MONITORING, OPTIMIZATION AND PRESCRIPTIVE ANALYTICS IN REAL TIME FOR MATURE FIELDS.

Application to an extra heavy oil pilot under steam injection.

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Key Words

Monitoring, Optimization, Prescriptive Analytics, Rational Infrastructure, Rational Digitization, Predictive Analytics, Big Data, Automatic Operational Portfolio, Organizational Change Management, Integrated Asset Management, virtual multiphase meter

Abstract

The concepts of Digital Field, Intelligent Field, Real-time Monitoring and Optimization, Prescriptive Analytics, Automation are not new in the E & P industry, but after 10 years, O & G operators currently have doubts about the applicability of these technologies (profitability) and about what can be expected from them (value).

On the other hand, the E & P industry has entered into a new market, marked by a demand for greater operational efficiency (Operational Excellence) associated with lower oil trading prices, and also by competition with alternative energy sources.

Currently the industry is under a process of slow recovery where the Mature Fields and Secondary and Tertiary Recovery are outlined again with great interest in order to reduce the geological risk with respect to Exploration activities.

In this context, the aforementioned technologies become more important in order to optimize oil and gas production under different recovery processes.

The present work seeks to conceptualize the necessary conditions for the applicability of these technologies to Mature Fields and Assisted Recovery, and also to present a real field case for extra heavy oil development under cyclic steam injection, where new concepts of "Rational Infrastructure" and "Rational Digitization" are introduced; achieving production increases of more than 10%, reducing production loss (deferment) more than 5%, and reducing operating expenditures as well.

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1 General Definitions

The definitions of key concepts on which this publication is based are briefly described below.

Monitoring: Its origin is found in the monitor, an apparatus that takes images from filming installations or sensors, and that allows to visualize something on a screen. Monitoring, therefore, helps to control or monitor a situation[1].

Optimization: refers to seeking better results, greater efficiency, or greater efficiency in the performance of a task. Hence, synonymous terms are to improve, optimize, or perfect. In Management, in which managerial areas of planning and management are registered, optimization is associated with seeking to improve work processes and increase performance and productivity. Hence, it can refer to the time spent by workers for the execution of specific tasks, or to specific methods or techniques that allow greater fluidity in the work, all of which would result in greater productivity, maintaining high-quality standards[2].

Big Data: is an evolutionary term that describes any voluminous amount of structured, semi-structured and unstructured data that have the potential to be extracted to obtain information.

Large data is often characterized by three Vs: the extreme volume of data, the large variety of data types, and the speed at which data should be processed. Although large data does not equal any specific volume of data, the term is often used to describe terabytes, petabytes, and even exabytes of data captured over time.

Such voluminous data can come from countless different sources, such as commercial sales records, the results collected from scientific experiments or sensors in real time. The data can be raw or preprocessed using independent software tools before the analyzes are applied.

Data can also exist in a wide variety of file types, including structured data, such as SQL database stores; unstructured data, such as document files; or data transmission from sensors[3].

Organizational Change: is the ability of organizations to adapt to the different transformations suffered by the internal or external environment, through learning. Another definition would be: the set of structural changes that organizations suffer and that result in a new organizational behavior.

The changes are caused by the interaction of forces; these are classified as:

• **Internal**: they are those that come from within the organization, arise from the analysis of organizational behavior and are presented as alternative solutions, representing equilibrium conditions, creating the need for structural change; an example of them are technological adjustments, change of methodological strategies, changes of directives, etc.

• **Externals**: are those that come from outside the organization, creating the need for changes of internal order, are examples of these forces: Government decrees, quality standards, limitations in the physical and economic environment, etc.

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[1] Source: Julián Pérez Porto y Ana Gardey. Publicado: 2010. Actualizado: 2013. Definición de monitoreo https://definicion.de/monitoreo/

[2] Source: https://www.significados.com/optimizar/

[3] Source: https://searchdatacenter.techtarget.com/es/definicion/Big-data

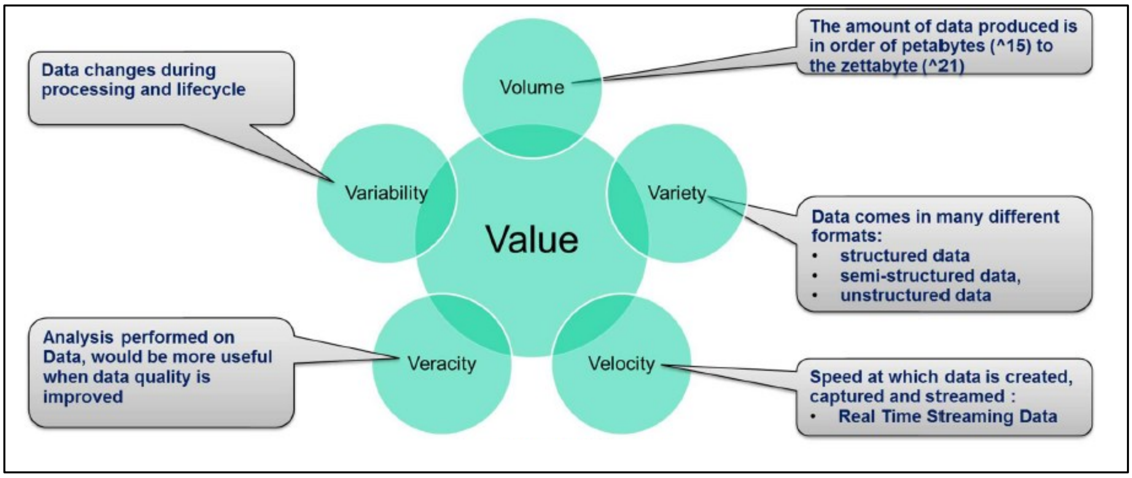


Figure 1-1. Definition of Big Data as the 6V: Volume, Variety, Speed, Veracity, Variability [4].

2 Concept Review

The objective of this chapter is to clarify some concepts that are important to understand the base of the proposed implementation in this work and demystify some beliefs to help understand the technologies that will be used during the implementation.

2.1 Mature Fields

This work focuses on mature (oil) fields because as mentioned above there is great potential in these fields, but it is complex to implement new technologies in these fields due to their nature and economy. Some possible definitions for the mature field could be:

1. More than 20 years of exploitation.

2. Production below the historic "peak production".

3. Accumulated production / (Accumulated production + 2P reserves) greater than 50%.

Mature fields present challenges for any digitization initiative, some of which are listed below:

• They are under the process of Primary Exploitation and / or Assisted Recovery.

• They have operational methodologies and workflows already established.

• They can count on other optimization initiatives.

• They have a large number of low productivity wells, some close to or below the economic limit.

• New technologies must be carefully evaluated to achieve profitability.

• In general, they have a low level of instrumentation. In case you already have a monitoring system, the technology must be able to adapt to what exists.

[4] Soruce: “How to use Big Data technologies to optimize operations in Upstream Petroleum Industry”, 21st World Petroleum Congress Block: 4 – Sustainable Management of the Industry Forum: F22 – The role of innovation and technology in shaping the oil and gas industry.

• They present a large scale of operation.

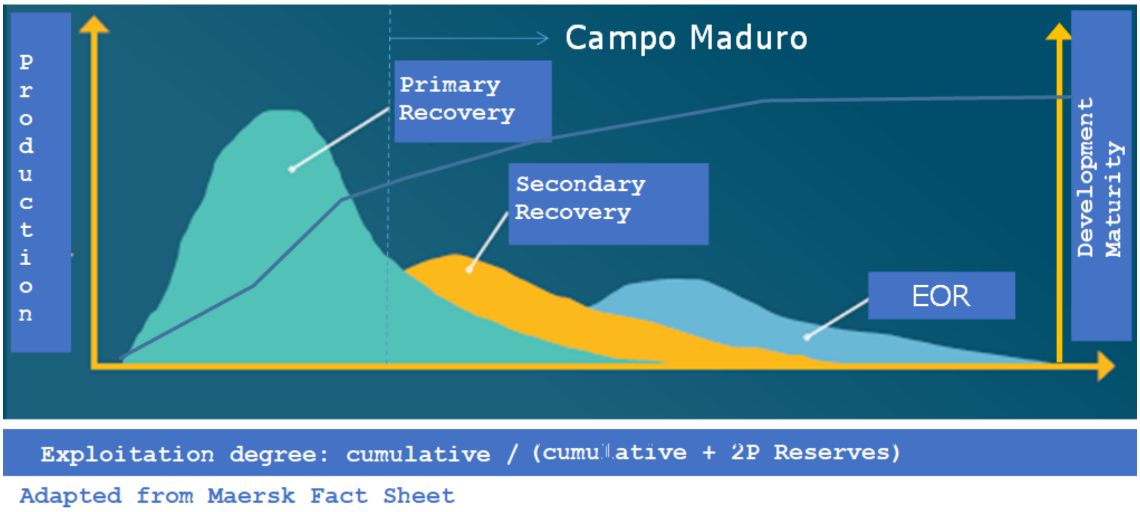


Figure 2-1. General definition of Mature Fields.

2.2 Mature Field Digitalization

In a general sense, the digitization of the O & G field consists of developing a complex system that combines the classic principles of Petroleum Engineering and Data Analytics.

"Digital Oil Field (DOF) technology for mature oil and gas fields is a comprehensive optimization solution based on descriptive, predictive, and prescriptive analysis through the combination of analytical techniques of data and the first principles of petroleum engineering.

This solution provides real-time information to optimize production and support operational decisions that lead first to "Increase in production and, second, optimization of operating processes with greater operational efficiency and reduction of production costs".

To carry out this type of initiative, it is necessary to comply with economic, technical, and technological criteria:

Economic Requirements

The solution must be economically viable for the operator, for which it is required that:

- The technology is profitable for the field operator.
- The technology must generate increases in production and reduction in deferred production.
- It must also reduce OPEX operating costs.

Technical Requirements

The solution must meet the following technical criteria to solve operational, and production and reservoirs engineering challenges.

- Real-time monitoring of P, T, in wells and production and injection networks.
- Integration of three-phase measurements in key points of the process.
- Real-time modeling of the multiphase flow (oil, gas, water).
- Automation of Operational and Reservoir Production & Engineering workflows

- Integrated modeling of production processes in real time: surface network: wellhead, production/injection heads (gas/water), artificial lift systems, pipelines, oil/gas/water plants.
- Integrated modeling of reservoir engineering processes in real time: subsurface: nodal analysis for multi-layer reservoirs.
- Virtual measurement of the three-phase flow in real time: at the well and subsurface levels (multi-layer allocation).
- Natural flow modeling and artificial production systems in real time: mechanical pumping system, gas lift, plunger lift, electro-submersible pumping, hydraulic pump (jet pump), progressive cavity pumping, chemical capillary injection for the dehydration of gas wells.
- Non-conventional assets - Optimization of hydraulic fracturing: proppant type and volume, fluid rheology, termination - drilling design.
- Secondary and Improved Recovery: optimization of injection rates, vertical and areal distribution of the displacement phase (gas, water, steam, polymers, bacteria, etc).
- Detection and mitigation of production loss in real time: the system detects and interprets the root causes of production loss, activating recommendations and processing alarms.
- Prescriptive analysis that allows detection, recommendation and ranking of optimization actions on wells and facilities. This requires the combination of Petroleum Engineering and Advanced Machine Learning models.
- Automatic Operative Portfolio: generation of a ranking of actions to be taken on the wells heads, production & injection manifolds, systems of artificial lifting of production; ordered/ranked by the associated production increase.

Technological Requirements
From the point of view of the solution, it must have the following characteristics:

- The technology must be modular: the communications infrastructure, wireless instrumentation, and multiphase measurement can be provided by an integral solution or the solution can be integrated into the existing infrastructure/services.
- Technological rationality: The infrastructure must be rational: measure what is needed in order to optimize services and costs.
- Provision as a Service: Structure of a rental service. The customer should not worry about maintenance, vandalism, replacements, technological updates of the solution, etc.
- Without IT infrastructure: The system must be WEB accessible so that it can be used directly from any person within the organization.
- Integrable with the existing infrastructure: The system must be able to adapt to the existing corporate databases and infrastructure.
- High availability: Availability of information 24 x 365.
- Decision Support Center: Operation, Production, Reservoir Engineering staff has an integrated technical discussion environment to streamline meetings for well and production follow up, review of recommendations to be made and the effectiveness of those which has been taken; generating a cycle of continuous improvement in a collaborative environment.

2.3 Artificial Intelligence (AI); "Machine Learning" (ML), Predictive Analysis and Prescriptive Analysis: Maturation of analytical modeling in O&G.

Below are several important concepts on which the digitization of fields is based.

Artificial Intelligence (AI) is the ability to take information, process it, and then apply it to new situations. Unlike general belief and knowledge, intelligence is not information but a process. The AI algorithm applied to the O & G with a specific purpose is by no means trying to emulate human intelligence in a broad sense.

Machine Learning (ML) is an AI technique in which algorithms receive data and are asked to process it without predetermined rules. ML algorithms use what they learn from their errors to improve future performance, with more accurate results when the algorithm has access to large amounts of data to refine its algorithm (Staish Sankaran, et. al., 2009).

Predictive Analytics: it is the analysis of historical information (as well as existing external data) to find patterns. These patterns are used to make educated predictions about future events, or an unknown value in the past, present or future. As a general rule, any attempt to quantify the possible unknown value based on past events is included in the predictive analysis (Rich Holsman, 2017).

Predictive analytics has grown in prominence along with the emergence of large data systems, or Big Data [5] (World Economic Forum, 2017).

Because predictive analytics is one of the most common business applications of machine learning, casual users think they mean the same thing. Machine learning is much larger than the predictive analysis.

Regression is a ML technique, and it is interesting to note that most O&G models use regressions at some point in their calculation process, so ML techniques have been used in O&G for many years. years.

Prescriptive Analytics: analytics that seeks to provide optimal recommendations during the decision-making process. Unlike predictive analytics, prescriptive analysis determines the ways in which business processes must evolve or be modified (Balaji, 2018)[6].

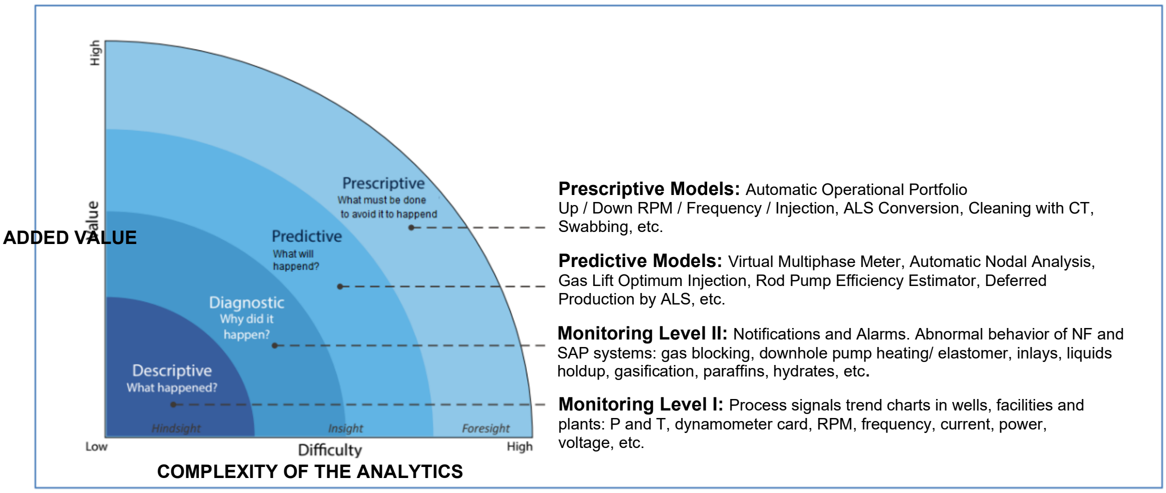


Figure 2-2. Maturation of the analytical modeling and its application to the Production Optimization of Mature Fields.

5 https://searchdatacenter.techtarget.com/es/definicion/Analitica-predictiva-o-analisis-predictivo
6 https://www.arimetrics.com/glosario-digital/analitica-prescriptiva

The above can be seen as a natural evolution of the concept of SCADA monitoring (acronym of Supervisory Control And Data Acquisition - Supervision, Control and Acquisition of Data), which starts from the acquisition and visualization of physical parameters in real time, and generation of simple alarms based on the levels of these parameters. Towards the concept of predictive and prescriptive analytics, thanks to the evolution of computer systems, AI techniques and algorithms, and Big Data management.

3 Optimization processes in O & G

Even though the previous concepts are not new, the implementation in the Oil Industry has been significantly slower. On one hand, historically, the processes of productive optimization were considered secondary with respect to the "main" processes that are the Prospective Exploration and Development of Reserves. Contrarily, the optimization of a field has been attacked initially by optimizing the workflows of Geology and Geophysics to make more efficient the interaction of the different disciplines, and later incorporating the Reservoir Engineering, which together are responsible for generating the Field Development Plan. In other words, the optimization processes have sought to improve the quality of the proposed drilling, workover, recovery schemes, etc.

The success of these optimization systems in terms of the associated production increase is difficult to quantify. On the other hand, the cost associated to the package of specialized programs (Geology, Geophysics, Reservoir Engineering - Production), can be a limitation for small operating companies.

Conversely, within the environment of production processes and operations, the concepts of cost optimization are already handled, since it is relatively straightforward to quantify a baseline of operating costs.

Finally, the concept of production optimization has been developed by the Production Engineering, which has looked almost exclusively at the flow within the well pipe from the perforations to the head of the well, and the optimization of the artificial production systems. Finally, the collection and injection lines to the plants were included.

Regarding drilling, in the case of high-cost wells and operational risk associated with particular environmental, rock and mechanical conditions, work flows exist that allow to connect the information of the well "almost" in real time through the records type LWD (Logging While Drilling in English), with the programs of the specialties of geology, geophysics and design of drilling, in order to be able to adjust the trajectory in a continuous way, reducing possible operational contingencies and ensuring the objective (exploration or maximum reservoir contact).

In short, O & G optimization processes have historically developed at different levels, using different tools, and working in general independently.

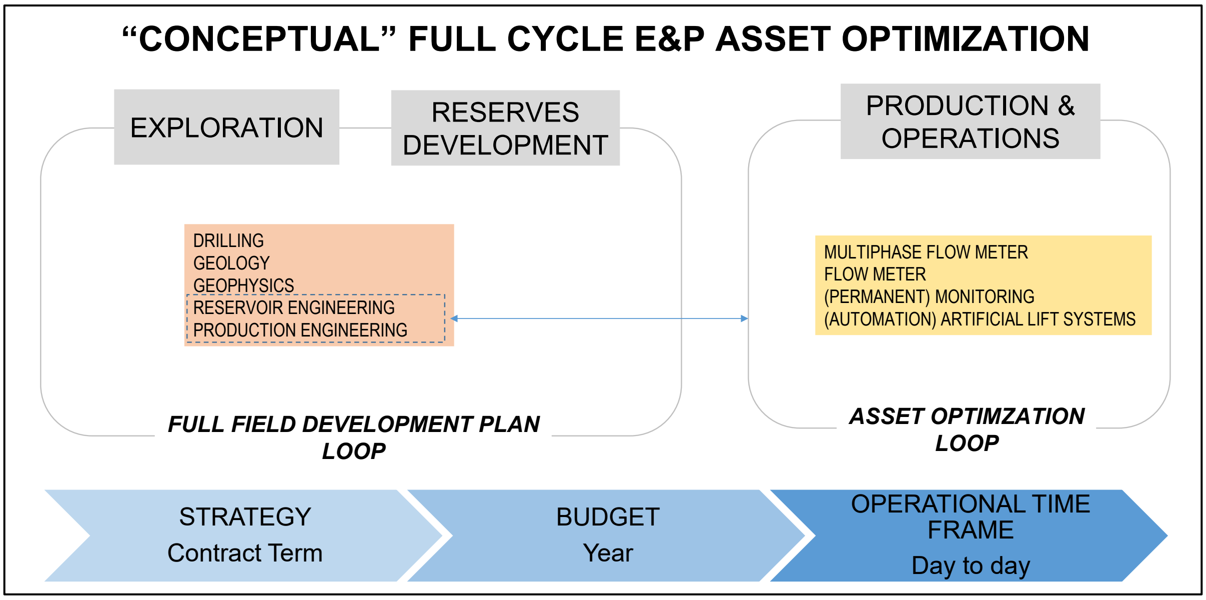


Figure 3-1. "Conceptual" Complete Cycle of Optimization in the Exploration and Development industry.

4 Concepts of Integrated Asset Management, Asset Optimization and Field Digitalization.

Perhaps one of the first Digitalization of Fields initiatives has been the attempt to encompass the optimization processes of the Development Plan with the Production and Operations process, for which the service providers have generated the packages of Integrated Asset Management; where a platform has all the specialized programs for the areas of Drilling, Geophysics, Geology, Petrophysics, Reservoir Engineering, Production Engineering and Process Engineering. Certainly these tools have increased the productivity of work teams, but the technological advance in terms of real-time data acquisition, Big Data, Artificial Intelligence, Predictive and Prescriptive Analytics have pushed their applicability to the limit.

In the opinion of the authors, the previous point generates a series of paradigms for the Digitalization of Mature Fields:

1. Confusion exists in regarding the scope of the concepts of Integrated Asset Management (Asset Management) and Asset Optimization (Asset Optimization). The first refers to the optimization of the Development Plan (Field Development Plan) and the second to the optimization of production and operational costs, the scale of time being very different (years and days).
2. It is necessary to measure much more, for which it is not profitable to massify the instrumentation and measurement of multiphase flow periodically, except in assets of high productivity per well.
3. Analytical techniques based on artificial intelligence lacks in oil engineering, so advanced data statistics techniques are built with limited applicability to solve operational problems.
4. It is possible to adapt the existing specialized programs of petroleum engineering to feeding with data in real time.

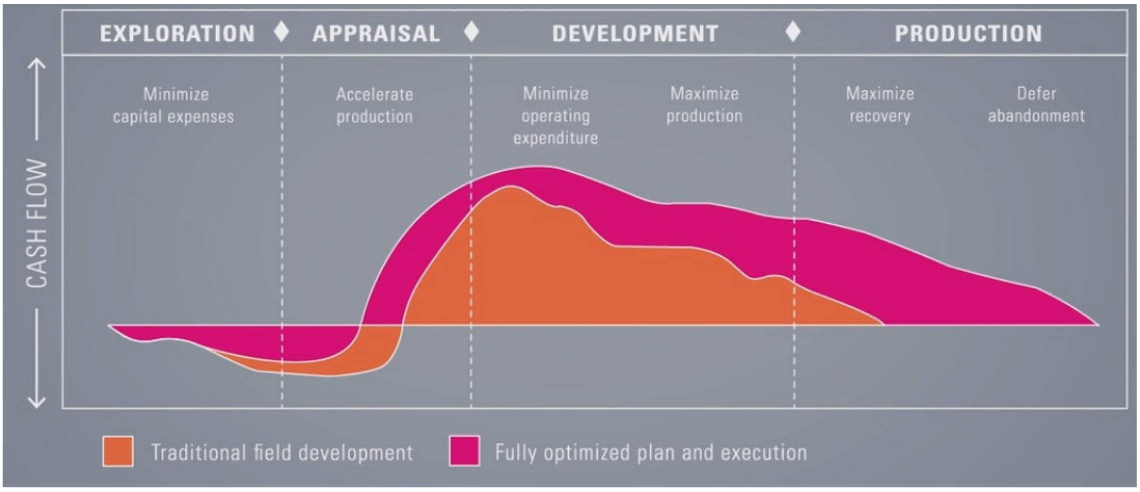


Figure 4-1. Conceptualization of "Integrated Asset Management".

Nota sobre la Figura: *Optimización del Plan de Desarrollo de un Campo, desde su Exploración hasta su abandono. Adaptado de SIS™ de la compañía Schlumberger*

Therefore, when it is desired to take the concept of the "Conceptual" Complete Cycle of Optimization to an Oil Field, there is a technological barrier when using the traditional workflow of reservoir engineering and production engineering in modeling in real time which is one of the pillars in the Digitalization of Fields.

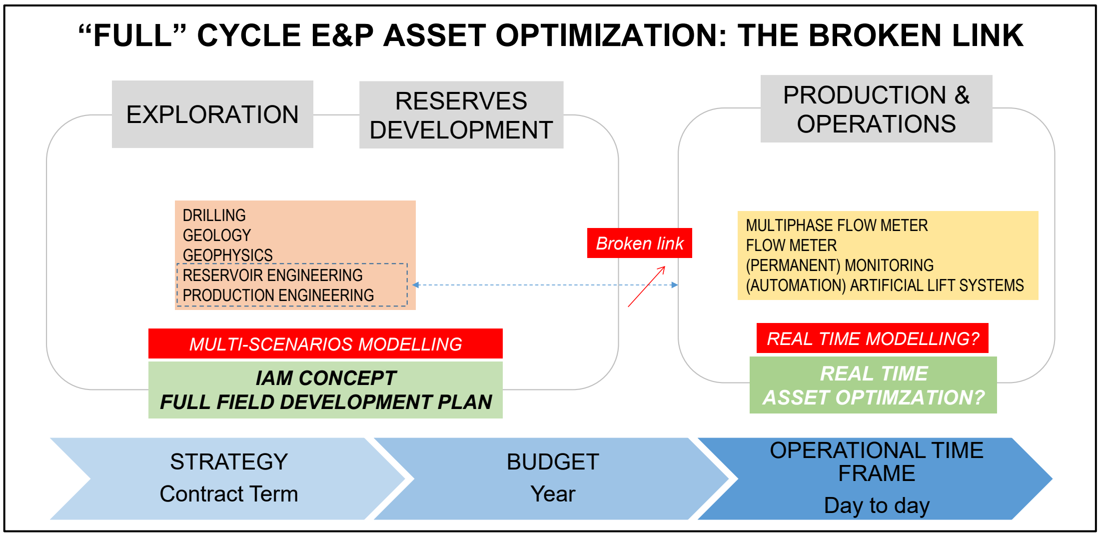


Figure 4-2. "Current" cycle of Optimization in the Exploration and Development industry.

Note on the figure: *The package of specialized programs currently does not allow to execute a Optimization of the Asset in real time because they are not prepared to work in real time, since they are designed to work in the scale of the years, and generating scenarios of developing. In this sense, there is a decoupling between the Integrated Asset Management and the Assets Optimization in real time.*

The previous concepts are developed in order to demystify the applicability of the Digitalization of Mature Fields..

5 Pillars proposed for the Digitalization of Mature Fields.

5.1 Unified and rational infrastructure

By Unified we mean complete and integrated for a specific purpose, and by Rational we mean that it has been designed and constructed for the specific field's requirements and for a specific purpose in mind. In this sense, the purpose of the implementation must be very well defined from the beginning.

Rationality in instrumentation, well tests, Machine Learning techniques, automatic workflows, etc. would lead to optimizing the aquisition cost and effort of implementation and maintenance costs of the required infraestructre; which is a necessary conditions for the digitization of mature fields.

5.2 Simple principles, keep focused

The Unified and Rational implementation has four areas of principles, whose definitions are the fundamental principles for the implementation of the DOF: main objective (value for the operator), process requirements and installation requirements. All these three components must be balanced to comply with the fourth principle that is the profitability of the implementation.

In this paper, we will propose a specific definition of value for the project, since the operating cost of the mature field contains the limits of the definition of main value for a key performance indicator (KPI) related to the economy. Intangible values such as the performance of life cycle assets or many other secondary benefits becasue of applying a digitization initiative to a field, such as improving the efficiency of the process, the better quality of the data to make decisions, among others, they are not key factors for the approval (viability) of a mature field digitization project.

• The increase in production should be established according to a reasonable objective, after having been evaluated and detected the main areas of opportunity from which to obtain incremental production.

• Process requirements must be defined based on the desired production increase.

• The installation requirements should indicate what should be added in the field, from the sensors to the data processing systems, and in the well.

These definitions allow you to easily verify the economic aspects of the implementation and review them in a cycling process to meet the objectives mentioned above..

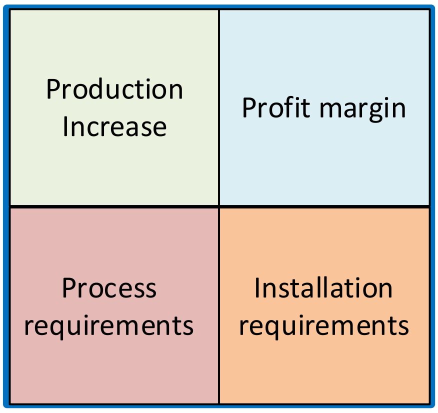


Figure 5-1. The 4 pillars necessary for a successful implementation of a Digitization of Mature Fields project.

These concepts force us to think of solutions outside the box, outside the real paradigm, that do not seek a broad and complex solution but a block of specific, and profitable purpose; which can then be integrated into a wider and more complete system (modularity), but which covers all the challenges from one end to the other, from sensing devices, through oil engineering, behavioral modeling, to workflows. optimization and training.

5.3 Data Analytics and First Principles

It is also well known that data-driven models are not fully understood by engineers who worked with the first principles for many years, and that there is a justified concern about the ability of data driven models to accurately predict the process in which the phenomena occur. It should be understood that there is no single solution that can describe the variety of phenomena that occur during the extraction of oil and gas, with the variety of artificial lift systems, complex reservoir geology; networks and process facilities. In the same way that the first principles models can not describe all the situations, the models based on behavior (data) can not describe them either. The solution is to use each type of model where it provides the best results in terms of accuracy, calculation speed, predictive capacity and prediction time frame. (J.G. Pickering, 2013)

The use of these techniques is not new to the industry and is one of the main research and development efforts in the oil and gas companies at this time (Balaji, 2018) (B. Jafarizadeh, 2009) . Data-based models are useful when there is sufficient data, with adequate quality, so that ML techniques can extract patterns, which can be used to predict an unknown variable in the future, in the past or in the real moment. Data-based models can not accurately predict behavior outside the "trained" range, however, with the proper retraining process this limitation can be overcome. This artificial intelligence technique can add real value in the E & P industry, mainly in applications related to the control and optimization of production, the simulation of proxy models and virtual detection (J.G. Pickering, 2013).

The first principles models impose certain border conditions and rules that must respect the behavioral models. Initially, during the training stage it is convenient to apply these conditions manually when the data models are being defined, training and verifying; to then implement automated verification rules that ensure the quality of the information generated by predictions and prescriptions (P. Chanana, 2016). This task is one of the key responsibilities of the oil engineer as Project Leader of the solution provider company (Project Product Champion).

5.4 Real-time simulation

Real-time analysis presents another challenge besides finding the right algorithm that can predict the target process variable with the specified precision and for the ranges of specific dependent process variables; which is that the algorithm must have the capacity of self-learning (unsupervised learning), or supervised learning with automated training; In addition, it must have resilience, that is, it must maintain the defined prediction quality when the condition of the operation changes. It must be taken into account that the operating conditions is a broader concept than the conditions of the process, since they also include, for example, changes in operating procedures or changes in the artificial lift system.

5. Digitization of Mature Fields and Oil Engineering in Real Time

In previous chapters has been presented what is the objective of the Digitization of a Mature Field, which are the pillars on which this type of initiative should be supported to meet business objectives, and what would be the relationship between Petroleum Engineering and its workflows with Data Analytics. The authors consider that together you can define or talk about an **Oil Engineering (Reservoir, Production, Process) in real time**, not because it is based on new physical or chemicals principles that support it, but because the management of Big Data associated with the enormous volume of data generated by sensors installed in the field requires the intervention of new techniques that also involve Data Analytics.

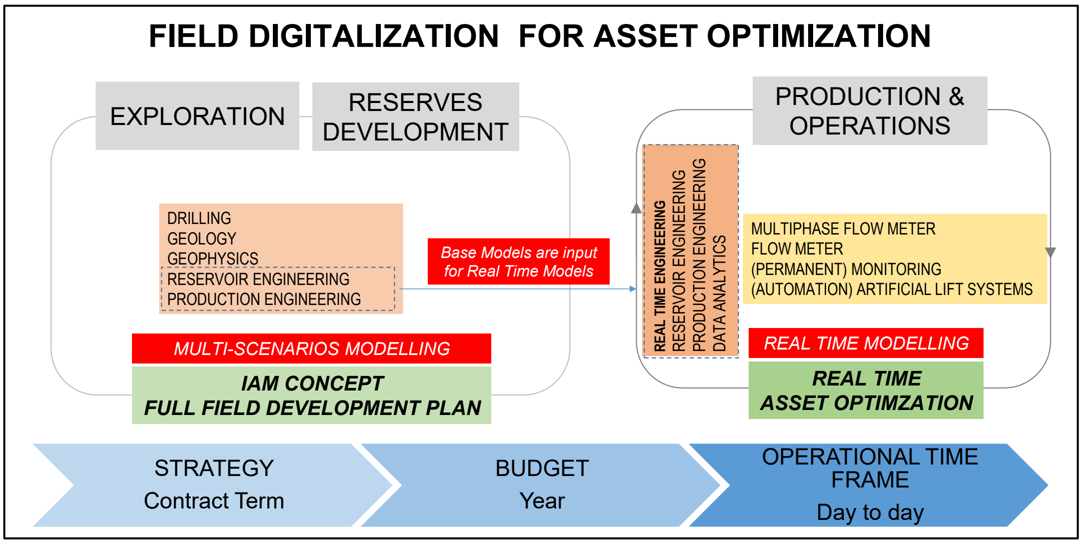


Figure 5-1. Definición propuesta para la Digitalización de Campos.

It is proposed to create reservoir and engineering models tailor-made, integrated to the data analytics that allows modeling in real time, creating predictive and prescriptive analytics according to the problems of the field in particular..

6. Automation of Workflows for the Digitization of Mature Fields.

Staring from the basic infrastructure of instrumentation, flow measurements, communications, integration of the system databases and the corporate bases of the operator, it is possible to optimize and automate the workflows of the departments of productivity engineering, production and operations, who are the "end users" of the optimization platform. This task represents the integration of the company providing the Digitalization solution with the field operator, and also with the subcontractors associated field services like well measurements, artificial production systems, and services to wells without equipment and tower equipment. This integration is a real challenge in a Digitalization of Oil Fields project and represents a barrier to overcome by the multidisciplinary team of the supplier and the operator.

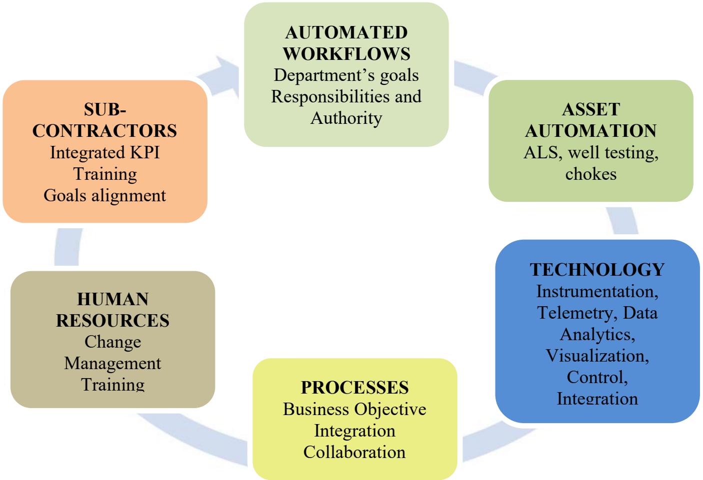


Figure 6-1. Critical components for the optimization and automation of workflows for the Digitalization of mature Fields.

7. Application to an Extra-heavy Oil Field

In the second part of the work, a real case of application of the proposed technology applied to a mature field of extra heavy oil under a scheme of cyclic steam injection operation is presented..

5.5 General Characteristics of the Field

The main characteristics of the field and its exploitation strategy are summarized below.

Exploitation

- Cyclic Injection of Mature Steam (Huff & Puff), and at present it has been injected on average 6 - 7 cycles / well.
- Current distance: 300 - 400 m
- Current production 11,000 bopd.
- Peak of Production 20,000 bopd.
- Artificial Systems: Gas Lift system - Mechanical Pumping (50% / 50%).
- In evaluation of continuous steam injection process / decrease of distance.
- Use of flow improvers to reduce oil viscosity through continuous dosing by capillary tubing.

Properties of Reservoirs

- Reservoir pressure and temperature: 97 kg / cm2, 45 ° C @ 900 mbnm.
- Type of rock: sandstones Not consolidated.
- Effective porosity: 25 - 32%.
- Water Saturation: 15 - 50%.
- Absolute permeability 3.000 - 5.000 md.

- Gross and Net Thickness: 300 - 500 m / 120 - 150 m.
- Deposit environment: fluvial type with channel and dyke trends.
- Multilayer Reservoirs: 3 main areas.
- Depth reservoirs: 700 -1,000 m

Properties of Fluids

- Extra heavy oil: 5 - 10 ° API, Viscosity 6.000 - 45.000 cp (45 ° C - 100 ° C), Rsi: 1 - 10 sm3 / sm3.
- Oil shrinkage factor by foam: 0.40 (Final Volume Oil / Initial Volume Oil with foam).
- Formation salty water: 50,000 ppm
- Associated gas: C1: 84%, C2 + <3%
- Gas pollutants: CO2 <2%, N2 ≈ 11%, SH2 traces - 5 ppm (in Batteries and process points)

Recovery factors

- R.F. Current 6%.
- R.F. Final injection Cyclic Vapor 15% (projected).
- R.F. Final injection Steam 30% (projected).

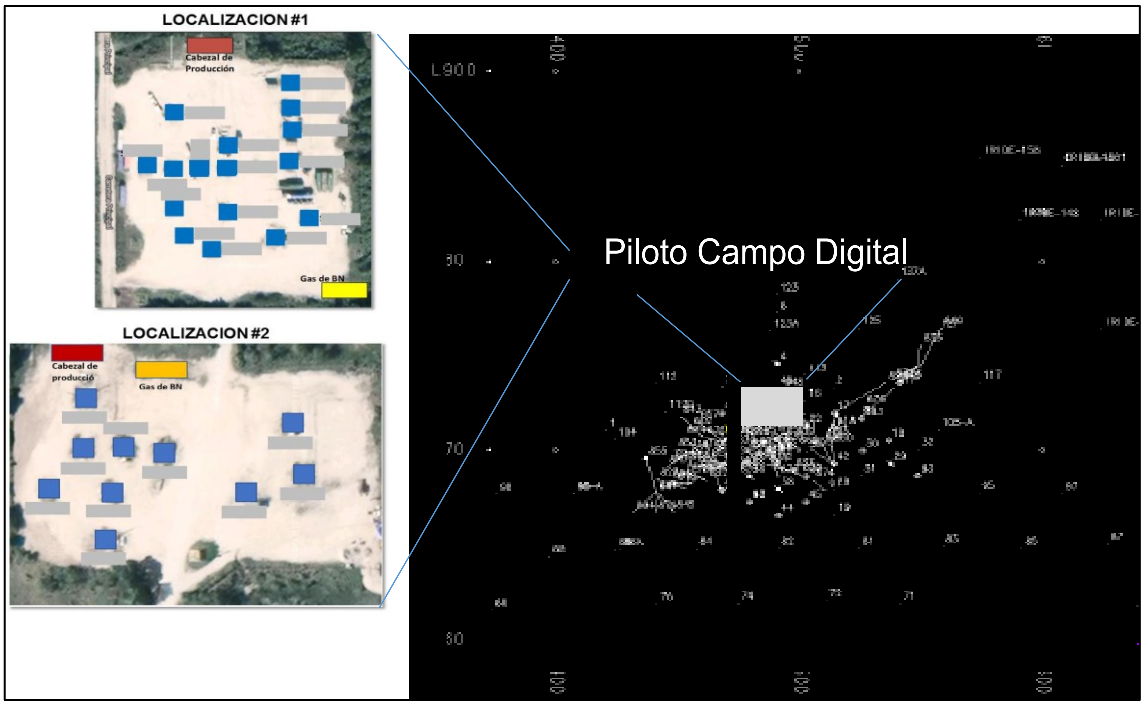


Figure 7-1. Map of the location of the field and the Pilot.

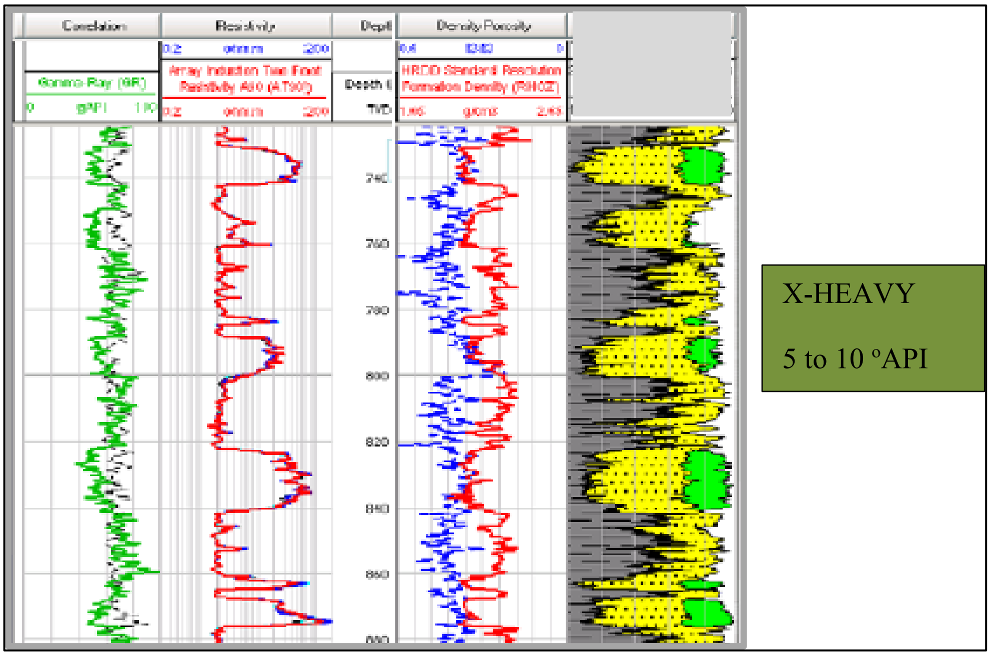


Figure 7-2. Typical vertical well logs for the Digital Field Pilot.

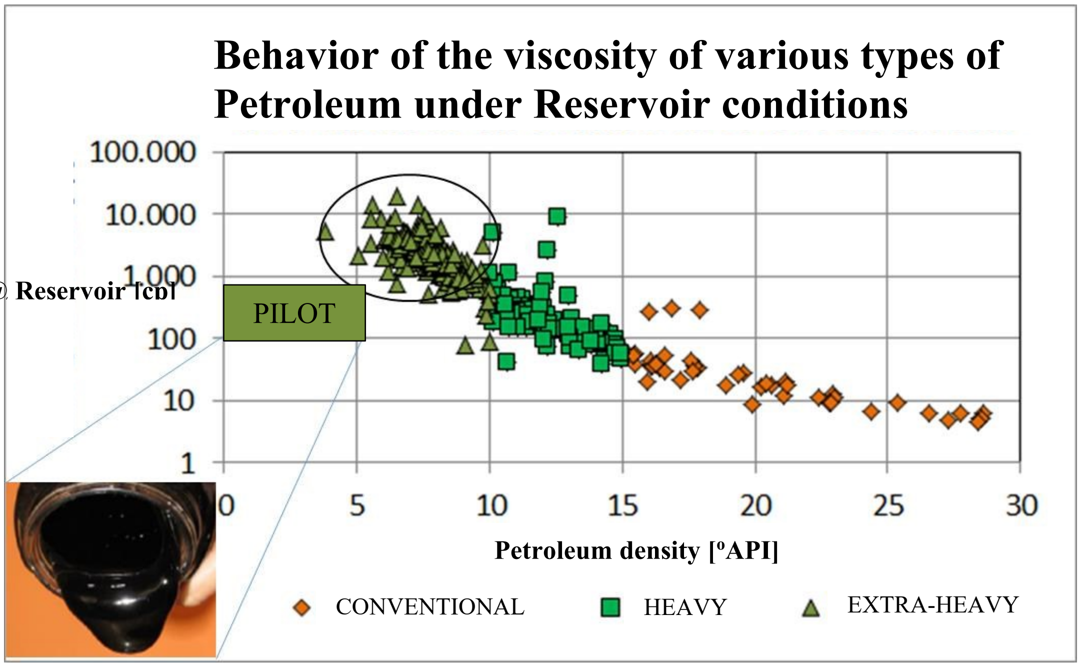


Figure 7-3. Comparison between the properties of conventional, heavy and extra-heavy oils.

5.6 Policy of Exploitation applied to the Field

The policy of exploiting a general well of extra heavy oil within the field (and the pilot) is summarized below:

- Vapor injection for approximately 15 days. Maximum surface temperatures of up to 400°C are reached.

- Soaking for the interval 5 days approximately. Cooling occurs up to approximately 30 °C / 200 °C.
- Start-up with gas lift system. Initially it produces with high water cut (steam's water) and then gradually decreases towards the formation's water cut. Dry gas from the injection network and a simple downhole completion using production line and circulation jacket above the perforations is used.
- Operation with gas lift system until the temperature drops below 60 - 70 ºC.
- Intervention with rig less truck to lower pump and rods. It is taken care not to exceed the temperature limit of the anchor type "tubing-in" (temperature limit of the elastomer).
- Operation with mechanical pumping system up to the economic limit.
- Rotation of the Artificial Lifting System (ALS) by converting the gas lift system to mechanical pumping every 6 months.
- Treatment with Hot Oil to well with monthly frequency (can be circulating or to the formation).
- Typically there are 2 well designs, vertical or "S" type well with deviation start ≈ 150 m, cased with 7 "L-80, 26 lbs / ft. Casing pipe. Above the perforations is a 7 "x 5" thermal hanger, from which "hangs" 5 "Liner slotted pipe, L-80, 15 lb / ft, 144 slots / foot. This thermal hanger is ≈ 20 m above the top of the perforations. The cementation of the area of interest is of the thermal type, suitable for steam injection.
- For a well with gas lift, the completion is composed of isothermal production pipe of 4.5 "x 3.5" BCN, 4.5 "thermal circulation jacket, 7" x 5 "thermal floating packer, ending in a tail pipe of 2 7/8 "L-80, 6.5 lb / ft, which can be" threaded "in some cases inside the thermal hanger ≈ 10 m. The circulation jacket is ≈ 20 m above the 7 "x 5" floating packer.
- For a well with mechanical pumping, an insertable pump with mechanical lower anchoring (tubing-in) with thin and thick wall barrel (RWBM 24-5 / RHBM 24-5), anchored in a tubing-in type anchor is lowered. 3.5 ", typically being ≈ 15 m above the thermal circulation jacket of 4.5". The diameters of the traveler plunger are typically 2 ", 2.25" and 2.5 ", and the bottom rods of 1" and the polished rod of 1.5 ". As for the surface equipment, the typical ones are 144-inch race, being hydraulic equipment and conventional units (beam pumps). There are also some long stroke units (320 inches).

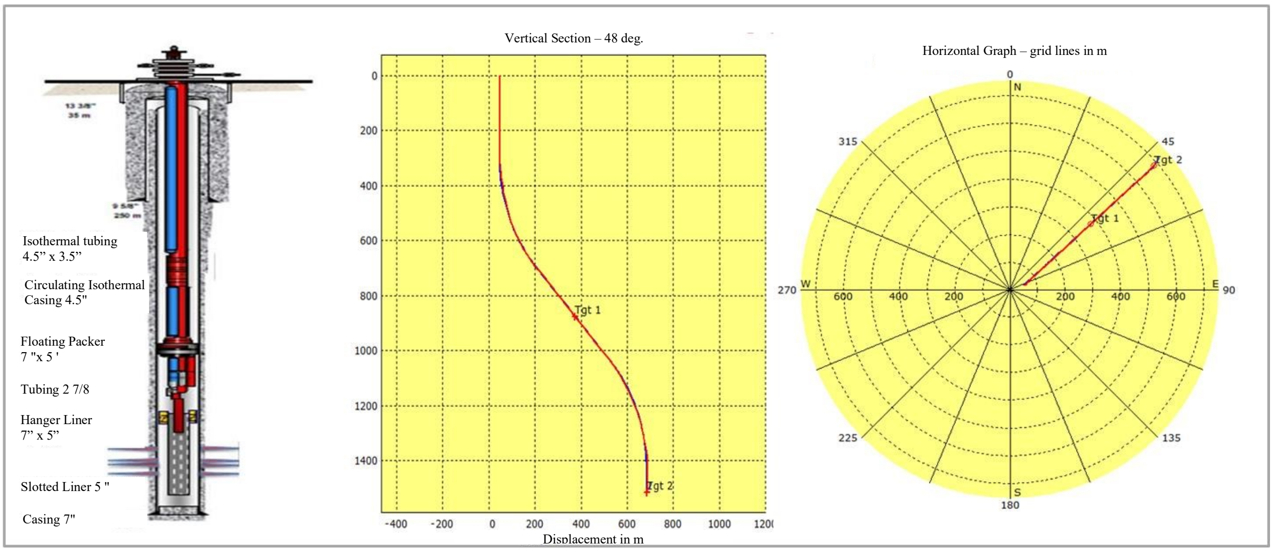


Figure 7-4. Mechanical scheme and geometry of a typical well of the project.

5.7 Pilot's Timeline

The Pilot test was divided into three phases. The first phase for the implementation of technology, field instrumentation and communications system; the second phase for the Adjustment and Validation of the portable well testing unit for flow measurement, and to create the production baseline per well, and the third phase for the implementation of the recommendations and optimization system. These stages were developed in 12 months total, 4 months for the first stage and 8 months for stages 2 and 3.

For the stages of Validation, Baseline and Optimization, a multidisciplinary work team was formed with personnel from Production Engineering, Production - Operations and the company providing the technological solution, which was carrying out the protocol of the technological test under the coordination of a Leader of Project of the operator and the technical direction of a Leader Champion of the supplier.

The communication between the personnel involved and field supervisors was reinforced through work meetings, emails and the Whatapp working group; keeping track of both planned and unplanned events through a log, and of operational requests through a weekly report and meetings.

5.8 Characteristics of the Pilot

The technology was applied in 2 well pads of the extra heavy oil field with its active wells under the scheme of recovery by Alternating Vapor Injection (Huff and Puff). During the development of the pilot the operator intervened with steam injection 6 active wells, which allowed the evaluation of the different behaviors during the stages of soaking, start-up with Gas Lift system, and mechanical pump change system.

Wells and production and injection lines did not have practically any instrumentation, neither a multiphase flow measurement system suitable for extra heavy oil. The instrumentation of all the wells and the 4 production - injection heads present in the 2 well pads were required.

- Active wells: 15 wells with two types of ALS: gas lift and mechanical pumping.
- Gathering network: 2 production headres and 2 gas lift injection manifolds.
- Without existing measurement infrastructure. Problems of vandalism in the area.
- Instrumentation: 49 wireless sensors installed.
- Flow Meter: 1 portable three-phase meter connected to the production manifold working 24 hours from Monday to Friday. Transportation to a wherehosue during the weekend.
- Pilot Duration: 12 months of execution.
- Stage I Installation Rational infrastructure: 4 months.
- Stage II Validation of the Portable Well Testing Unit with extra heavy oil: 1 month
- Stage II Baseline: 3 months.
- Stage III Optimization: 4 months.

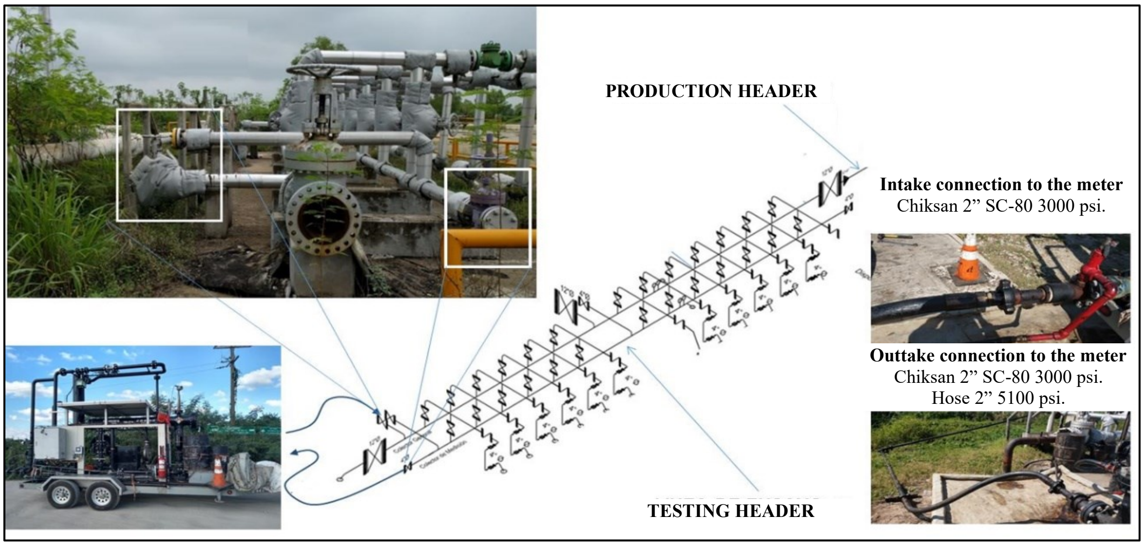


Figure 7-5. Measurement scheme with portable well test equipment for extra heavy oil.

Note on the Figure: *The measuring equipment is connected to the 4" test line of the production header from Monday to Friday. Allowing continuous measurement for 24 hours, minimizing unproductive assembly and disassembly time.*

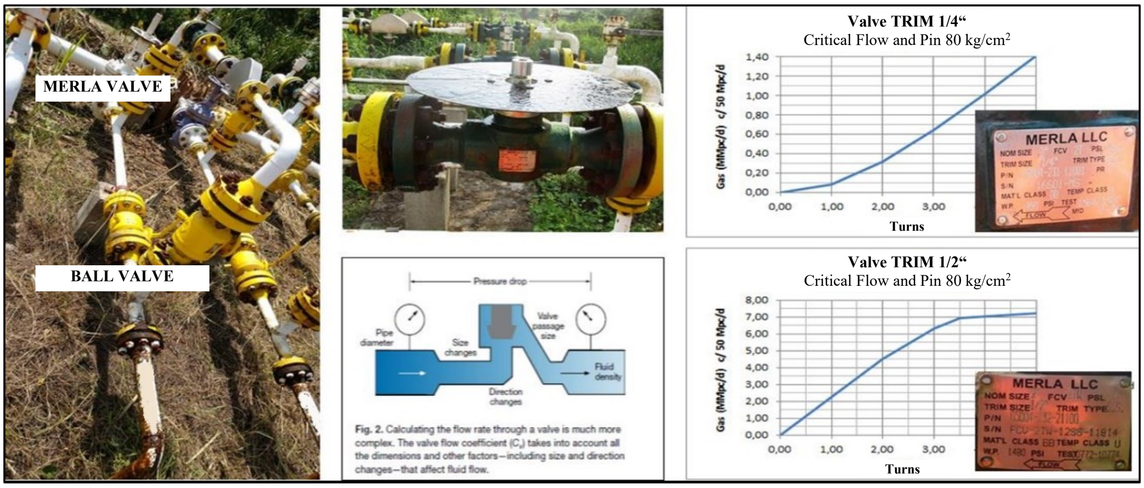


Figure 7-6. Injection scheme for the Gas Lift system.

Note on the Figure: *Detail of the valves used by the operator to regulate the injection gas. Before the project the operator injected directly by a ball valve and without pressure or flow measurement, generating over injection to the well and a lower production due to over cooling..*

5.9 Information generated by the Pilot

During the execution of the pilot, the following volume of data was generated.

Real Time Data

- Storage time: 6 months
- Wireless sensor data: +3 Million
- Dinamometric charts in 1 month: +400

Continuous Measurement Extra Heavy Oil

- 200 measurements, 1800 hours of measurement, 1300 cuts of water processed.

Real Time Models

- Quantity self-generating models: 80 (Machine Learning techniques, and Multivariate Statistical Analysis).
- Internal / external notifications: 500 (detection of anomalies in real time).
- Well observations: 68 (information on potential automatic optimizations).
- Well optimizations: 27 (optimizations executed by the operator based on the automatic recommendations made by the system).

5.10 Implemented system

The System implemented for the Pilot Test includes the following components:

- WEB system where users access for the analysis of data, information and decision making, under the concept of Decision Support Center or Unified Center for decision making (collaborative environment).
- Predictive Models - Prescriptive and Autogenerable, automatically and in real time.
- Operational analytics in real time, with fallback strategy to maintain the operating system.
- Weekly Operating Support. Generation of a report of operational recommendations automatically (Operational Portfolio).

Componentes del Sistema
Real-time signals

- Pressure and temperature sensors in the wells, production headers and gas lift injection manifolds.
- Periodic measurements of three-phase flow for each wells for the adjustment of virtual production models per well, and of the behavior models.
- Incorporation of information of the databases of the field operator and quality control: ecometers, dynamometers, operational parameters of the equipment.
- Wireless real-time dynamometry and integrated to the behavior models for the wells with mechanical pumping system.

Operational Analytics

- DSC (Decision Support Center) or Decision Support Center.
- Modeling of oil and gas production in real time per well.
- Performance Indicators for mechanical pumping system in real-time .
- Performance indicators for gas lift system in real time.
- Automatic Nodal Analysis Model for mechanical pumping systems.
- Injection performance curve - production for gas lift system in real time.

Alarms and Notifications System

- Definition of the alarms and their parameters for each type of artificial lift system.
- Warning frequency, indicating the anomaly and criticality.
- Operations Staff of the operator copied in notification emails automatically.

Operative Weekly Programming Platform and Reporting System

- Work meetings based on the diagnosis of the system to define the optimizations and register in the follow up system for later user by the operator's users.
- Weekly report of recommendations for well optimization.
- Weekly report of a ranking of actions to be taken on wells prioritized by the increase in the associated production.

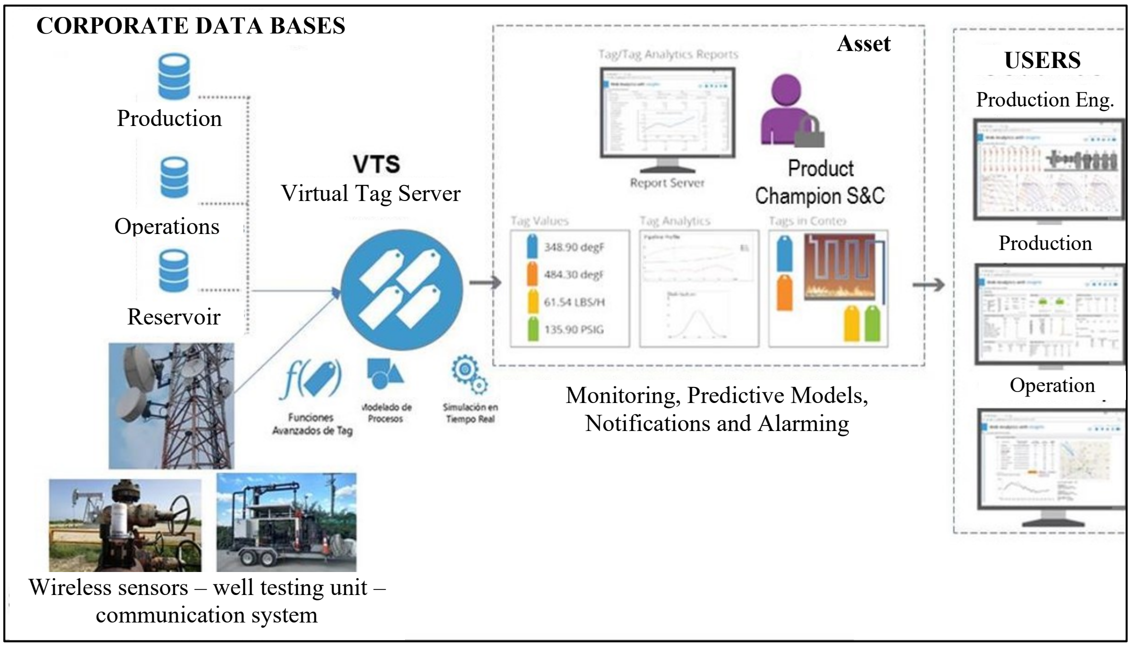


Figure 7-7. Architecture of the implemented System.

Note on the Figure*: Infrastructure, Communications, and WEB System for monitoring, predictive models, prescriptions, alarms, notifications and support for Weekly Operative Programming.*

Optimization and improvements in Workflows

The workflows of the operator were reviewed in conjunction with the production and production engineering areas, achieving through a cultural change the incorporation of the system into the day to day of the operation.

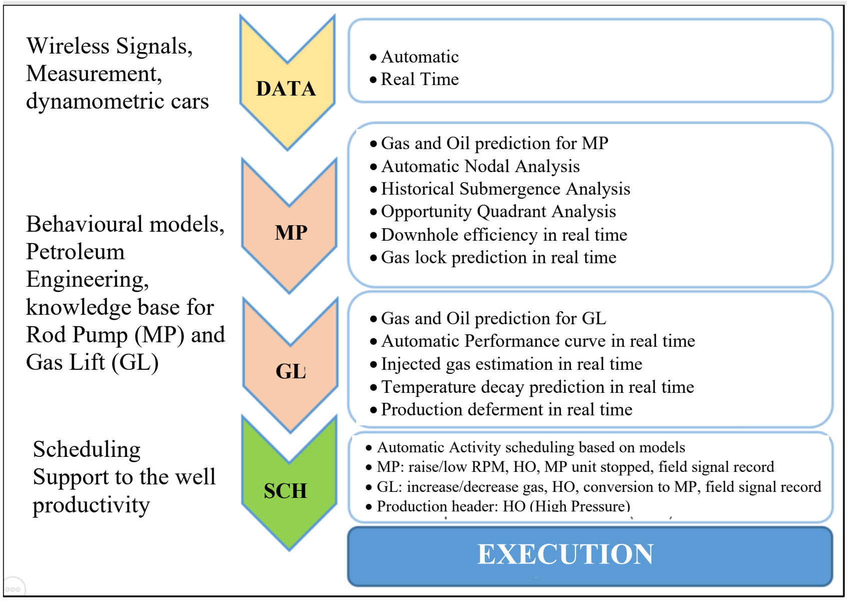
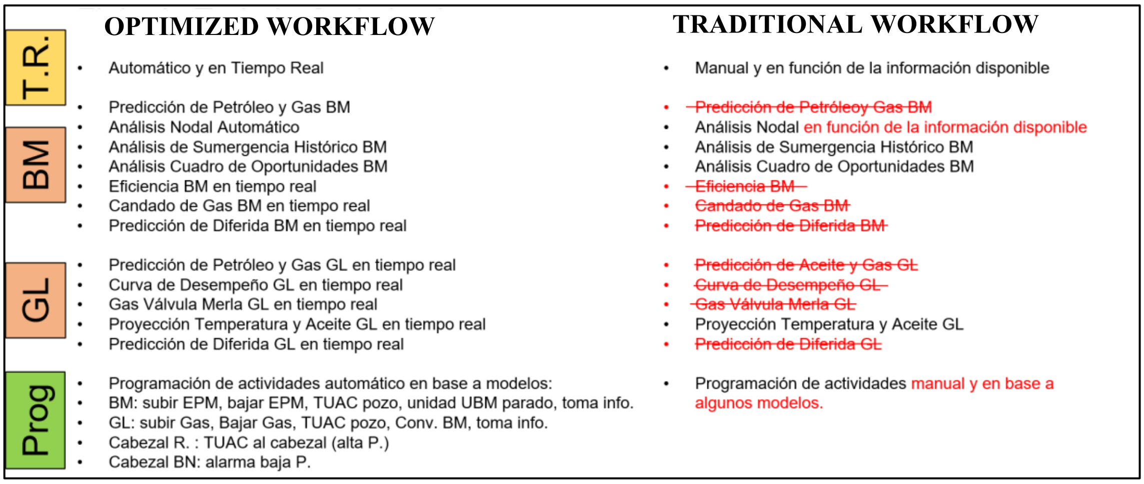


Figure 7-8. Automation of the workflow of the production area and production engineering for an extra-heavy oil field under the injection of Cyclic Vapor.



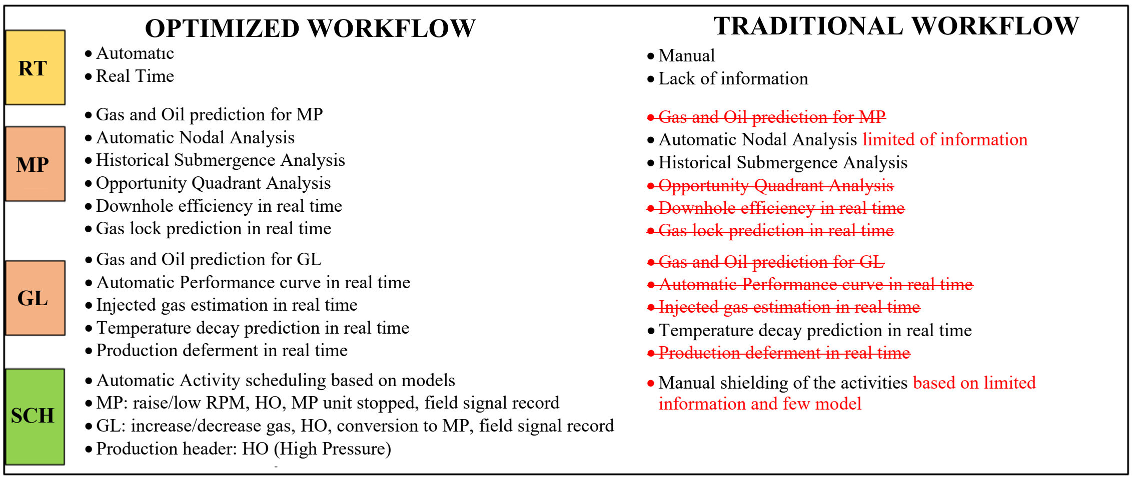


Figure 7-9. Workflow Optimization.

Note on the Figure: *Comparison of the workflow after implementing the technology with the traditional work flow carried out by the operator before the implementation of the Digital Field project.*

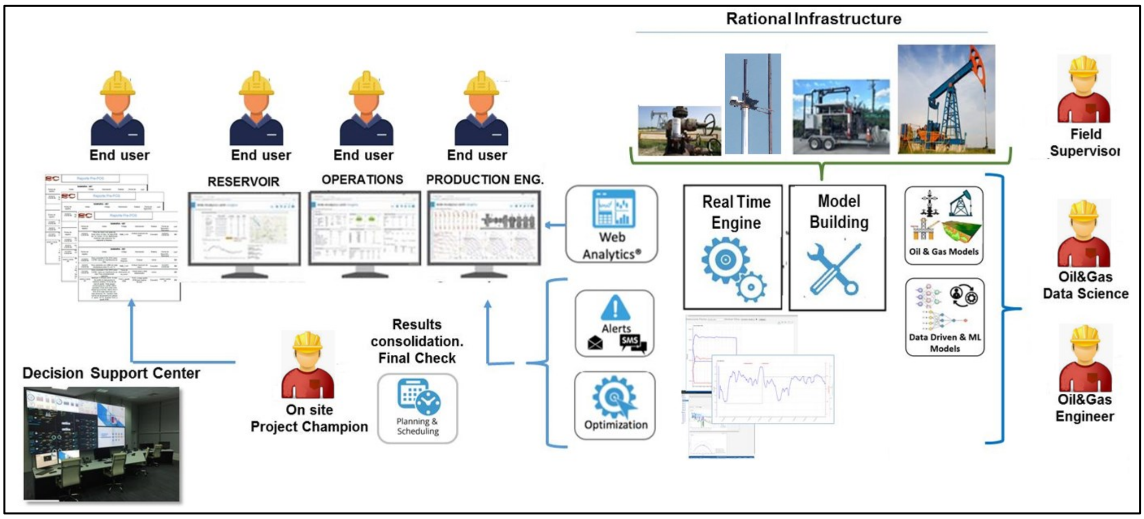


Figure 7-10. Workflow after implementing technology.

Note on the Figure: *Workflow from the operation in the field to the DSC (Decision Support Center) after implementing the technology. integration of the system, the operator' personnel and the service companies' personnel.*

5.11 Modules of optimization of the Artificial Lifting Systems

Conceptually, the system counts 3 modules for each artificial lift system which provides information in real time:

1. Virtual Multiphase Meter Module - MVM (VFM, Virtual Flow Meter).
2. Nodal Analysis Module.
3. ALS Performance Module.

The **MVM Module** performs a behavior analysis of the field signals in real time, plus the information of flow from the well teting measurements against the behaviors observed in the field. It is based on Machine Learning techniques, from which a virtual three-phase flow meter can be created (Keat-Choon Goh (Shell), 2007) (R. Cramer, September 2013) (Pejman Shoeibi, 2018). For the project, It was done the adjustment of an MVM for each well, considering the type of extraction system, mechanical pumping or Gas Lift. Using this flow meter the losses of production, production lost or deferred production can be predicted.

The **Nodal Analysis Module** is generated automatically for each well and is updated with each new three-phase flow measurement. In this way, the production engineer can monitor the performance of the reservoir and evaluate, in conjunction with the reservoir engineer, the need for remediation, stimulation, cleaning, etc., through the appropriate well interventions with or without tower equipment..

The ALS **Performance Module for Gas Lift** system builds an **Injected Gas vs Production curve**, automatically and **in real time**, which shows also the current operating point (of the moment) of the system. On this curve the operator can define the optimal injection range.

For mechanical pumping system the performance is measured from a System Efficiency curve that is updated in real time, which is fed by the interpretation of the dinamometric charts, the well tests (three-phase flow measurements) and the operative parameters of the ALS (barrel diameter, speed, stroke).

The following chapters show examples of the WEB screens accessed by the operator users (production and production engineering) from their work stations or from the DSC (Decision Support Center) monitors for analysis and decision making..

5.12 Ejemplo de Optimización pozos Bombeo Mecánico

The following screen shows several performance indicators for the mechanical pumping system: real-time prediction of oil, water and gas production, nodal analysis, dynamic level monitoring, monitoring of surface and bottom dynamometric charts, and chart of extraction opportunities of the extraction system; all these variables are **updated automatically and in real time.**

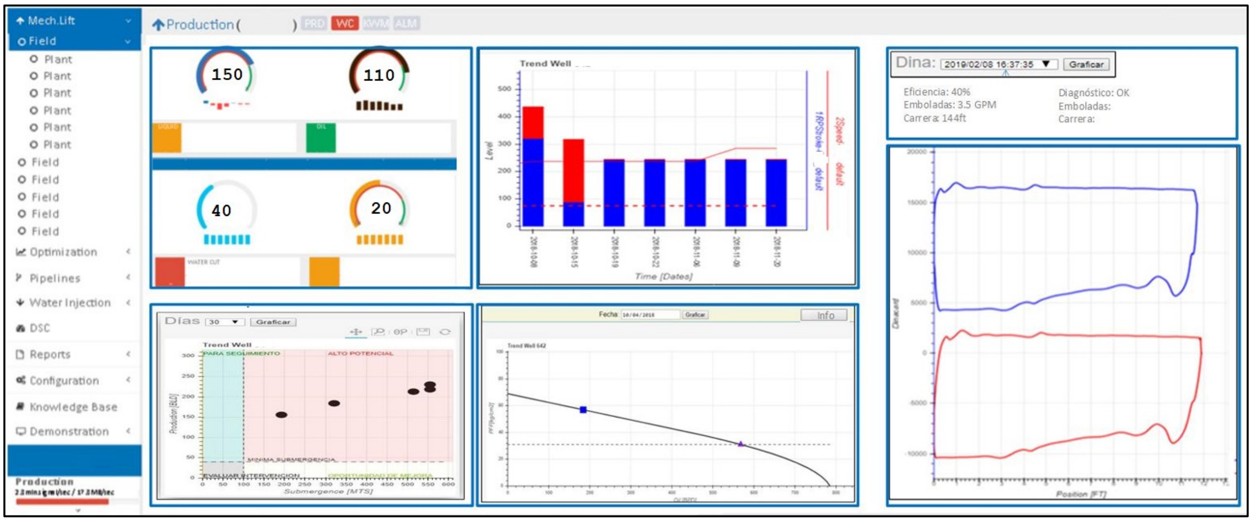


Figure 7-11. WEB screen for mechanical pumping system.

Note on the Figure: Predicted production, nodal analysis, dynamic level monitoring, surface and downhole dynamometric charts and opportunities chart.

The following figure shows a detail of the VPM - Virtual Production Meter for the mechanical pumping system. Also is is shown the deferred production or lost production, which is reported by the system along with the cause: **equipment stopped, Jack gas stopped, low pump efficiency due to high oil viscosity, decrease in water percentage, clogging of the plunger with sand, etc..**

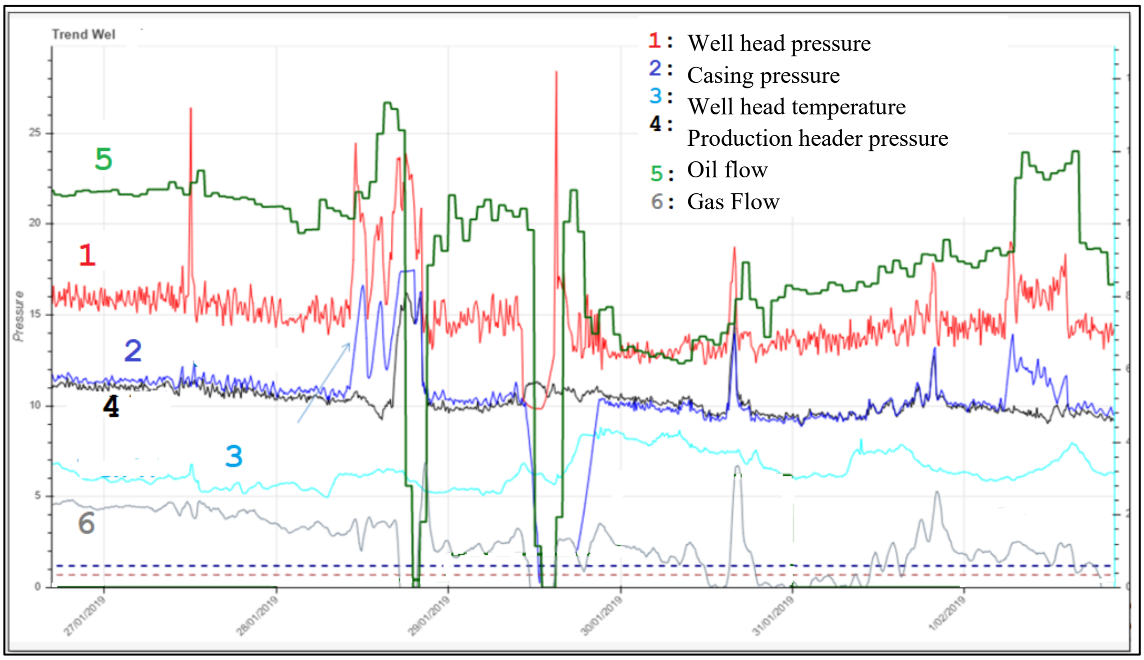


Figure 7-12. Virtual Production and Deferred Production Meter for a well with mechanical pumping system.

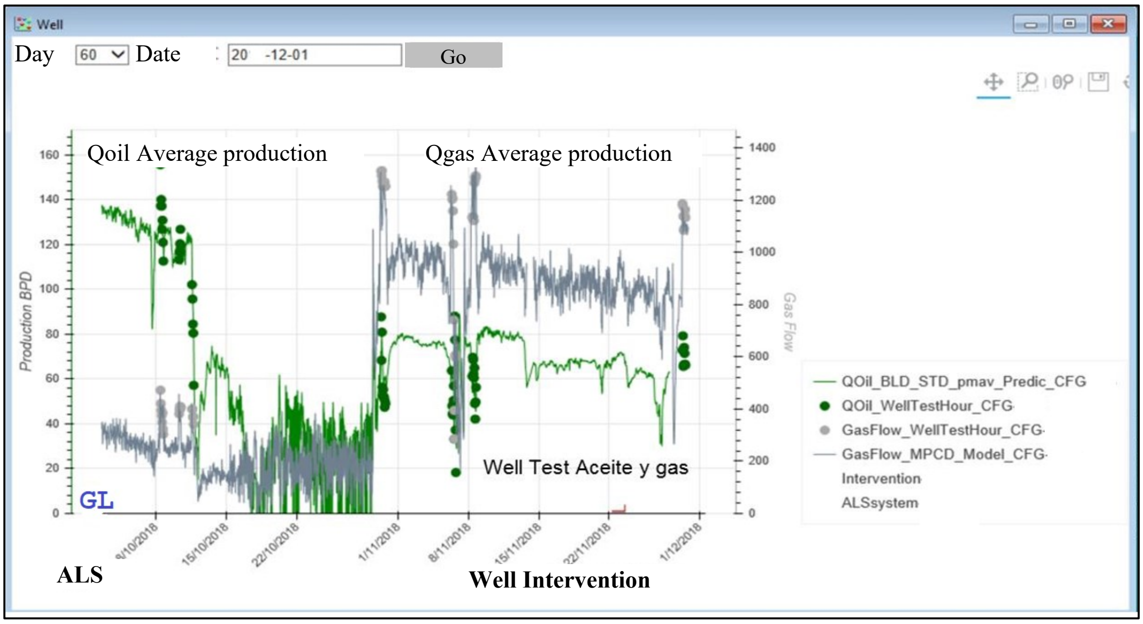


Figure 7-13. Calibration of the Virtual Production Meter with flow measurements, and pressure and temperature signals.

The following figure shows the recommendation of the system to increase the RPM in a well with mechanical pumping system. The system generates an opportunity alarm and the operator makes the change, generating an increase in production from 100 bopd to 150 bopd, which is verified by a flow measurement with the portable equipment 20 days after the change (155 bopd).

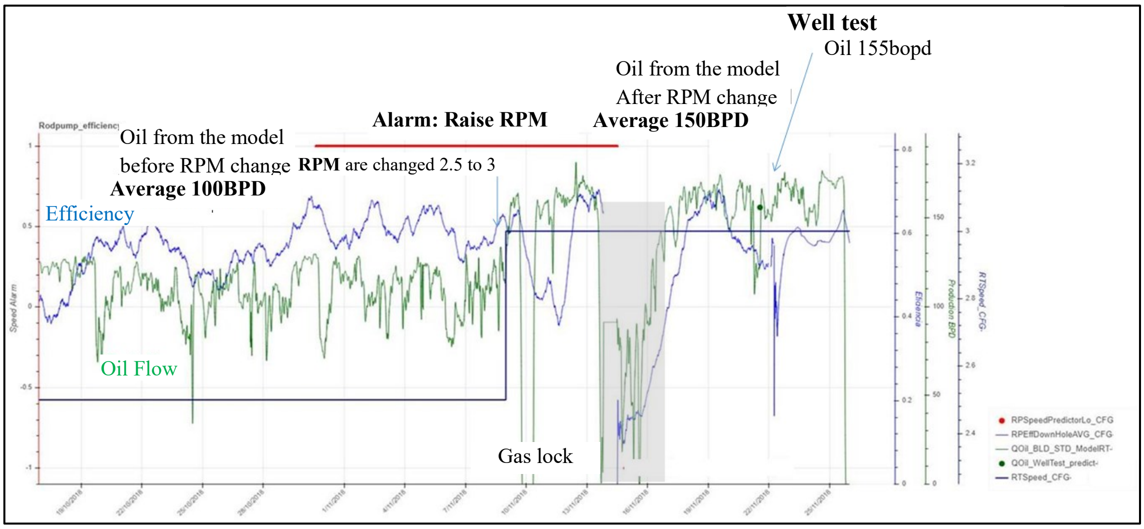


Figure 7-14. Virtual Meter of Production and pumping efficiency for a well with mechanical pumping system.

Note on the Figure: *The system recommends raise the RPM from an alarm triggered by the system, therefore which the operator increases from 2.5 to 3 RPM, generating an increase in production from 100 bopd to 150 bopd.*

5.13 Example of Optimization wells system Gas Lift

The following screen shows several performance indicators for the Gas Lift system: real-time prediction of oil, water and gas production, production performabce curve: Production vs Injected Gas, calculation of injected gas, oil cooling prediction and recoendation to change to mechanical pumping system, operative point and optimal injection point; **all these variables updated automatically and in real time**.

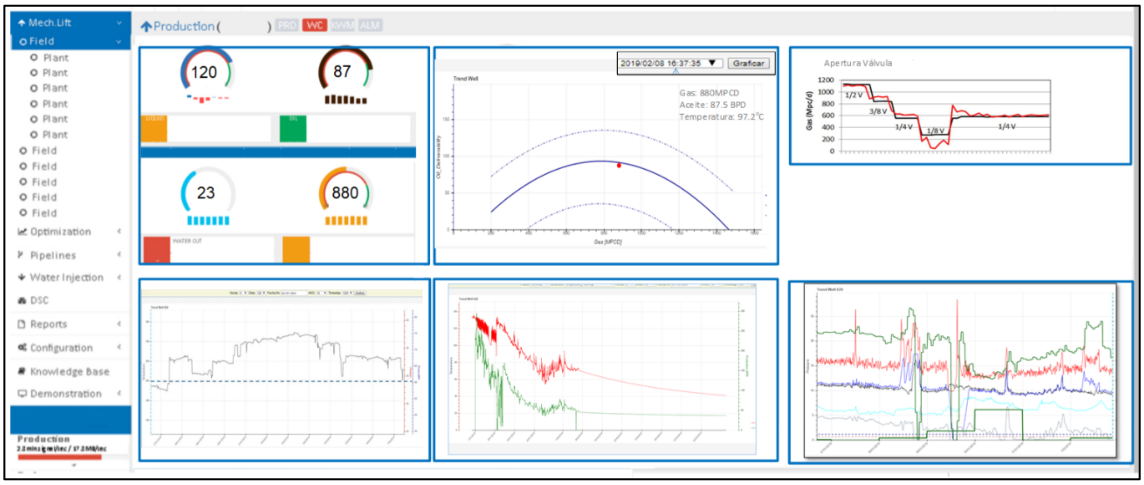


Figure 7-15. WEB screen for Gas Lift system.

Note on the Figure: *Predicted production, performance curve Production vs Injection, calculation of injected gas, prediction of cooling and change to mechanical pumping system, operating point and optimal injection point.*

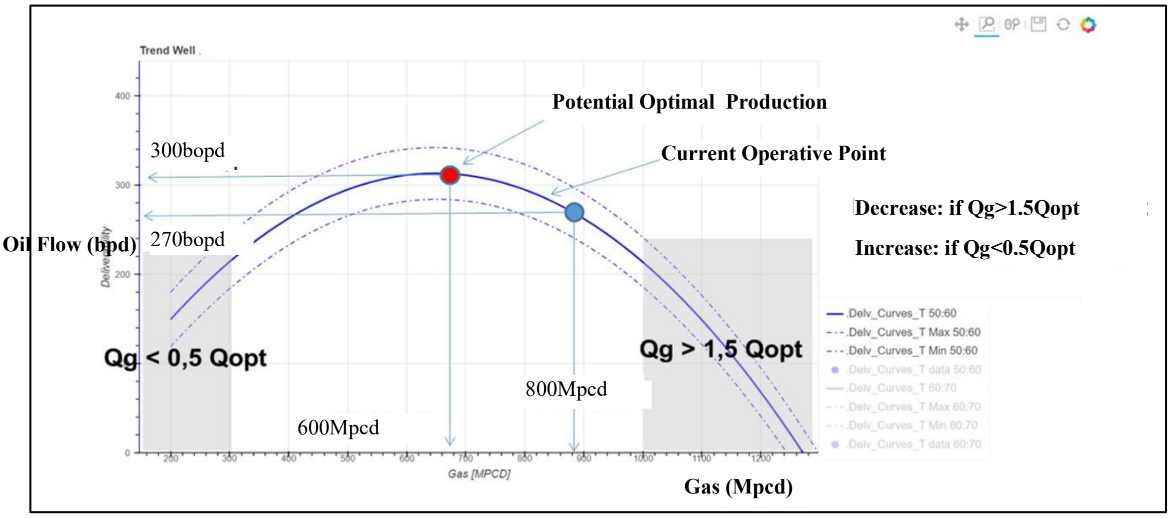


Figure 7-16. Performance curve Production - Injection for Gas Lift system.

Note on the Figure: *This information is updated automatically in real time. The system presents the current operating point, the optimal point of gas injection where production is maximized, both are updated in real time. The definitions loaded to the system for the generation of alarms and notifications are also presented: Gas injection falls below 50% Optima injection, Gas injection rises above 50% Optima injection.*

5.14 Recommendations made by the system

The following is a summary of the observations and recommendations automatically generated by the system during the optimization stage for the optimization of extraction systems. It is worth mentioning that these recommendations must be verified and approved by Leader Champion before being published on the platform to be exectuted..

DIGITAL FIELD PROJECT

Summary for the Optimization Stage – Observations generated

Stat

End

Observations

Month	Year	Qttv
5		9
4		19
3		21
2		13
1		6
		68

Observations by APS

Month	Year	MP	GL	
5		8	1	
4		19		
3		12	9	
2		6	7	
1		4	2	
		49	**19**	**68**

Observations by Code

Month	Year	RPM Change	Hot Oil Cleaning	Keep Conditions	ALS Maintenance	RMA Stem Injection	RMB Stem Injection	RMB Change ALS	Dyna and Echo Update	Hot Oil	Hot Oil And RPM	
5		2							1	4	2	
4		5							14			
3		12		1	1		1	3	3			
2		8	1		1	1	1	1				
1		1				1	1	1	2			
		28	**1**	**1**	**2**	**2**	**3**	**5**	**20**	**4**	**2**	**68**

Figure 7-17. Summary of the observations generated by the system.

Note on the Figure: *Summary of the observations generated by the system for the optimization of artificial systems. They are reviewed and approved by Leader Champion before being published in the system. An observation is generated from notifications and alarms sent by the system depending on the current production, deferred or lost production, nodal analysis and performance of the artificial lift system.*

DIGITAL FIELD PROJECT

Summary for the Optimization Stage – Optimizations executed

Stat

End

Optimizations

Month	Year	Qttv
5		7
4		4
3		10
2		5
1		1
		27

Optimizations by APS

Month	Year	MP	GL	
5		7		
4		2	2	
3		4	6	
2		5		
1			1	
		18	**9**	**27**

Optimizations by Code

Month	Year	RPM Change	Hot Oil Cleaning	ALS Maintenance	RMB Stem Injection	RMB Change ALS	Dyna and Echo Update	Hot Oil	Hot Oil And RPM	
5		1						4	2	
4					1	1	2			
3		5	1	1		3				
2		3			2					
1						1				
		9	**1**	**1**	**3**	**5**	**2**	**4**	**2**	**27**

Figure 7-18. Summary of the optimizations executed.

Note on the Figure: *Summary of the optimizations executed from the observations generated by the system for the optimization of artificial systems. Once a trend in the behavior of the well is detected, based on the accumulated notifications and alarms, the multidisciplinary team evaluates the information and decides the implementation of an operational actions: raise /*

lower RPM, raise / lower gas injection, perform well/header treatment with hot oil, gather additional information to mention the most representative actions.

5.15 Prescriptive Analytics - Automatic Weekly Operative Programming

From the Virtual Multiphase Meter modules - MVM, nodal analysis, ALS performance analysis, notifications and alarms; the system generates a weekly list of operational recommendations on the wells, prioritized by the current production of the well plus the potential production gain associated to the executing the recommendation.

Within the pilot's time, the most frequent recommendations and the greatest impact on field production were programmed into the system. They are liested below.

Mechanical pumping system

- Raise/ lower RPM.
- Up / Down stroke.
- Hot Oil Treatment.
- Unit stopped / Gas Jack stopped.
- Gahter aditional information.

Gas Lift System

- Increase / decrease injection gas.
- Hot Oil Treatment.
- Conversion to MP.
- Gahter aditional information.

Production header and gas injection manifold

- Production Header: Hot Oil Treatment to the head
- GL header: check header because of low injection pressure

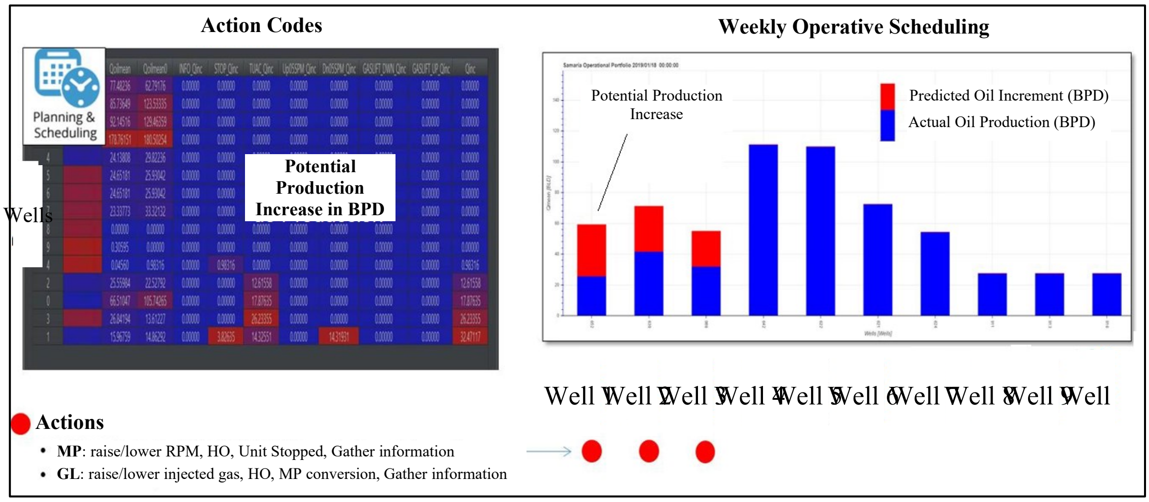


Figure 7-19. Weekly operational programming.

Figure Note: *Weekly operative programming generated automatically by the system. Wells are prioritized by the predicted production plus the potential production to be gained by the implementation of the recommended action*

Below is an example of a well with mechanical pumping system where the MVM module predicts production reduction while the system recognizes that the Gas Jack is stopped, generating an increase in the pressure of the casing by gas increase, with the consequent decrease in barrel filling efficiency and production drop.

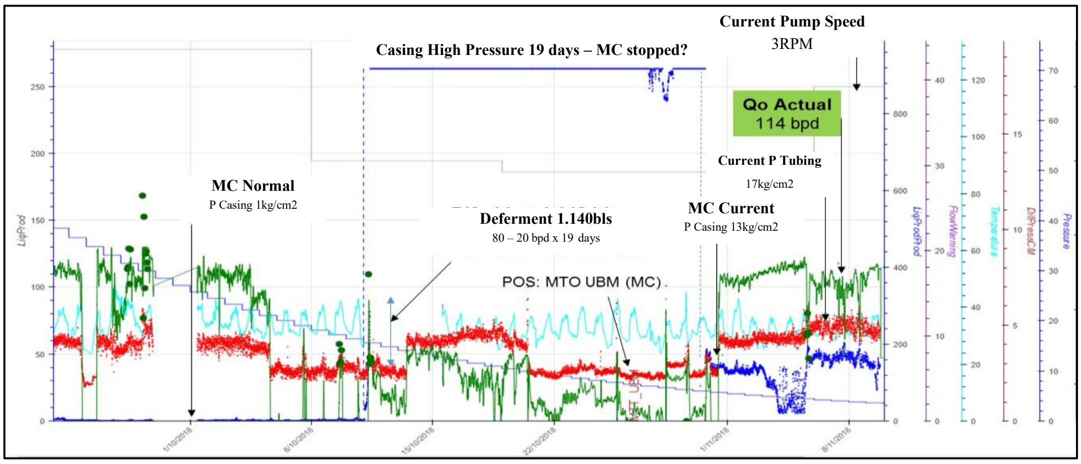
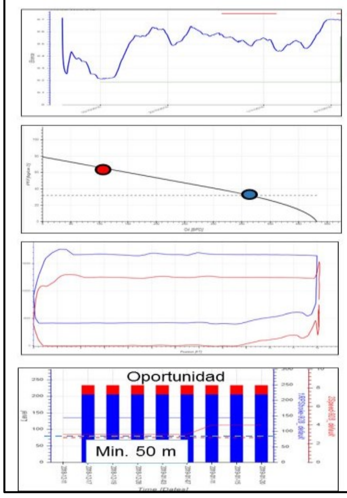


Figure 7-20. Logic of the prescriptive analytical system.

The following figures show some examples of how the logic of the prescriptive system operates for a mechanical pumping system to recommend Rasie RPM, Lower RPM, and Perform Hot Oil Treatment to break viscous oil plugs within the pump and pipe production by cooling.

Rise RPM – Mechanical Pumping System



Efficiency in real time: **greater than 0.7**

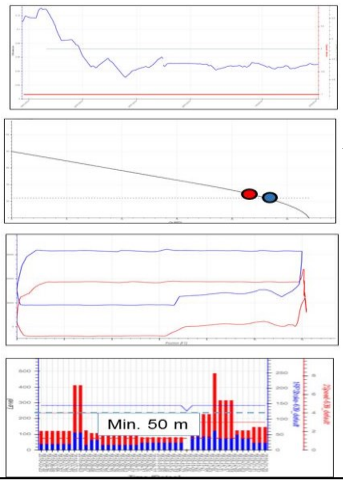
Nodal Analysis: **Potential production increase greater than 30 BOPD**

Downhole Dynacard: **Low gas interference**

Submergence: **greater than 100 mts**

Figure 7-21. Logic of the prescriptive analytics for MP – Raise RPM.

Lower RPM – Mechanical Pumping System



Efficiency in real time: **lower than 0.5**

Nodal Analysis: **Low Potential production increase**

Downhole Dynacard: **High gas interference**

Submergence: **lower than 100 mts**

Figure 7-22. Logic of the prescriptive analytics for MP – Lower RPM.

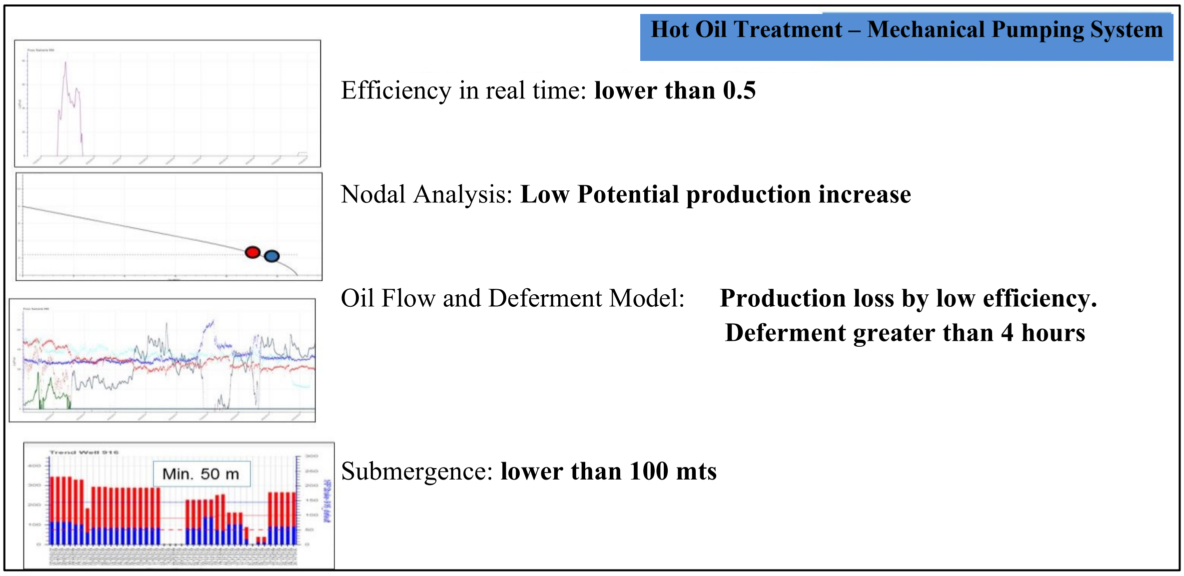


Figura 7-23. Logic of the prescriptive analytics for MP – Hot Oil Treatment.

5.16 Production increase reached in the Pilot

The implementation of the proposed technology generates optimizations from the following vectors:

- Mapping / Digitalization of wells and artificial lift systems based on pressure, temperature, dinamometric charts, gas injection parameters; continuous and frequent three-phase flow measurement, integration with the information acquired by the operator (fluid physical measurements, PVT, depth measurements, etc.).
- Integration and generation of monitoring dashbvods, performance analysis of the artificial lift system and the reservoir.
- Coverage of all active wells. Typically in non-digitized fields only 20% - 30% is covered.
- Generation of alarms and notifications automatically on deferred production and problems with extraction systems (prescriptive analytics).

The optimization process can be conceptualized as a cycle that starts after the generation of baselines per well.

1. Measurements Wells Baseline - generation of production baseline curves per well.
2. Prediction Multiphase flow by ALS and prediction of deferred production.
3. Analysis of the performance of the ALS. Generation of Automatic recommendations.
4. Wells signal Measurements - Optimization.
5. Evaluation of operational recommendations / Execution / Follow-up

The cycle is repeated from point 2 to 5, allowing the models and the analytical system implemented to be adjusted to predict accurately the behaviors observed in the field.

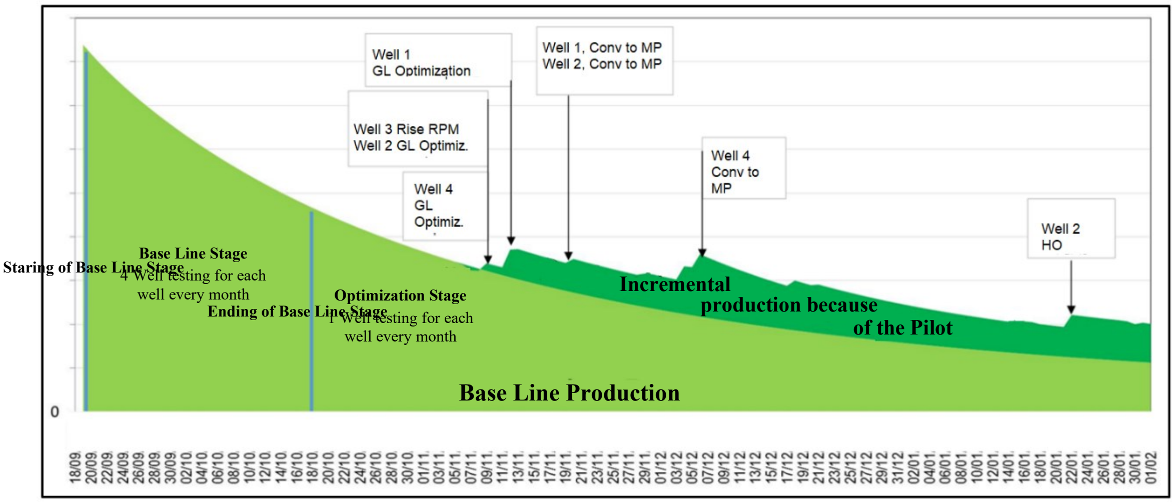


Figure 7-24. Increase in production generated by the recommendations based on the technology implemented.

5.17 Benefits Reached by the Pilot

The benefits achieved with the application of the technology during the Pilot Test are summarized below:

- Technology based on the concept of "rational engineering" where the installation of costly sensors in the field is avoided, minimizes the risk of vandalism, and the times of effective well testing measurement are maximized by an optimal programming of the three phase measuring unit in the field.
- Automation of Workflows in the Wells Productivity area that allow to optimize MP and GL systems in real time, in a field of high operational complexity of extra heavy oil, under steam injection and continuous rotation of the ALS.
- Prescriptive system that generates programming and automatic prioritization of optimization recommendations, whose execution generated an increase in production of 16%.
- The implementation of the proposed technology is profitable and attractive for mature assets, particularly for fields under a cyclic steam injection scheme where there are higher operating costs; you get a return on investment measured as the Net Present Value after Taxes / Present Value of the Investment of 3.
- The system calculates and classifies deferred production of MP and GL systems in real time

8. Conclusions

This paper presents a real case of application of Digitization of a Mature Field under a scheme of cyclic steam injection, where the following challenges were solved in order to implement the project.

- **Very low level of initial instrumentation and no well testing measurements**, and with the additional complexity of being located in a sensitive area due to vandalism. During the year of development of the project, there were no acts of vandalism on the instrumentation or mobile equipment, nor of insecurity due to the personnel.
- It was possible to **integrate the acquired signals**, multiphase flow information that comes from the periodic well tests with the corporate databases of the field operator automatically (operation of the pumping equipment, well interventions, physical measurements, etc.) .
- The **different well behaviors for mechanical pumping system and gas lift system** were mapped, **generating a multiphase virtual meter** - MVM per well with the error lower than 5% with respect to the tests, and the rotation of the models of the ALS accompanying operations in the field.
- In addition to the **MVM**, a **deferred production model** was developed for each ALS, associated with the causes.
- Several models were built to measure the performance of the ALS, and in conjunction with the MVM and the deferred model, an **Automatic Weekly Operative Programming module** was developed, a tool that adds efficiency to the process of defining actions to be taken on the wells, by **automating the workflow between the Production and Production Engineering departments**.
- A procedure is implemented to generate the production base lines of the wells based on flow measurements during the period prior to optimization.
- Predictive and prescriptive analytics implemented generate a value for the operator by **improving production over baseline by + 16% accumulated oil**, generating profitability indicators that show that the optimization process implemented is self-financing for the operator

As final comments, this technology can be used in water injection sweeping projects, preferably once the filling stage of the reservoirs has been completed.

Regarding surface gathering networks and production - injection plants, there are currently other projects underway where the multiphase flow in oil fields is modeled and optimized, adding automatic integration with existing ALSs. In the Pilot test presented, the network of production surface and gas lift injection was out of scope because the highest opportunities were visualized in the optimization of the ALS, and on the other hand in order not to extend the Pilot execution time..

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