L., Nguyen, S.H., Gasbarri, S., 1999. “Optimizing Plunger Lift Operations in Oil and Gas Wells”. SPE 52119, presented at the SPE Mid-Continent Operations Symposium, Oklahoma City, Oklahoma, March 28-31, 1999.

Daneels, A., Salter , W., 2000. “What is SCADA?”. International Conference on Accelerator and Large Experimental Physics Control Systems, 1999, Trieste, Italy, pp. 339-343.

Dourado, O. A., Bolonhini, E.H., Alsina, P. J., 2006. “Pilot Plant for Study of Wells with Plunger Lift”. Rio Oil & Gas Expo and Conference , Rio de Janeiro, Brazil.

Souza, R.B., Medeiros, A.A.D., Nascimento, J.M.A., Maitelli, A.L., Gomes, H.P., 2006. “SISAL – Um Sistema Supervisório para Elevação Artificial de Petróleo”. Rio Oil & Gas Expo and Conference , Rio de Janeiro, Brazil.

Gasbarri, S.,1996. “Development of a Plunger Lift Model for Gas Wells”. Master Thesis, University of Oklahoma, Norman, Oklahoma, 1996.

Gasbarri, S., Wiggins, M.L., 2001. “A Dynamic Plunger Lift Model for Gas Wells”. SPE 72057, was revised for publication from paper SPE 37422 first presented at the 1997 SPE Production Operations Symposium, Oklahoma City, Oklahoma, March 9–11.

HIT, 2006. “ACOS205 manual” HI tecnologia. 22 Mar.2011 < http://www.hitecnologia.com.br/ >.

Lea, J.F., 1981 “Dynamic Analysis of Plunger Lift Operations”. SPE 10253, presented at the 1981 SPE Annual Technical Conference and Exhibition, San Antonio, Texas, October 5-7.

Maggard, J.B., Wattenbarger, R.A., Scott, S.L., 2000. “Modeling Plunger Lift for Water Removal From Tight Gas Wells”. SPE 59747, presented at the 2000 SPE/CERI Gas Technology Symposium, Calgary, Alberta Canada, 3-5 April 2000.

Rossina, L.,1983. “A Study of Plunger Lift Dynamics”. Master Thesis, University of Tulsa, Tulsa, Oklahoma, 1983.

Santos, H.G.,2007. “Desenvolvimento de um Supervisório Modular para uma Célula Flexível de Manufatura”. Master Thesis, University Federal of Santa Catarina,Florianópolis, Santa Catarina, 2007.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.