PULSATING INJECTION SYSTEM-OPTIMIZATION OF CONVENTIONAL METHODS OF WATER INJECTION IN SECONDARY RECOVERY PROJECTS

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SYNOPSIS

The Pulsating Injection System (Powerwave) generates pulsations of water, adding sufficient energy and momentum to produce a dilation of the porous spaces in the rock, permitting the passage of water and movement of oil through oilfields that are difficult to reach with conventional injection systems, in order to eventually release the oil trapped by capillary forces. In this way, an attempt is made to increase the recovery of oil by improving volumetric efficiency and reducing its residual saturation following water filtration.

The original source of energy used is that available in the water injection system of the Secondary Recovery project. The water pulsations are produced within the injector well, and in opposition to the punched interval that it is attempting to stimulate, by means of a tool that cyclically interrupts the flow of injected water.

Currently, two pulsating injection tools have been lowered. One of these was lowered with Wire Line equipment and operates mechanically, adjusting its frequency of operation in accordance with the differential pressure applied to the bottom valve. The other tool was lowered with pulling equipment and operates electrically, connected via a cable to its controller at the mouth of the well. The latter tool has the advantage of having its frequency of operation be able to be changed from the surface, by means of the control panel. It is estimated that by February of the current year a third tool will be lowered, also electrically operated. Connection will be made to the SCADA System in order to achieve real-time monitoring of the operating variables, as well as turning on and shutting off the injector remotely and also to warn the operators of a power failure, the controller having the ability to restart the injector automatically.

It is planned to move a fraction of the isolated oil, considered until this point to be unmovable by conventional technology using flooding with water, as a result of the timing of the water applied in “waves” causing the coalescence of residual drops of oil allowing these to be produced.

The response time, on projects with a history of injection, is estimated to be between 4 and 12 months, counted from the beginning of the pulsations.

The efficiency of the system will be measured through the initial increase in the production of oil, the decrease in the percentage of water and the improvement in the annual rate of decrease of oil, which in its totality will result in an opportunity to increase productivity and recoverable reserves.

INTRODUCTION

Location of Oilfield

The Las Flores Oilfield is located northeast of the Cerro Dragón area, (Fig. 1), approximately 90 km west of Comodoro Rivadavia; it is a monocline elongated area with northeast-southeast orientation that is divided into two blocks by a direct fault, one located in the southern part, known as Block I; the other located in the northern part of the aforementioned area, identified as Northern Block (Fig. 2).

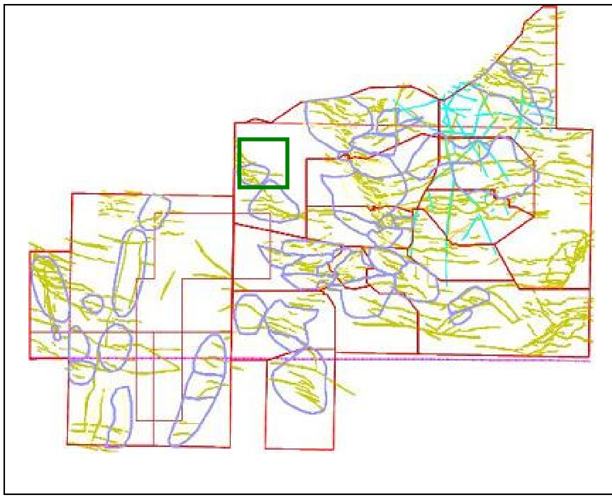


Figure 1: Las Flores Oilfield

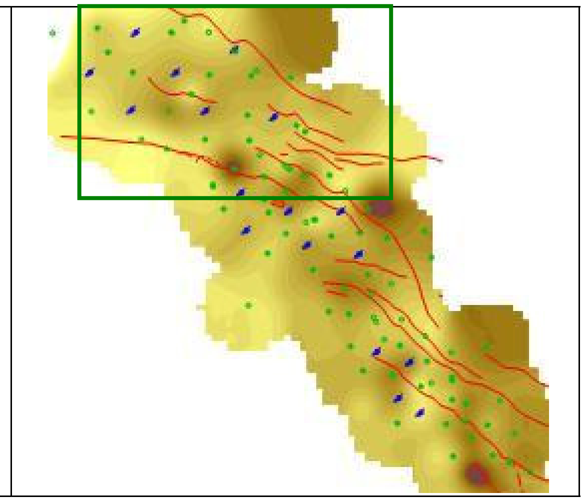
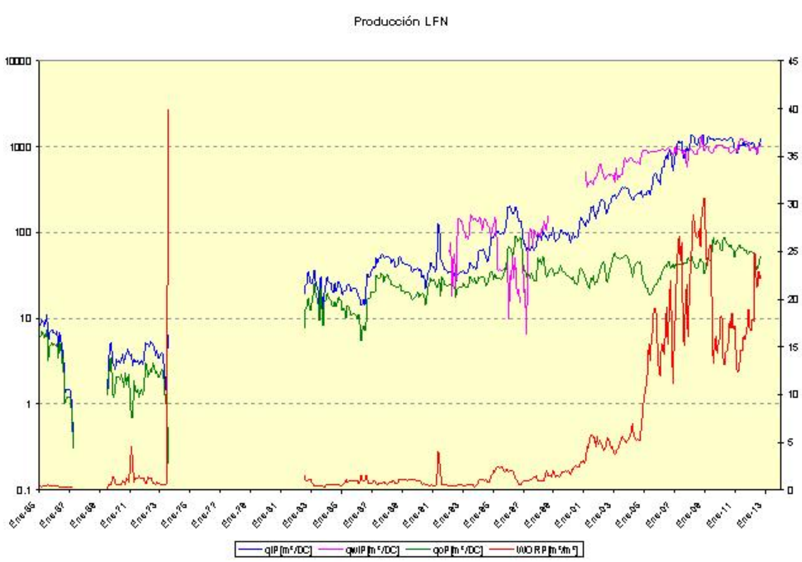


Figure 2: Block I & N

The principal distinguishing characteristic of the norhtern block “N” is that the greatest primary and secondary recovery originates from a single area known as layer E1. In contrast, the southern block “Block 1”, although it also developed E1 as one of its most important layers, also offers other sands that contribute to the reserves of the oilfield.

Production and Injection History

The block selected to implement the present pulsating injection project is Block N, which initiated its secondary recovery project in February of 1992 with 2 injectors (LF-Z and LF-Y) and 4 producers, later eventually reaching the current 7 injectors affecting 11 producing wells.



Graph 1: Block N Production Curves

The production and injection histories of the block are shown in Graph 1; it may also be seen in this graph that beginning in 2007, the liquid produced exceeds the water injected, establishing a tendency to improve the balance of fluids from the block.

Additionally, production and injection from the original project and the variations produced by the 2 successive expansions are shown, including a period without injection that runs from August of 1998 to February of 2001.

Production and injection from the block under consideration for August of 2011, is indicated in the values shown in Table 1:

Description	Production		Water Injection
	Oil	Water	
Daily Production (m^3/d)	57	973	1.139
Accumulated M^{m3}	386.3	2.740	3.281
Active Wells	9		7

Table 1: Block N Production

Oil production has remained stable since this date, showing consistent behaviour with a good produced/injected balance in recent years.

Development/Objectives

The principal objective is to increase the production and recovery of oil, achieving a greater volumetric efficiency per filtration in the layer of interest and, in addition to proving the efficacy of a new technology such as the flow pulsation tool, the possibility of expanding the pilot project to other layers of interest will be evalulated in accordance with the results obtained during the testing period.

According to results obtained from other oilfields, this new technology counts among its most important advantages:

- an improvement to the Wcut.
- an increase in the accumulated production of oil in the network by up to 18% (in front-line producers).
- Following peak production, the block declines with 6% less of a slope compared to previous declines.
- response time is estimated to be between 4-12 months (6 months average).
- an increase in reserves of between 2-5% of the IOIP.
- As a result of the pulses of fluid, neither the rock formation nor the tool is obstructed, as long as the tool constantly has fluid to inject.
- Helps to keep the punchers clean.

A full review of the static and dynamic engineering and geological models of the N project will be done, so that the results obtained will be able to be used for re-evaluation of the project.

Principle of Operation

The Powerwave tool generates pulses of fluid pressure that provoke a momentary elastic flexion of the porous structure (wave theory). This pulse of pressure moves the fluid in and out through the various porous networks of the oilfield, obtaining a more uniform frontal injection, resulting in increases in oil recovery.

The installation in the injector well is permanent, through which there is constant flow; this makes cleaning unnecessary since the pulsations of fluid do not allow for an accumulation of obstructing solids at the outlet of the tool.

The processes are universally applicable to all oilfields with injection systems. The tool is cost-effective, requiring minimal installation work, while at the same time requiring no maintenance. Powerwave has demonstrated both in the laboratory and in the field that it can improve performance of the injection of water, CO_2, chemicals, surfactants and polymers, proving to be effective in operations with secondary recovery systems and improved, in conjunction with well stimulation projects (Acidic-Non-Acidic).

The principle of operation consists of releasing the injected fluids through pulses created by the rapid opening and closing of a specialized high-speed circumferential valve that is part of the BHA (*Bottom Hole Assembly*) of Powerwave. The pulses of fluid are highly effective in controlling the fluids injected, for the following reasons:

- creates pulses that encorage the movement of fluids trapped in the rock. Travelling at an average speed of 100 m/s, the fluids accelerate through the pores, forcing the trapped fluids to move towards the producers; this increases the production of oil, reducing the volume of difficult-to-recover oil trapped in oilfields using conventional methods and tools, causing the trapped fluids to move by means of three-dimensional waves, towards the producing wells.
- The pressure gradient involved in the normal flow of fluids through the resevoir is generally very small when measured in centimetres, however these small differences determine the channels of least resistance that govern the normal flow of fluids. A typical amplitude in a conventional injection system is around 250 psi (17.5 kg/cm^2), possibly higher amplitude in tight formations. The pulsations generated allow the fluids injected to travel in a more uniform way in the oilfield, accessing areas of greatest resistance and preventing the fluid from flowing only through the channels of least resistance.
- The pulsations created force the fluids to penetrate the spaces in the rock and the sand, causing a very small, undamiging effect of expansion and contraction in the spaces, which causes an increase in the permeability dynamic of the oilfield.

This increase in the pemeability dynamic of the oilfield, and the pulsations created to move the fluids, permits the liquids to travel more easily through the sand, filtering oil trapped in high-resistance areas that have not been able to be mobilized by a conventional injection system, as shown in Figure 3. The continuous rapid expansion and contraction of the process creates a more uniform movement of the fluids injected, and accelerates the movement of the fluids towards the producing wells.

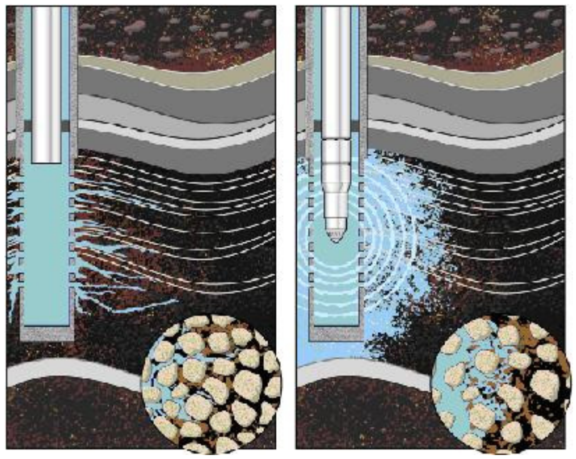


Figure 3: Optimization of movement of fluids in the oilfield by Powerwave (right). Conventional Movement (left).

The pressure of the pulsations generated never exceeds the level of pressure already present in the oilfield. The tool accumulates energy adding “momentum” to the fluid, so that it is released forcefully and returns to its normal pressure level in order to begin to accumulate energy again for the next pulsation.

The Powerwave tools generate pulsations of asymmetrical pressure permanently and constantly, stopping momentarily and releasing the injection of water as shown in Figure 4; in this way, peak pressure will be equal to the pressure at the bottom of the well, and the average of the pressure at the bottom of the well during the injection will be, in consequence, slightly lower than that of a standard injection. The pressure at the bottom of the well can be controlled from the surface.

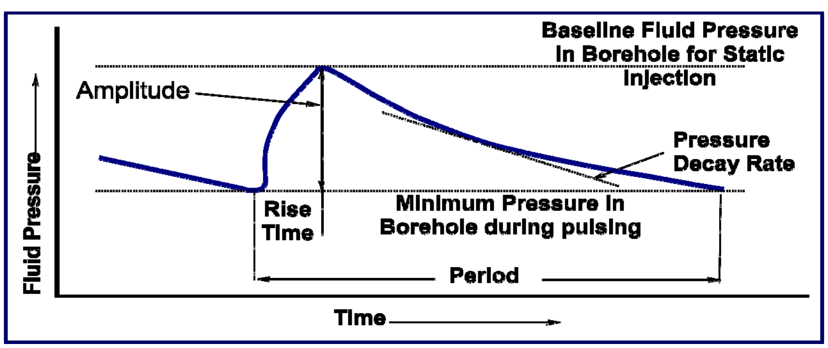


Figure 4: Characteristics of a Powerwave Pulse Waveform

When the tool opens the pressure increases rapidly to its highest value. The maximum time it takes to reach its maximum pressure is called “Build-Up Period”, and this parameter needs to be calibrated to the unique characteristics of each reservoir.

AVAILABLE POWERWAVE TOOLS

Tools are availabe in two versions. The type of tool to be used is selected depending on the needs and objectives of the producing field, the number of layers to be injected, and the type of injection equipnent present in the well.

Electrical Tool- Powerwave Dragonfly

The most notable characteristics of this tool are:

- does not depend on oilfield conditions to generate its pulsations;
- has the ability to vary fluid injection volumes, from 40m^3/day, up to 1600 m^3/day.
- Includes a computer on the surface, which has the ability to:
    - configure the variation of the volume of the injection desired, specifying the number of pulsations per minute, the closure time of the flow valve on the tool (in order to accumulate the greatest energy and momentum possible in the water), and opening time of the same valve (in order to achieve the optimal frontal injection impact towards the face of the formation).
    - Stores in memory the history of the number of the number of pulsations accumulated in the injector.
    - Visually reports the opening and closing of the tool.
    - Reports the temperature of the tool.
    - Reports the voltage and amperage utilized by the tool.
    - Has power sensors, which, in the event of a power failure in the well, have the ability to restart automatically once power is restored.
    - Has temperature sensors, which shut off the tool in the event of overheating that is dangerous for the tool, and that restart automatically once the temperature in the bottom of the well has decreased. Should this occur, the tool will remain open while stopped, allowing normal injection volume as programmed for the injector well.

- Has the ability to incorporate SCADA technology, so that the injector may be contolled and monitored remotely.

Requires tower equipment (PU or WO) for installation, placed across from the drilled well to be optimized (where there is more than one drilled well). The tool generates its pulsations with a computer installed at the surface.

The computer, within a control panel tested in all weather conditions, is what regulates the number of pulsations per minute that the tool must generate at the bottom of the well. The above-ground computer permits better control of the tool. Given that the pulsations are constant, as is the fluid that passes through the tool, it does not allow for the accumulation of solids, rendering the tool maintenance-free. In contrast to the mechanical tool, the Dragonfly tool can handle very poor water quality. The above-ground control panel only requires a maximum of 5 Amperes. In the absence of electricity in the well, a battery can be used, or a solar cell.

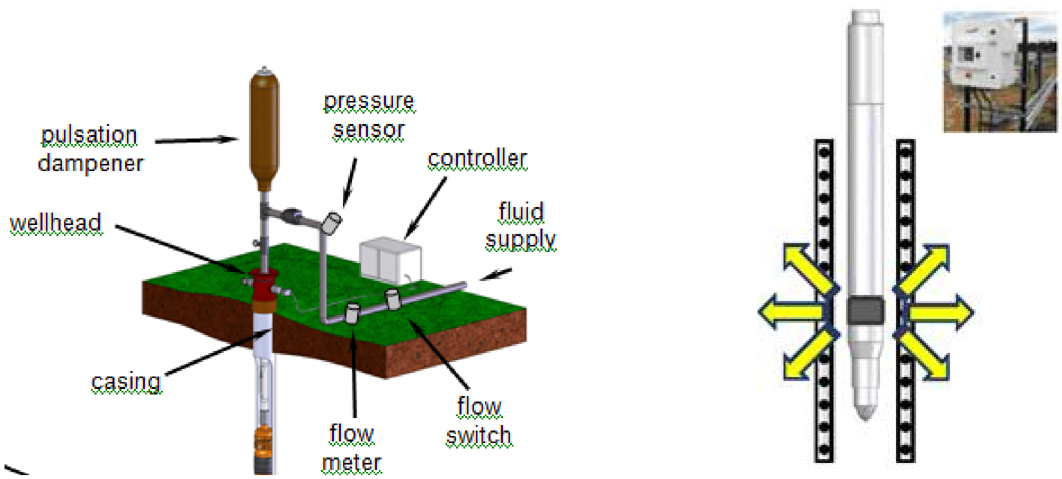


Figure 5: Electrical Tool Above Ground Equipment

Mechanical Tool - Powerwave Voyageur

There are five mechanical versions (from 150 to 1200 psi), which are selected depending on the type of oilfield and oil in the injector (the greater the pressure in the reservoir, the greater the pressure differential required in the tool).

It can handle less injection volume than the electrical tool (up to 240 m^3/day).

Installed in the injector well with WL equipment, anchored to the nipple, situated across from the drilled well that is to be optimized (where there is more than one drilled well), the tool generates its pulsations on the basis of the pressure differential exerted from the surface, and the existing pressure of the oilfield. Electricity is not required. The pressure differential allows the tool to open and close its valve, generating pulsations of fluid that uniformly penetrate the oilfield. Given that the pulsations are constant, as is the fluid passing through the tool, it does not allow for the accumulation of solids, rendering the tool maintenance-free. Only very poor water quality may block the tool.

Pulsations may or may not be detectable on the surface, depending on the injection equipment and the depth of the well, as well as the volume of the injection.

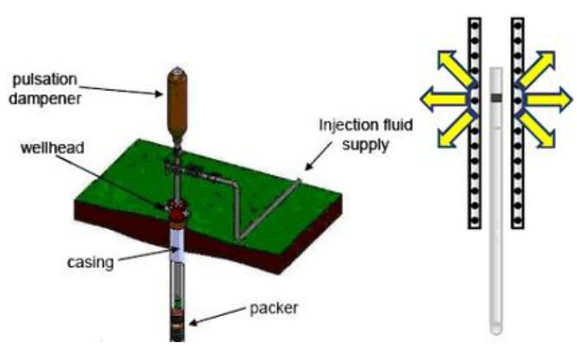


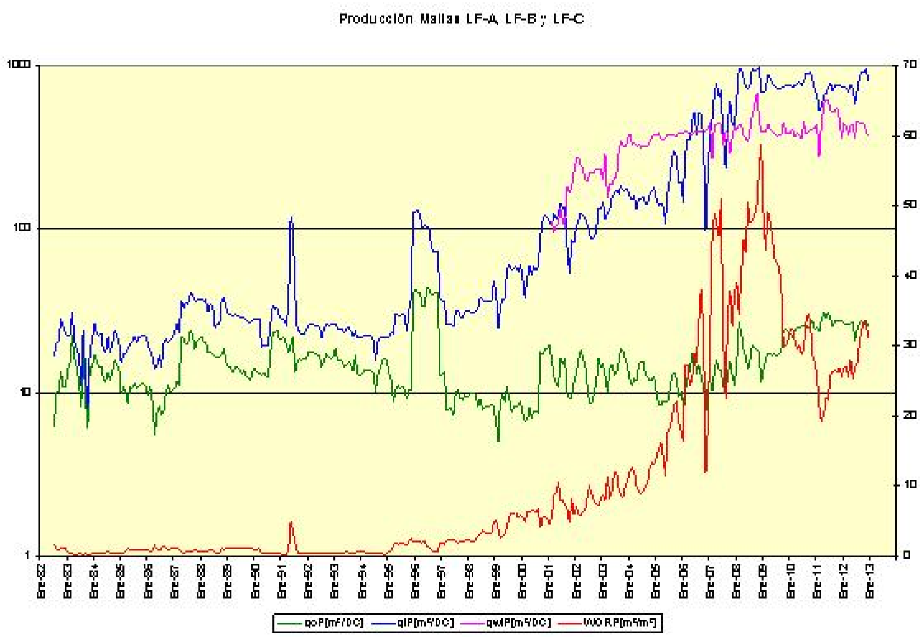
Figure 6: Mechanical Tool Above Ground Equipment

PROJECT SELECTION

Taking into account the operation of the tool, different Cerro Dragón oilfield projects were evaluated, Las Flores North block being selected, which initiated its secondary recovery project with 2 injectors and 4 producers, later reaching the current number of 7 injectors and 11 producing wells.

The first producing wells of N block were drilled and put into production in January of 1965, the majority of which documented pressurized oil with high volumes of dry oil, for the final tests of layer E1. Gas tests were also performed on this layer in the uppermost area of the structure.

In August of 2011, block injectors injected a total of 1139 m^3/day. From the total, 3 injectors were selected on which to install the Powerwave tool: **LF-A, LF-B** and **LF-C**, which are located in an area with fewer faults and therefore better connectivity between wells.



Graph 2: Production in area implementing the Pilot

Figure 7 shows the isopachous map of layer E1, with very good continuity and thickness in the area.

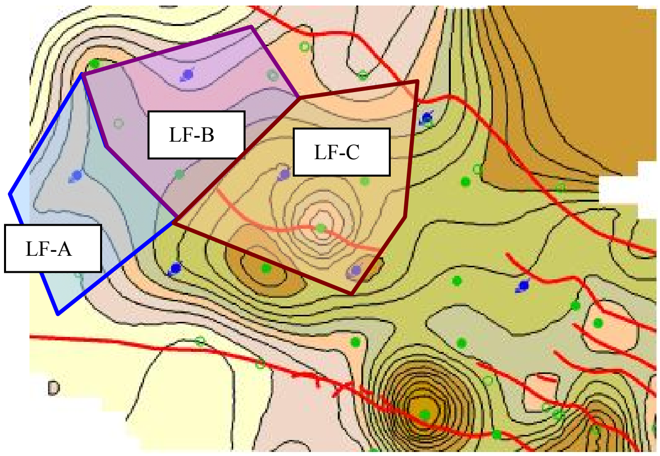


Figure 7: Las Flores Oilfield

The predominant natural production mechanisms prior to the start of water injection, deduced from the production history and pressures, were monophasic expansion and later expansion of the gas in solution.

Layer E1, highly permeable and accessible, found in a shallow area approximately 700 m down (bbp), is currently depleted, given that it is accesible without applying pressure at the mouth of the well. It has good thickness and surface area. Additionally, important individual evidence of oil has been documented, without the need for fracking. The specific characteristics of the layer are summarized in Table 2.

WF Start:	Feb. 92
Pilot Injectors	LF-A, LF-B and LF-C
Pilot Producers	LF-1, LF-2, LF-3, LF-4, LF-5 and LF-6
Liquid Production	665 m^3/day
Oil Production	24m^3/day
Injection Area (3 Injectors)	300 m^3/day
Original Average Reservoir pressure	63 kg/cm^2
Average Permeability	200-260 m/day
Injection Pressure	15 kg/cm^2 (213 psi)
Dead Oil Density	0.924 g/cm^2 (21.6 °API)
Soa:	57%
Current Primary Fr	4%
Current Secondary	3.5%

Fr	
(Prim+Sec. Fr.) 2047	17%
VP	1128 mm^3
Average Porousness	24%
Average Dist. Inj.-Prod.	460 m
Inj. VP	42%
Viscosity	12 cp@ res. temp. 38ºC
Layer E1 Average Thickness	6 m
Balance Qwiny/Qliq	1.1

Table 2: Layer E1 Characteristics

Analyzing the most recent entries we can see that the injectors show an injection pressure at the mouth of the well of between 4 and 30 kg/cm^2 for the month of August of 2011.

Considering the available technologies amd the characteristics of the reservoir, as well as the injection design, it was decided to test the two tools in the following manner:

- Electrical Tool: LF-A and LF-C
- Mechanical Tool: LF-B

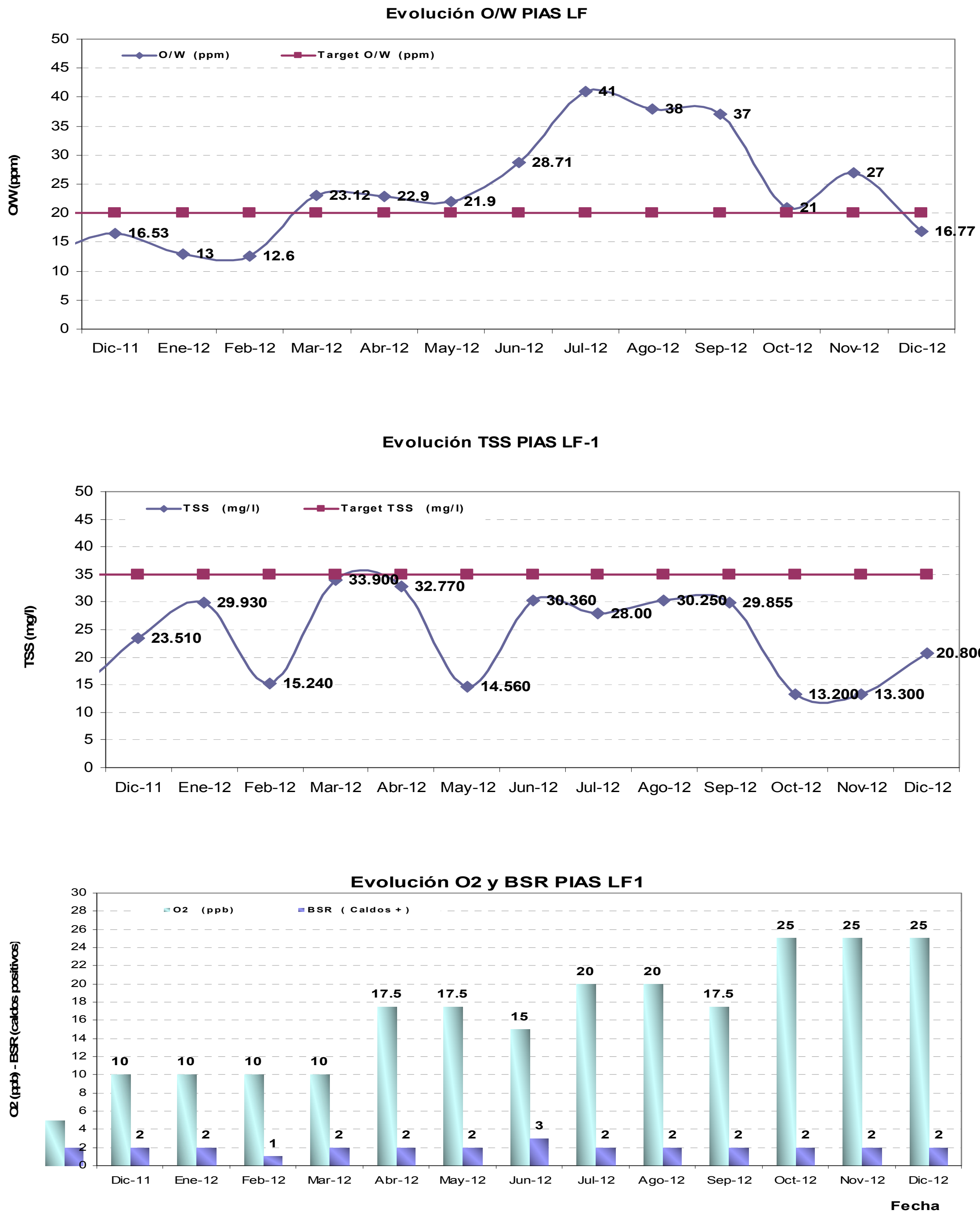
IMPLEMENTATION

Initial Conditions

Prior to beginning the pilot project, the stability of production and injection of the area must be assured, through an increase in production controls and daily monitoring of injection volumes. In this way, a referencial base line of production is guaranteed, upon which the variations in production as a result of the pulsating injection system will be able to be estimated safely.

Water Quality

Water quality is monitored through daily testing of parameters such as ppm of oil in water, total amount of soluble solids (mg/l) and the amount of oxygen (pbm) and bacteria present (col/ml). On the following graphs it can be seen that said parameters are within good quality ranges set principally not to lose injectability as a result of clogging in the secondary layers.



Graph 3: Water Quality Parametres

Surface Equipment

Injector well LF-A has an aqueduct 620 m in length and 2” in diameter, which connects it to the manifold. Injector well LF-B has an aqueduct 600 m in length and 2” in diameter. Injector well LF-C has an aqueduct 890 m in length and 2” in diameter.

The injection pumps used in the PIAS are quintuplets with a manifold pressure of 1450 psi. The distance from the PIA to the manifold is 16 km.

Currently the injection parameters are obtained with surface measurements through calibrated digital flow metres located in the injection manifold. Said data (volume and injection pressure) are sent to the SCADA system for better monitoring of same.

Length of Pilot

The pilot project will have a duration of 12 months from the lowering of the first tool; this will include the installation of 3 pulsation injection tools, 2 electrical and 1 mechanical, affecting 6 producing wells where it is hoped to obtain incremental results.

Electrical Tool Installation: LF-A and LF-C

LF-A began injection in Jan. 2001 with 2 asociated producers (LF-1 and LF-2) and LF-C in Sept. 2001 with 3 front-line producers (LF-2, LF-5 and LF-6). Added to these in 2009 were LF-3 (well with a production history, but layer E-1 had not been penetrated until that time) and in 2011 LF-4 (final well to be drilled in the network).

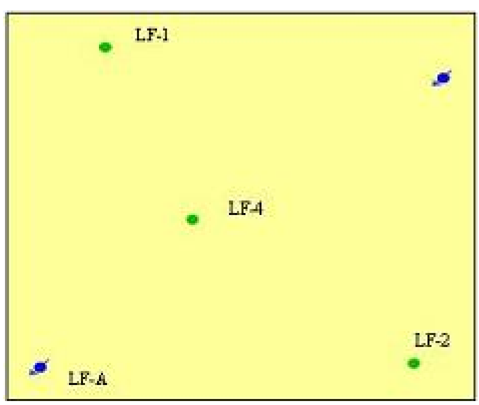


Figure 8: LF-A Network

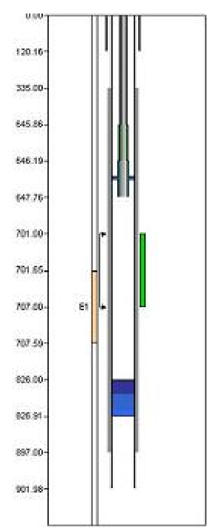


Figure 9: LF-A Injection Installation Design

Well LF-A was selected to install the electrical tool since it was the only candidate that had just layer E-1 penetrated, and as a result only 1 packer on top of same was able to do the installation.

With the electrical tool comes the complication of having to use specialized packers, since it is through these that the power cable must be passed.

The jobs that must be completed in the well prior to the entry of the PU equipment consist of the following: lowering of the power cable to the injector, redesign of the injection bridge (changing the wellhead), calibration of the flow metre, and procurement of tools and special services for the lowering of the tool (such as special packer, service company for the strapping of the power cable).

During the operations of the PU, there were no difficulties in the lowering of the tool. What was noted was that as a result of the time that the injector was closed, the reservoir depressurized and when injection was restarted the pressure at the mouth of the well was 2 kg/cm^2 (previously it had been 30 kg/cm^2).

In spite of this, once the power was turned on in the well, calibration of the tool went ahead (from the controller); it was set to 12 pulses/min (with 1.5 seconds open and 2.5 seconds closed of the tool). At the end of the second day following the installation of the tool, it was noted above-ground that the pressure had returned to normal, that is to say, 30 kg/cm^2.

Installation of the same tool on injector LF-C is planned for mid-February 2013.

Mechanical Tool Installation: LF-B

LF-B began injection in Feb. 2009 with 2 associated producers (LF-1 and LF-2). Added to these were LF-3 in 2009 (well with a production history, but layer E-l had not been penetrated until that time), and LF-4 in 2011 (the final well to be drilled in the network).

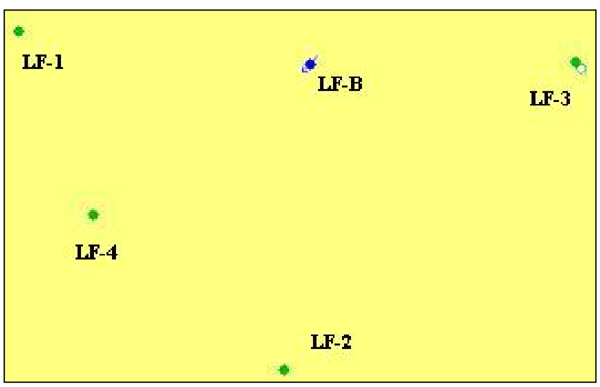


Figure 10: LF-A Network

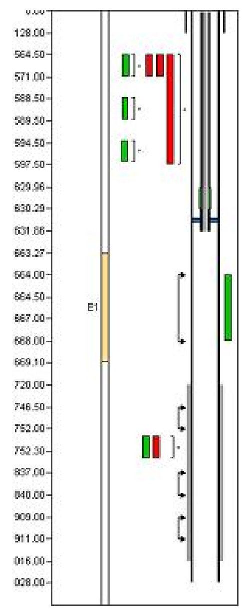


Figure 11: LF-A injection installation design

While the use of PU equipment is not necessary for the lowering of the mehanical tool, given that this injector has more layers than E1 penetrated, tower equipment was utilized to attach tpn N under the layer of interest and a double packer was employed in order to isolate the upper areas that were not of interest.

Once the PU equipment was dismantled, the WL equipment was set up in order to lower the tool. The work was carried out without incident.

As happened with well LF-A, while injection was halted during the involvement of PU and WL, the reservoir depressurized and when injection was restarted the pressure at the motuth of the well was 0 kg/cm^2, when previously the pressure had been 1.5 kg/cm^2 (20 psi). In this instance, it took 7 days for the reservoir to begin to pressurize, reaching its original pressure (20 psi) 14 days following the re-establishment of injection.

Monitoring Schedule

A monitoring schedule was implemented in accordance with the expected results in the estimated times, with the objective of determining if a response was produced in the volumes of the affected producing wells in the Pilot. The producing wells of the networks involved were tested at least 2 times per month, for the first 9-months.

Day	Pulses Accumulated	Bottom Temperature
18/01/2013	1909K	77ºC

The submersion depth of the pumps was tested more frequently, in order to quickly correct any variation and maintain them at optimal performance.

The remaining work was completed (WO and/or PU) prior to the installation of the pulsating injection system on the producers and injectors in the networks involved in the Pilot. Production and injection was stabilized and tested in order to reach a base declination curve that was as stable as possible, at least a month before the installation of the tool.

Measurements of injected volume are taken at the surface with calibrated flow metres. Surface pressure and temperature is also recorded (for the injectors on which the electrical tool is installed).

To the present time, production remains at baseline, without notable response, levels in associated wells unchanged. On the affected injectors, the accumulation of pulses and the surface pressure is being monitored as shown in the following tables:

Day	Pressure Mouth of Well (psi)
18/01/2013	280/460

In the case of the mechanical tool, the pressure observed at the mouth of the well is that reached at the time of closure, this being its maximum value, later to decrease to 0 psi when it is open; these are instantaneous measurements, in which the cycle lasts approximately 8 seconds, and thanks to the accumulator installed at the wellhead, it does not affect the equipment at the surface.

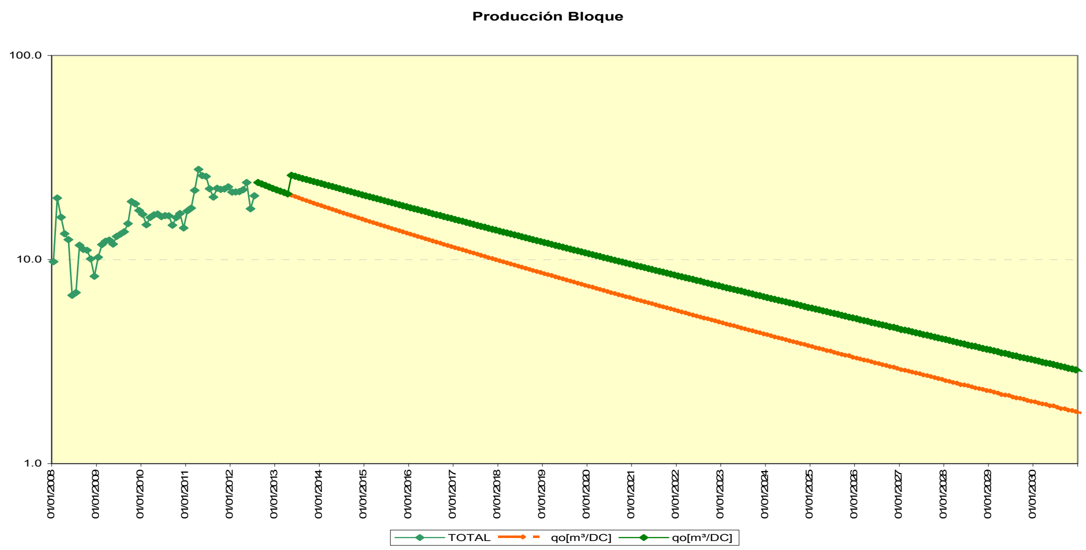
Expected Results

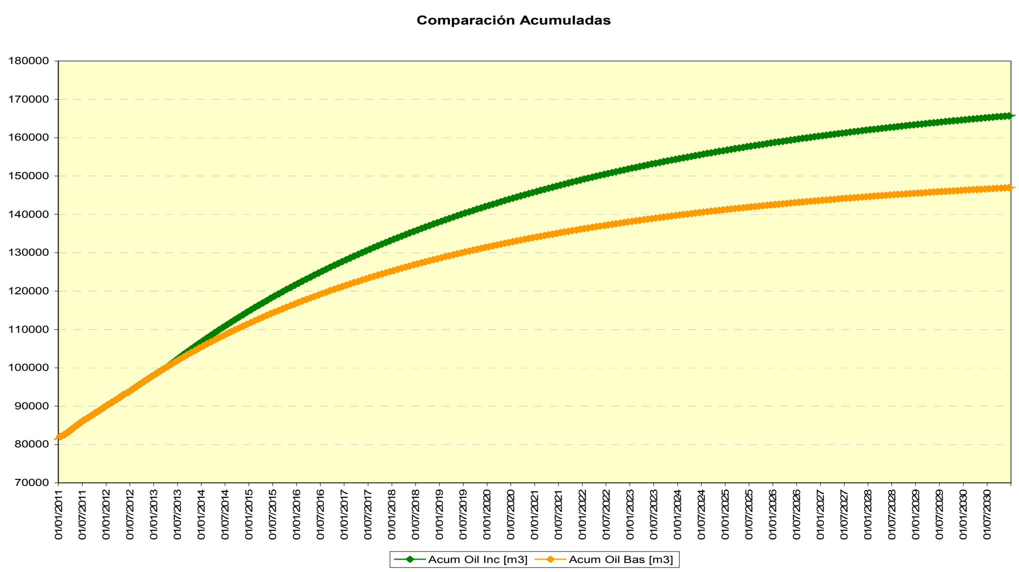
As was mentioned among the advantages of the pulsating injection system, an increase of up to 20% in oil production in the associated producers would be expected, and a reduction in declination of 6 percentage points, with an average response time of 6 months.

A reduction was made to the actual production curves of the affected producers in the pilot project, and a declinatory value of 18% was obtained, this is the curve from the base example in comparison to that obtained in the pilot project. The remaining reserves were obtained from this curve.

Later, taking into account the incremental values and average response time of 6 months, there was a 6% improvement and a 20% increase in production with pulsating injection. Therefore, a declination of 12% was utilized.

Below are the results obtained from analyses, in total and accumulated production.





Graph 4: Comparison of Baseline vs. Expected Production

CONCLUSIONS

The use of this tool aims to optimize the injection of water, taking into account that in this oilfield it was applied to a single-layer reservoir in order to facilitate the evaluation of the tool.

The final tool was lowered in December of 2012, and the response time is estimated to be between 4 and 12 months. As a result, neither an increase in oil nor a change in the declination of the wells has been observed as of yet.

After a month of pulsations, it can be concluded that monitoring changes in the pressure at the mouth of the well, the temperature of the tool, as well as the pulses it emits is fundamental (in both cases only applicable to the electrical tool). Monitoring is done weekly, acquiring field data, keeping a record to determine variations.

In order to ensure the success of of these types of systems that increase final recovery of oil, we must focus especially on maintaining the wells in the best extractive state possible so as to capture the increases in oil associated with this technology.