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Intelligent-Well Technology: Are We Ready for Closed-Loop Control?

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Abstract

Over a few short years surface control of the reservoir by intelligent well technology has become a reality allowing improved efficiencies and economics by well documented measures. Downhole control valves have evolved from simple open/close zonal control to downhole chokes that allow metering of fluid rates from or to multiple producing zones. Complementary instrumentation of the wellbore provides real time data for pressure, temperature and flow. These capabilities along with computational and communication technologies provide the necessary ingredients to allow remote control of production in a variety of settings. In addition to remote control, the opportunity also exists to automate production even to the extent of closed loop control. As the complexity of surface controlled reservoir control valves has increased, so has the frequency of operators selecting microprocessor controlled surface hydraulic control systems to manipulate the valves. With microprocessor control in place at the well location, remote control options become the next logical step in the evolution of intelligent wells. Once remote operation has been chosen, the options for system architecture and communication are quite extensive. Successful implementation is a matter of effective interface engineering between the operator and the various service providers. Lessons learned in developing remote control solutions will be presented along with an outline of the remaining steps that will be needed to implement closed loop control.

Introduction

Much of the focus in smart fields revolves around the reservoir. In the context of closing the loop, it is important to bring focus on the well. In this paper we will look at optimizing production by closing the well-centric loop. There are multiple references to two optimization loops (see Fig. 1), the reservoir-centric slow loop and the well-centric fast loop. Closing the fast loop can be done via interventions to the well, a workover, or by operation of intelligent well equipment. In this context, intelligent well equipment is any device that allows adapting the well to its best possible operating condition without an intervention. This equipment includes well monitoring devices and intelligent well equipment. It can also include other functions like intelligent artificial lift or flow assurance but these will not be the focus of this paper.

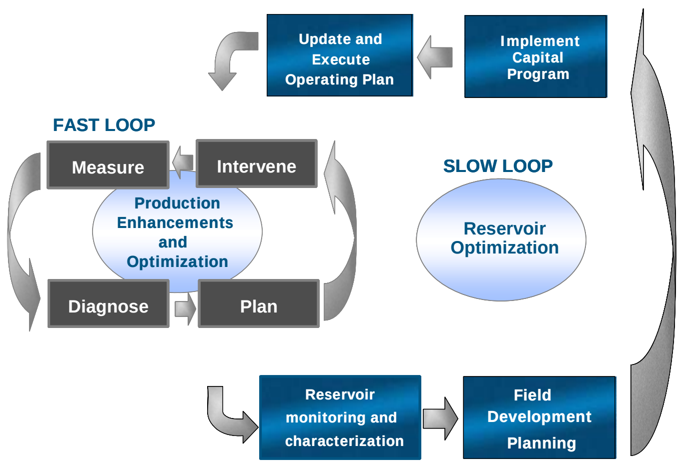

Fig. 1. Fast Loop vs. Slow Loop

In order to justify the additional cost of an intelligent completion, service companies compare the expected performance of an intelligent well to a conventional installation. Benefit can come though increased ultimate recovery (produce more of the oil), accelerated production (produce it faster) or cost reduction (1 wells does the job of 2) or a costly intervention is avoided. This paper will cover how this requires reservoir simulation and nodal analysis. This produces a model of how the well is expected to behave and implies time varying optimal configurations for the intelligent equipment therein. If this model justifies the added expense in the intelligent well the client is apt to purchase. Unfortunately, the information on what configuration the well needs to be in at which point in its life remains in the sales proposal until there is a mechanism for closing the well-centric loop.

The well loop can be closed by having a human monitor the well, observe how actual production compares to the original analysis and issue commands for the intelligent well to be reconfigured at the appropriate times. As intelligent wells gain acceptance we will move beyond human activity closing the loop to automated systems. These add value by retaining the well model, changing the monitoring activity from polling to interrupt driven and eventually will be able to advise when wells deviate from their expected behavior in ways that prompt diagnosis of emerging unexpected problems early enough to avoid them.

The rest of the paper will illustrate how we arrive at systems that close the loop. The elements of the intelligent well and its control system are explained at a summary level. Building on the intelligent well the opportunity for closing the control loop is discussed. Finally the challenges and lessons learned regarding implementation of remote connectivity to the intelligent well is provided.

Intelligent Well Systems

Many definitions have been provided over the years as to what constitutes and intelligent well[1,2]. For the purpose of this paper, an intelligent well system is defined as a completion system that provides the ability to remotely monitor and control production or injection in a multitude of zones in a single well.

Intelligent well systems are employed primarily to enable the operator the ability to monitor the condition of the well and then to implement in near real time decisions to optimize the production or injection process.

There are numerous applications where an operator may choose to employ an intelligent well system. For an example case, consider a field that consists of two main producing intervals with similar reserves in each zone. On an individual well basis, the operator would look to conventionally co-mingle these intervals or produce them in bottoms up fashion where the lower zone is first produced to depletion followed by production of the upper zone. However, conventional co-mingling of multiple zones is not technically feasible nor is it allowed by the regulatory authorities due to the risk of misallocating or losing resource. Therefore the field was originally developed drilling multiple wells to target the two intervals. This leads to a significant delay in reserves and additional well count to deplete the reserves.

In order to maximize the value of the asset, the operator employed an intelligent well system as shown in Fig. 2. This system has an instrumentation system that monitors pressure and temperature in both intervals as well as flowrate and water cut from the lower zone. Combined with a three phase flowmeter at surface, this system can allocate three phase production to both the upper and lower zones. In order to optimize the production rate from each zone a remotely operated downhole choke is employed to regulate the drawdown pressure from each zone to minimize crossflow and/or optimize production rate from each zone. Because these wells are low pressure and will not naturally flow, an Electrical Submersible Pump (ESP) is used to lift the fluids from to surface.

The incremental production benefits associated with this system are shown in Fig. 3. Prior to running the intelligent well system the well produced at approximately 3500 bpd. After the intelligent well system was installed, both zones were co-mingled and the production from each interval optimized. As a result of the intelligent well system installation the well rate increased from 3500 bpd to nearly 6500 bpd.

Surface Control Systems for Intelligent Wells

The first element of control for an intelligent well with hydraulically operated downhole chokes is the hydraulic power unit (HPU) providing the surface control function. In the case of subsea multiplexed control systems the equivalent functionality is provided by the combination of an HPU on the host facility plus the subsea control module (SCM) mounted on the subsea tree. Although control options are similar for subsea and surface controlled systems, this paper will focus on the details for surface controlled systems for simplicity. Without regard to where and how control of the system is implemented the functional requirements of the control system are to supply the hydraulic energy to shift the downhole choke.

Preferably the control system for downhole chokes will also monitor feedback from control outputs to track the current setting of the downhole choke. Monitoring hydraulic fluid volume returned to the control system is the preferred feedback parameter employed for Baker Oil Tools' adjustable chokes. This type of downhole choke uses two hydraulic control lines, one to increase the valve opening and the other to reduce or close the valve opening. Within the downhole choke a jay slot mechanism limits each change of the valve opening to a specific axial travel distance which also corresponds to the volume of hydraulic fluid which is displaced during the travel. By monitoring the volume of fluid returning to the control system, the movement of the sleeve to each successive position can be confirmed at surface. Alternative means are also available utilizing an electronic position indicator that transmits a signal via an electrical conductor.

Although manual operation of the control system is possible where remote operation is of no interest, there is a preference for microprocessor control of the control system. Providing a microprocessor controlled system opens the door to many remote control options. Baker Oil Tools selected Microsoft .NET programming language to develop the control program for the Surface Control System (SCS) which is the HPU plus associated logic control equipment. The flexibility of .NET and the use of industrial class computers facilitated the adaptation of the SCS for either local operation or remote operation via Supervisory Control and Data Acquisition (SCADA) or remote client. The control program uses server-client architecture with all of the control logic residing in the server application running in the local system computer. A separate optional Human Machine Interface (HMI) program can also be installed in the local machine when there is a requirement to operate the system locally. This HMI operates as a client that can also be operated remotely utilizing the operator's intranet or even an internet connection for communication. By placing all of the control logic within the locally running server the communication and logic necessary to operate remotely is kept to a minimum. A SCS and the local HMI screen are illustrated in Fig. 4.

As stated above, the capabilities of the standalone SCS also allow it to be networked into various remote monitoring and control systems. Additionally the capabilities of the SCS are adequate to allow processing of the sensor data and application of decision logic. Both functions are enablers to achieving a Closed Loop system. While a robust intelligent well implementation can incorporate remote capabilities in closing the loop, the opportunity exists to begin at the SCS without the additional burdens of the remote technology.

So, are we ready for Closed Loop Control?

Enhancements of closing the loop will take the form of improved efficiencies and recovery above and beyond what is currently realized from the intelligent well control and remote monitoring alone. Monitoring of intelligent well data by itself does not add much value. This is due to the very high volume of unprocessed raw data which does not add value until analyzed. Much of the data is redundant and only of value for failure analysis. Going forward the emphasis is shifting to providing systems that use the available data for decision making that can increase well value, systems that facilitate closing the loop.

There are many challenges associated with moving to closed loop systems. There are also many different objectives that can be achieved by closing the loop. This paper will attempt to identify as some significant closed loop opportunities and offer not only a roadmap towards implementation but also demonstrate some examples of what problems can be handled by a closed loop intelligent well system.

Defining Closed Loop Control

The main components of an intelligent production system with closed loop control are:

I. Well Monitoring
II. Well/Reservoir Modeling
III. Decision making
IV. Control and Optimization

One definition of closed loop is to remove human intervention from the loop. This would require a tremendous investment on technology and proof of reliability to mitigate any HS&E risks. Closing the loop on some operations may never be fully completed. This aside, we will be focusing on several groups of operations where adding intelligence to the intelligent production system will provide a degree of automation exceeding currently available functionality. Automation of key tasks which are calculation intensive by current operator workflows will provide this closed loop control. Automation is further defined as the continuous and automatic transfer of the data between the systems including the generation of alarms based on user-defined rules.[4] This automation firstly will be in the form of data concentration. Already many SPE papers have been presented describing various closed loop systems for intelligent wells.[4,5,6,7,8,9,10] Many of these discuss the subject at the field level rather than the individual well level to be addressed here. Many organizations are already working on establishing reservoir modeling techniques on a very large grouping of systems. If one of these components fails or the communications link is broken, the entire system is subject to instability. Many previously published papers took the basis that communications were always present back to a central database or data center[5]. Yet, SCADA systems were not traditionally designed to be used over unreliable networks[6]. By bringing the same critical processes outside of unreliable communications links the level of stability and reporting is elevated, which is currently achievable but not implemented.

Purpose of a Closed Loop System

Moving from an intelligent well controlled only by operator initiative to a closed loop system is only of interest where there are clear benefits. Here are some of the available benefits.

Benefit 1: Maximizing Efficiencies

The first enhancements that will be identified are greater efficiencies in the form of resources, equipment and workflows. The most obvious resource efficiency is freeing up either a dedicated reservoir engineer in the office and an automation technician in the remote location to directly monitor and control the intelligent well operation during increasingly routine operations.

As with any new technology, a closed loop system for intelligent wells will be designed to take over mundane or routine tasks. It may be premature to give direct control to a computer but we can use it to facilitate direct human intervention. Increasingly more complex Distributed Control Systems (DCS) are being put in the field. Often these systems have a common PC platform. By combining common platform systems we can create a new level of equipment efficiency. The first step will be in the form of integrated permanent downhole instrumentation surface systems with data reduction, alarm generation and intervention advice capability.

Benefit 2: Well Optimization and Recovery

Intelligent wells optimize the function of a well and their impact on the entire reservoir. This can be by accelerating hydrocarbon recovery or improving ultimate recovery. The longevity of most producers can be prolonged by careful monitoring and adjusting a few simple parameters within an intelligent well. As government regulations increase on national and international operators, it can be expected that the ability to control production will become even more important. For both governmental agencies and investor groups, the ability to accurately forecast production flows is crucial to operations today. The future requirements are undeniable. Incorporating well model algorithms into a local control system allows the operator to focus on field optimizations.

Benefit 3: Safety and Reliability

When there is the thought of taking human intervention out of a system, invariably there are concerns of safety and job protection. What we are proposing is not taking a person out of the loop, but rather placing that person on the side of the loop in order to monitor the system's activities based on pre-qualified alarm conditions and user feedback notifications in which it is permitted to operate autonomously. We argue job security and safety can be enhanced by reducing human error due to simple mistakes or oversights. Furthermore, there is the benefit of reducing some points of failures by integrating common system components. Minimizing the number of components helps with system installation and makes the system more cost effective due to the removal of redundancies. Already, there is the capability within individual systems to generate alarms when components need maintenance.

By closing the loop and combining systems together there is an added ability to inform operators when maintenance is needed on the well. A closed loop system can be designed to minimize dependency on remote communications blackouts by concentrating the essential element at the well site. This means that the intelligence can always be turned on and the operator's well can be optimized. In this situation the local control system is the backup data historian which can be resynchronized to the central databases upon restoration of communications. In the end, the final goal is protecting the reservoir assets, the recoverable hydrocarbons and the personnel who are there to do the job. Allowing expert personnel to perform their job in their normal environment both increases efficiency and reduces exposure to the hazards of commuting to the wellsite.

Benefit 4: Costs and Profits

There are plenty of beneficial reasons for moving forward with a closed loop intelligent well solution. Technically speaking there are no real challenges which cannot be crossed. What the operator hopes to see in the end is an appreciable cost savings and increased profits. These cost savings will directly come in the form of a reduction of integration costs as more vendors become capable of offering these features. The second form of cost savings are more indirect but possibly more substantial due to leveraging both operator and vendor experts back in the office. Concentrating reservoir experts in operator data centers is becoming the norm. Taking one more upstream petrochemical operation and closing the loop is one of the predominant themes in today's E&P market as the move towards the digital oilfield is showing cost savings. These movements towards the fully connected field are sometimes at the exclusion of actual increased reservoir production with the exception of intelligent wells. Certainly closing the loop on an already intelligent well will only add marginally better expectations. What can be expected is a system with a faster response during dynamic well processes which can only add to recovery and profits over traditional intelligent wells. Another expectation is reducing time before decisions can be made by sending alerts on certain predefined conditions.

Well-centric Monitoring and Control

Implementing a closed loop intelligent well has challenges that can't be solved with a single approach. What can be accomplished however, is hard-coding a well strategy instead of having a one size fits all system. This closed loop well strategy will be bounded by a small set of known configurable parameters. The more difficult challenge will be technology acceptance within the industry. A careful analysis of operator personnel workflows must be completed first to make sure there is ample room designed in for specific job assignments. As discussed earlier in the paper, communication and control loops are always kept in mind. For the majority of intelligent well installations, the speed at which the principal control loop will need to operate is on the order of minutes to hours. This makes the problem easier to solve as subsets of reservoir models can still be run on relatively limited processing capabilities within the control systems. These reservoir models will enable the local control system to provide planned versus actual production analysis. Introducing new technology to the E&P industry must be taken in a staged approach. Weighing the risks is paramount and should be mitigated by analyzing a few operations to find the best candidate for closing the loop.

Several candidate operations for closed loop control in order of increasing risk are; well surveillance, water injection, coordinating ESP operation during changes to downhole choke settings. Each of these stages has several increasingly more complex levels of automation in order to gain user trust. This iterative approach will achieve the highest level of industry adoption through the consistent demonstration of reliability and safety. The negative of this approach is the length of time for complete implementation. Each stage will consist of the following three steps as they are gradually installed in the field:

I. Confirmation of all Actions
II. Confirmation of Major Actions
III. Control System Event Logging of Major Actions

Most vendors are at various levels of steps *i.* and *ii*. Taking each of these operations in sequence, the lowest risk task would be having a system which automatically notifies the reservoir engineers of possible well problems. Well surveillance can be demonstrated by Fig. 5.

In the first plot, surface and bottomhole pressures are declining, but the curves track each other, suggesting normal well depletion. The second plot shows a pressure divergence and a drop at a rate faster than the bottomhole pressure. One possible conclusion is that salt, scale or paraffin is plugging the production tubing. In this scenario, an alert would be sent to the reservoir engineer of this condition for a more thorough analysis. With full implementation of automated closed loop control, remedial action can be initiated to the extent that the control algorithm is able to correctly identify the cause of the deviation and direct appropriate action.

Consider for this example the inclusion of chemical injection within the scope of intelligent control and that the monitoring algorithm anticipates the possibility of blockage due to treatable plugging. The controller could then make an appropriate change in treatment rate and measure its impact on the observed differential pressure. Another possibility will be that the blockage is associated with a controllable producing interval that can be choked back to remediate the problem. One thing is almost universal within the downhole reservoir environment, to expect the unexpected. Having the ability to adjust your well's performance without intervention is one of the biggest factors in choosing to install an intelligent well.

As confidence is built up by early adopters, a feedback loop using a learning/refining model can be implemented. This model places much more control in the local system and will add a component of generic-ness creating wider closed loop control intelligent well and production optimization opportunities. The above was a simple example of what can be done with a closed loop intelligent well. Next we will discuss a more thorough example based on water injection.

Water Flood Closed Loop Example

A common problem experienced during water injection or water flooding is poor vertical sweep efficiency. Conventionally, water will be injected into the wellbore with little to no capability to monitor or control the vertical conformance of the injection process. As a result, high productivity zones tend to take the majority of the water injected into a single well. Consequently, the production wells tend to produce significantly more from these intervals that are both higher productivity and now receiving a higher volume of water. This discrepancy in injection leads to a condition where injection water is merely cycled through this high productivity interval and a significant volume of unswept oil remains in the other zones of the field.

An increasing number of intelligent wells are being applied in water injector applications specifically to address the vertical sweep efficiency problem. Using an intelligent well, an operator can continuously monitor the injection rate into each zone as well as the pressure in each of the intervals. Based on the reservoir model and produced well information, the operator can then make decisions about the most appropriate volume of water to continuously inject into each interval and then execute that decision by remotely adjusting the down hole choke position without intervention. This ability to dynamically adjust the intelligent well chokes helps account for geological uncertainties and often crude model approximations.[7]

The initial desired choke positions can be remotely set and then the well will inject at the desired rate for a period of time. However, as conditions, such as skin, pressure and productivity, begin to change then the injection rates into each zone will also change, not always in an optimum fashion. Closed loop control can be implemented in this situation to maintain the injection rate over a period of time.

In this case, the water injection well is a two zone injector illustrated in Fig. 6. In this case, there is a single phase flow meter at surface measuring total injection rate, and an additional flow meter positioned between the two zones measuring the rate into the lower zone. Upper zone flow rate is determined based on the equation:

$Q_{uz} = Q_t - Q_{lz}$

Where:
Q_{uz} = Upper Zone Flowrate (bbl/day)
Q_t = Total Flowrate (bbl/day)
Q_{lz} = Lower Zone Flowrate (bbl/day)

During the initial well setup, the operator will rely on reservoir analysis to determine the optimum injection rate into each zone. This rate will be based on the estimated volumetrics of each zone combined with the estimated deliverability and required production rates for the field over time.

To adequately estimate the required choke position for each zone, a nodal analysis model of the well will be set up. The nodal analysis will require data such as reservoir pressure, permeability, skin, fluid properties, injection pressure etc. Using this model, the choke settings required to achieve the desired injection rates will be determined. An example of the results of the initial Nodal Analysis is shown in Fig. 7. The inflow curve is the positively sloping line that flattens out at the reservoir fracture pressure. As injection pressure increases, the inflow is dominated by the Darcy flow of the formation. As fracture pressure is exceeded, the IPR flattens out and injection is "infinite." The tubing curve or vertical lift performance curve is shown as the negatively sloping line, and the intersection of the two curves determines the injection rate and bottomhole pressure. Q_1 is the desired injection rate and requires a bottomhole pressure of P_1 to achieve that rate at initial conditions.

Over time, the skin damage of each zone will increase and there will be a corresponding decrease in injection rate. As this occurs, the injectivity of the zone decreases and the IPR moves from IPR_i to $IPR_{t.}$ This results in a decrease in the total injection rate and drives the solution point to Q_2 and P_2. In order to maintain the desired injection rate the downhole choke is then opened up further and the VLP driven from VLP_i to VLP_t. The result is an increase in the injection rate back to Q1 with a new increased bottomhole pressure of P_2. As the production parameters change over time there is a constant need to monitor the required injection rate vs. the actual injection rate and make changes in the system to optimize the overall sweep process.

The scenario described here is nothing new and in fact happens in injection wells all over the world today. Closed loop control offers the operator the ability to remotely and continuously control and optimize this process. In the case where a closed loop optimization system was in place, this entire process could be handled for a multitude of wells in a field with little to no human interaction.

A closed loop optimization system is envisioned in Fig. 5. This system would consist of the surface controls (surface chokes and valves), surface instrumentation system, the downhole control and monitoring system and a surface control system that is capable of monitoring and controlling these systems. In the closed loop system, a well model would be developed and used to optimize the initial state of the system just as is done today. However, as time progresses and new information is captured, the closed loop optimization system will continually gather and then analyze that data. There are currently a variety of opportunities to capture updated reservoir data in this scenario that go unseen because of the slow pace of current production organizations. For example, during an unplanned water injection shut-in, the closed loop optimization system can immediately close both downhole chokes. In addition to eliminating crossflow and the potential sand control and fluid incompatibility problems associated with this event, high quality downhole pressure data will be captured on a second by second basis. This gauge data will provide key data for performing an injectivity fall off test. The results of this fall off test can then be used to update the well model with key parameters such as injectivity index and reservoir pressure. As time progresses and the desired injection rates remain static or continue to change, the well model will be updated and will adjust the choke settings to achieve the optimum injection rate.

Incorporation of the watchdog, alarm, feedback and control functions into the local intelligent well surface controller provides a distributed solution as opposed to concentrating these activities at a central facility serving an entire field or larger enterprise level. With this approach the value of the active feedback can be captured regardless of the extent of remote connectivity. When robust communication paths are available between the controllers and centralized facilities the receipt and processing of the feedback can occur off-site. Conversely when the communication links do not exist or are temporarily unavailable the benefits are still accessible at the local level. The flexibility of the computer based controller architecture is well able to support the addition of the monitoring and remote communication functions. When implemented as a standalone solution the controller can also be linked in the future when the communication infrastructure becomes available.

Remote Surveillance and Control

While one thesis of this paper is to present the advantages to concentrating closed loop control functionality at the well controller it is also recognized that complimentary remote communication is usually desired. The logical progression of the locally controlled automated intelligent well completion (IWC) system is to extend the surveillance and control capability to personnel in remote locations. It is anticipated that adoption of the closed loop principles presented here will be accompanied with the requirement to closely scrutinize any actions taken autonomously by the control system.

Remote Technology Overview

Establishing reliable communication from the permanent sensors to remote computers is one of the key factors to a successful implementation of a remote control and monitoring system. Unfortunately, there is not one solution that will meet all needs due to technological, commercial, geographical and regulatory reasons. In this section, we will look into some of the more common communication hardware both wired and wireless and some common software and communication protocols that are available today and that are coming on the horizon. We will also overview the various system architectures that may be adopted for the IWC system.

Wireless Communication Technology

Unless the wellsite is situated in a location where wired telecommunication is readily available, the system will need equipment to bridge the communication gap between the wellsite location and the remote computer. Requirements such as timeliness, data rates and volumes, bi-directional communication and costs will dictate which satellite solution is appropriate. For example, to use the low earth orbit (LEO) satellite based system, only a small mobile transceiver is needed. Due to lower data transfer rates, such a system is suitable for an IWC system that has low data requirements. The geostationary earth orbit (GEO) satellite based system requires a larger dish transceiver pointed directly at a stationary satellite. It provides much higher data transfer rates but also adds a significantly higher startup and overhead costs. A cost-benefit analysis must be performed carefully especially when the system is designed for long term control and monitoring.

Other technology that is worth mentioning includes wireless broadband network using mobile phone technology and WiMAX.

Wired Communication Technology

Despite the industry buzz on wireless communication technologies, wired technologies remain the most reliable method for data transmission. Even when wireless communication technology is adopted, the wired communication technology will likely be a major part of the IWC system. This is mainly due to the pervasiveness of devices that still support serial communication like RS-232C and RS-485C.

Ethernet communication technology, though not as common as serial communication technology, is gaining support. With the availability of low-cost switches, bridges and routers, it is possible to install an Ethernet based network at the wellsite. Ethernet also supports longer distances between devices and has speeds many times faster than serial communication.

Software Protocols

Modbus, despite newer protocols, is still one of the most widely supported software protocol in the automation environment. Modbus is a simple messaging structure that allows client-server communication between the multiple devices. Modbus TCP/IP overcomes serial communication limitations by using the Ethernet network. With Ethernet TCP/IP, Modbus protocol is no longer limited by data rates. Moreover, with Modbus TCP/IP, multiple clients (master) may concurrently connect to the server (slave) device. A gateway device is also available to convert existing serial interface devices to Ethernet and from Modbus protocol to Modbus TCP/IP protocol. However, Modbus limitation such as the limited Modbus address space still persists.

OPC is another standard protocol that is based on Microsoft's COM (component object model) and DCOM (distributed component object model) technologies. With OPC, data is accessed using tags rather than addresses like Modbus. Therefore, OPC does not have address space limitation like Modbus. In addition, OPC supports alarms, events and security not addressed by Modbus.

XML is an extensible markup language that can be used to describe other languages. One of the new protocols that is under development is ProdML for well production. The definition of the ProdML language is described using XML. Unlike Modbus and OPC, ProdML not only defines the protocol but also the data interfaces to help facilitate the data exchange between devices and between software applications. Other protocols include Profibus and OPC UA.

It is important for the IWC system to support not only Modbus but also Modbus TCP/IP and OPC in order to enhance flexibility in the communication protocol supported between the remote software program and the IWC system.

Web-based System

Data delivery through a web-based infrastructure is relatively easy on the consumer of the data because in most cases the only software tool needed is the web browser. Since most PCs are equipped with a web browser, the client-side deployment complexity is greatly reduced. The web content is provided by applications that are running on the server-side. The servers typically reside in a data center with highly secured and reliable networks. The typical server-side applications are the web server for presenting the content to the web browser; the app server for hosting the various applications that collect, calculate, convert and store data; and the database server for storing and retrieving data from the database. One of the most important factors to the success in building a web-based IWC system is the infrastructure of the data center. The servers hosted at the data center should be managed by specialized personnel who are able to ensure uptime and to provide 24/7 support.

Another factor to consider when building an IWC system using web-based technology is that real-time data delivery is generally a problem because the IP technology used to build the public Internet is non-deterministic. As a result real-time delivery is only approximate.

Proprietary Client-Server System

A system based on client-server architecture is exemplified by an application (client) in a remote location that interacts with another application (server) for resources such as data and files. The client side application may employ a private data exchange protocol with the server application. Newer programming languages provide native support for remote programming interfaces between client-server applications such as Microsoft .NET Remoting and Java RPC. The tight coupling makes it easier for client and server applications to communicate efficiently. It also makes it easier for higher level of integration between client and server applications to include real-time data delivery, authentication, access control and event handling.

SCADA System

Another client-server based architecture is the Supervisory Control and Data Acquisition (SCADA) system. The SCADA is responsible to acquire data, make calculation, check data for alarm conditions, automate alarm handling and log data. SCADA communicates with the remote devices using protocol such as Modbus RTU, Modbus TCP/IP and OPC.

Remote Control Implementation

The following steps outline the major tasks in implementing the IWC system that will allow remote control and monitoring:

Planning

1. Decide the number of wells and zones that will be controlled.
2. Procure IWC equipment including the HPU. Typically the HPU is powered by either external pneumatic sources or an electric pump with an accumulator to actuate the hydraulic control lines to the downhole chokes.
3. To support automated remote operation, the HPU typically will have Programmable Logic Controller (PLC) to control the pump and valves and read pressure transducers. Also, the HPU may have an industrial class computer the runs application that provides the control logic to control the pump and valves and to log data. Optionally, the computer may also run the HMI application for the operator to change the choke size of a downhole valves through a touch screen or a mini display module with keypad mounted on the HPU.

Communication Infrastructure

4. Run cabling from the HPU serial or Ethernet port to the control room.
5. Control room should have Ethernet connection to the remote location. If not, then satellite vendor must be sourced and selected for the communication between control room and the data center. In addition, the data center may have to be sourced and selected to provide the communication infrastructure to the remote computer.

Test the connection from the remote location

6. Start HMI application and login into the remote HPU by entering the computer domain name or IP address.
7. If connection was established, the HMI should configure itself using information obtained from the remote HPU. If for example the HPU is able to control 4 wells, then the HMI will show a graphical representation for 4 wells.
8. The HPU is now ready to accept remote operational commands.

Program the SCADA to allow remote operation

9. Obtain the Modbus address map documentation for the HPU.
10. Program the SCADA to display the well information. The address map will specify the Modbus address that contains the well information.
11. Add new control on the SCADA to display a drop-down menu for choke percentages. Also add a button that will run the script to operate the downhole valve. Program the script to write the well number, zone number, new choke position and command number into the appropriate addresses.
12. SCADA should watch command status address to monitor the progress of the operation.
13. After programming the SCADA, send a command to the HPU to test the communication.

Program the SCADA to handle operational exceptions

14. If the status of the operation was returned with an error code, then the SCADA may also be programmed to handle the exception.
15. The SCADA should provide the appropriate available options on the next course of actions to operator.
16. The operator chooses one of the options and sends the feedback to the HPU.
17. The HPU continues to operate and sends the appropriate intermediate status update and final update.

Note: workflow described above is highly abbreviated.

Other Deployment Considerations

While the benefits of implementing remote control and monitoring of the IWC system are clear, there are also challenges, both technical and logistical. While these challenges are surmountable, they should be addressed as early as possible to avoid delay. The following are some of the challenges:

Challenge 1: Remote Communication Reliability

Securing reliable communications from the wellsite to the office is crucial to the success of the remote IWC system. Due to geographical, commercial and legislative reasons, there is not one off the shelf solution for all geographical locations. The first step before selecting the communication partner is to determine the current and future communication needs. The solution is driven by your communication needs.

Factors influencing vendor selection includes the startup costs; the overhead (ongoing) costs; who will provide the hardware equipment; how the hardware equipment will be installed at the wellsite and data center; who will provide the support at the data center; and whether 24x7 support required.

Challenge 2: Wellsite Hazards

Specific placement at the wellsite determines the enclosure needed for your communication devices and IWC system surface equipment. It is important to work with the service company earlier in the development cycle so that the appropriate enclosure may be sourced according to site specific requirements such as environmental or explosion-proof requirements.

Challenge 3: Communication Security

It is important to realize the data communicated over the public Internet is not secured and is opened to eavesdropping. However, the communication can be protected by using secured communication technology such as secured HTTP protocol and virtual private network (VPN). Security consideration should be built into the communication infrastructure from the beginning.

Conclusion

The challenges to closing the loop on an intelligent production system are very manageable when constrained to the applications this type of solution is most apt to handle. Furthermore, this constraint creates a well scenario of which it is easy for operators to see the value and immediately grasp the importance. Proving its added efficiency is much easier at the well level than doing so for an entire reservoir. Taking an approach to build user trust through a sequence of increasingly complex chores over time creates the best opportunities to show a concept's reliability and safety. At one time it would have been hard to imagine cruise control for automobiles or fly-by-wire for aircraft. Careful management of user's expectations and delivery of promised efficiencies and benefits are the way to introduce the industry to this new technology. An intelligent well completion is designed to provide options for addressing expected and unforeseen well and reservoir conditions. It only makes logical sense to add a degree of intelligence for processing the information that is available. So, are we ready for closed loop control? The authors of this paper firmly believe the time is ripe for its introduction.

Nomenclature

COM	Component Object Model
DCOM	Distributed Component Object Model
ESP	Electric Submersible Pump
GEO	Geostationary Earth Orbit
HMI	Human-Machine Interface
HPU	Hydraulic Power Unit
HS&E	Health, Safety and Environmental
IWC	Intelligent Well Completion
OPC	Open Process Control
SCADA	Supervisory Control and Data Acquisition
SCM	Subsea Control Module
XML	Extensible Markup Language

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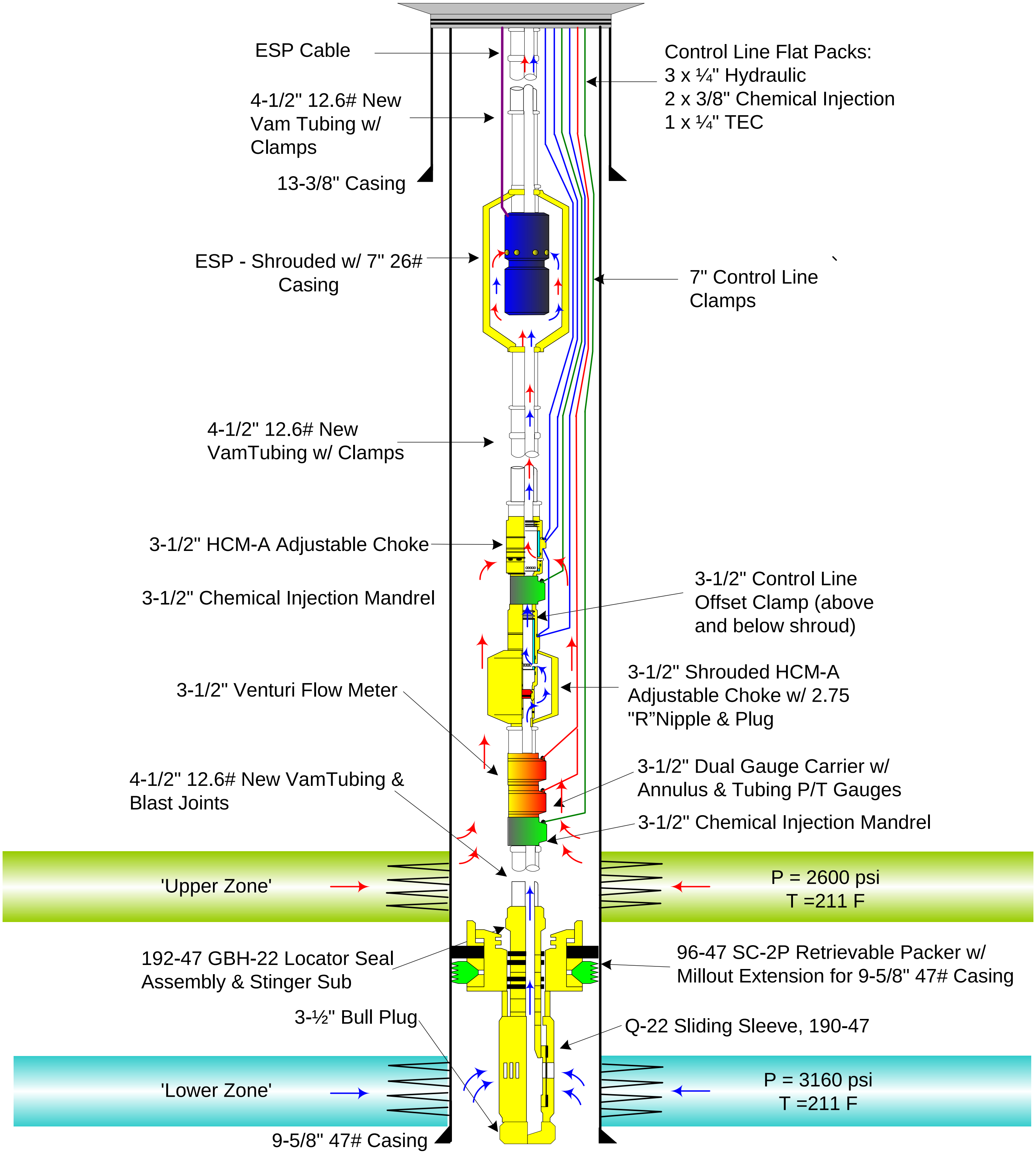

Fig. 2 – Intelligent Well System Diagram

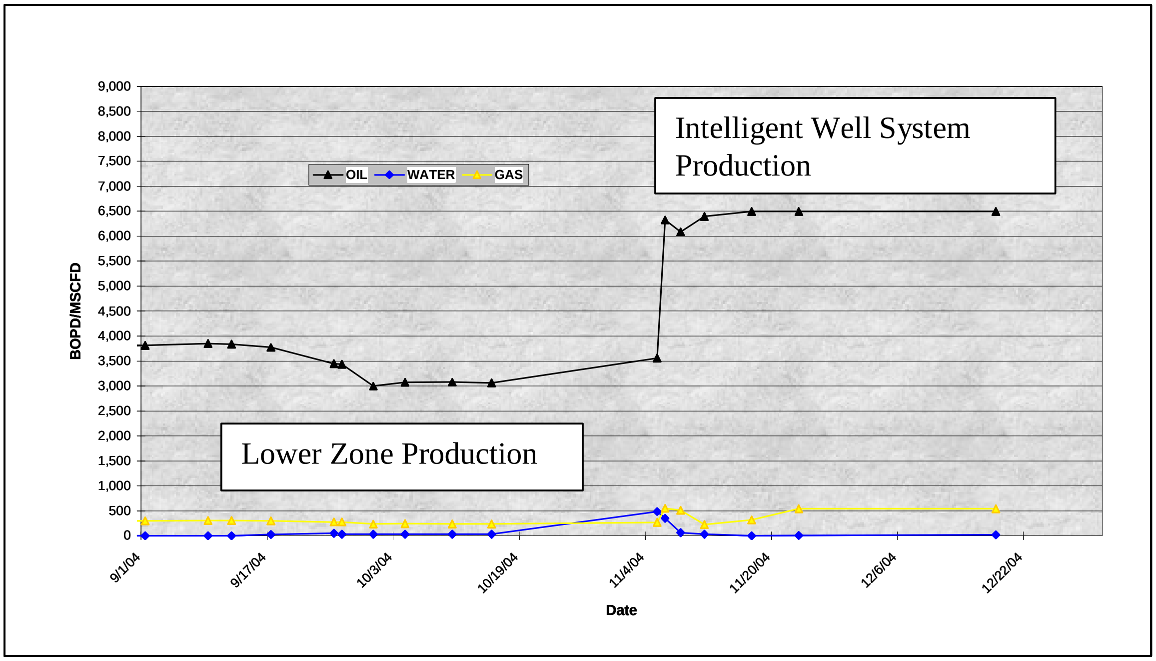

Fig. 3 – Incremental Production achieved using Intelligent Well System

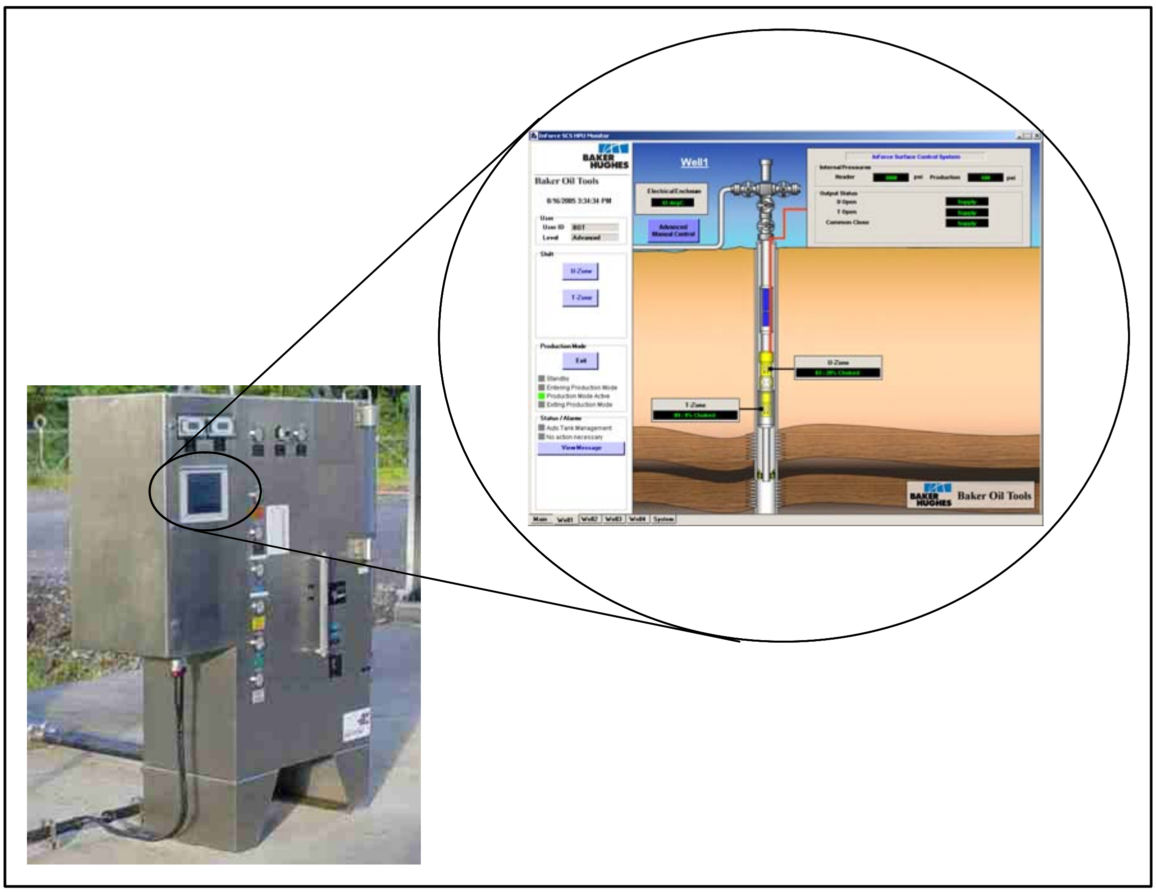

Fig. 4. Surface Control System and HMI Example

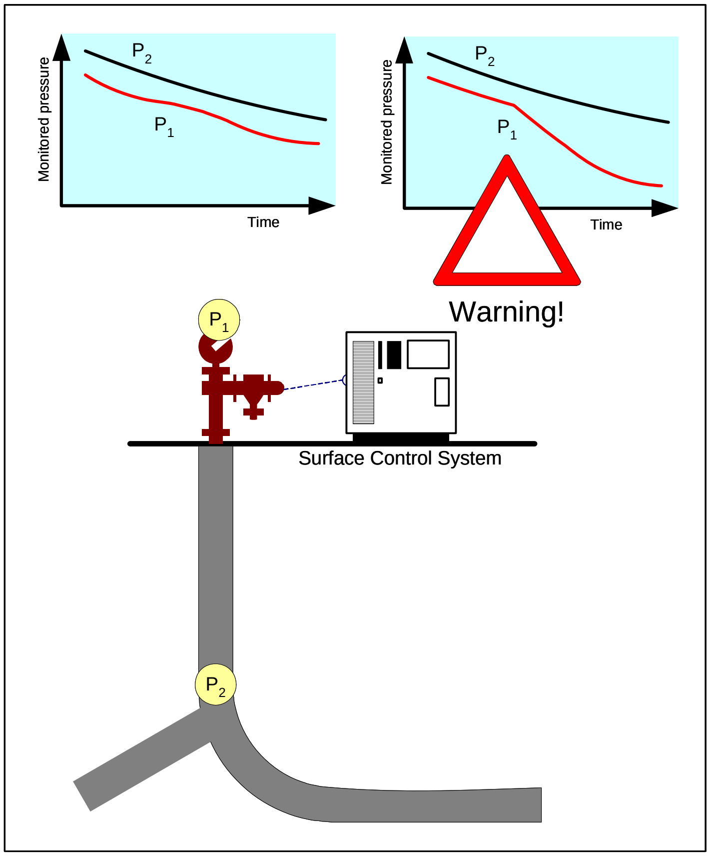

Fig. 5: Well Surveillance Closed Loop Example

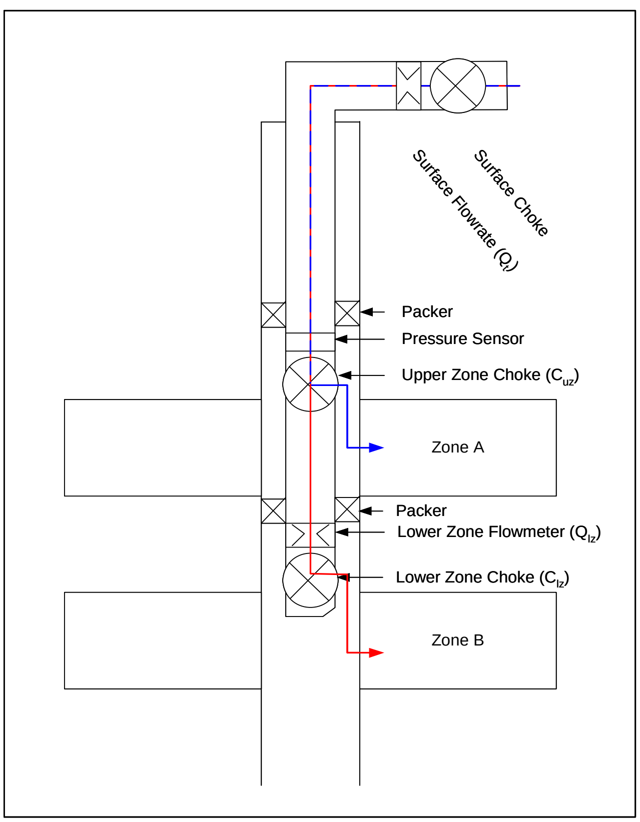

Fig. 6: Water Injector Intelligent Well Completion

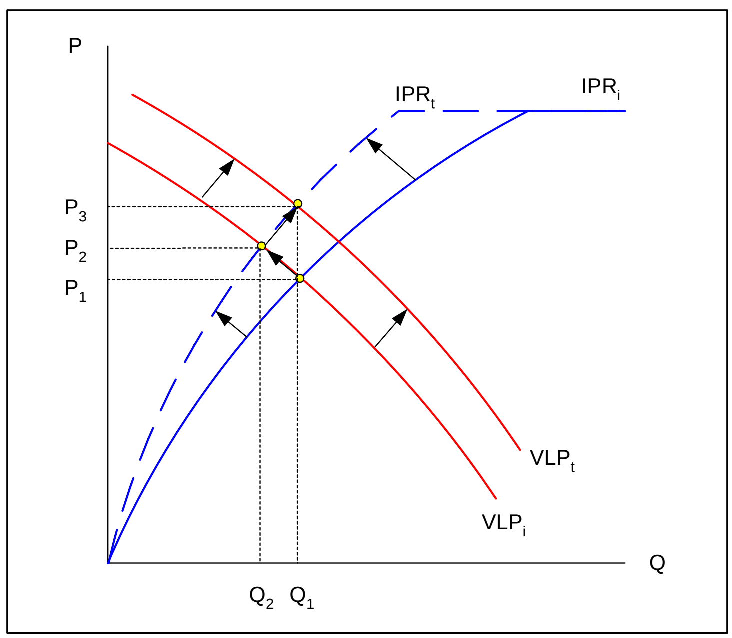

Fig. 7: Water Injector Optimization Closed Loop Example