Real Time Diagnostics of Gas Lift Systems Using Intelligent Agents: A Case Study
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Abstract
This paper describes a new method to continuously monitor and diagnose the condition of wells producing via continuous gas lift. The paper describes the application of this system in a mature onshore gas lift field in the Western United States and the results obtained therein. A central problem related to the operation of gas lift wells is the ability to identify underperforming wells and to address the underlying issues appropriately and in a timely manner. This problem is compounded by the trend toward leaner operations and relative scarcity of application specific domain knowledge. The purpose of this method is to address these issues by leveraging real time data, gas lift domain expertise and proven steady state analysis techniques in a desktop software application.

This system performs four key functions: monitoring the wells’ condition by collecting data; assessing the meaning of this data; recommending actions for correcting problems and responding to threats; and explaining their recommendations.

The performance of the system has met initial expectations and provided additional unforeseen benefits. This paper sites specific cases which compare agent predictions to expert diagnoses and quantify the benefits of taking the recommended actions. What was found was that while the correct diagnoses of well performance issues was beneficial, the real benefit was in allowing production engineers to analyze a greater number of wells in far less time. To that end, the paper will discuss the role of this system as it relates to the overall production management workflow.

The success of this project has demonstrated that intelligent agents can be used to effectively perform functions which were historically performed by a handful of experts. The paper will discuss key system design features which enable this level of functionality as well as other potential areas where the technology can be extended in the future.

Introduction
One of the current challenges facing the upstream E&P industry is the growing scarcity of specialist domain expertise and trained personnel needed to efficiently operate oil and gas assets. In cases where these resources are limited or unavailable, automation technology has often been touted as a solution. While the introduction of such technology has delivered numerous improvements in operational efficiency, it has also introduced new challenges. One such challenge involves the introduction of vast quantities of data that results in minimal actionable information. Operators are faced not only with the information technology task of managing this data, but also with the business challenge of leveraging the data to improve their profitability. In response to this new challenge, a growing number of projects are being initiated to help close this gap between data and information. This paper discusses one such effort.

In this project, new technology has been developed to assist production engineers in the well-by-well optimization of gas lift systems. Well-by-well optimization has long been recognized as having value, but has often proven impractical to carry out on a routine basis due to the labor-intensive nature of the work and the limited number of individuals with the required level of expertise to perform it. This project sought to solve this problem by developing a system of intelligent agents which leverage both real time data and gas lift domain knowledge to assist engineers in these well-by-well optimization tasks.
An intelligent agent is defined as “an autonomous entity which observes and acts upon an environment and directs its activity towards achieving goals”\(^4\). In the context of this project, intelligent agent systems are software applications designed for surveillance engineers and production managers to diagnose problems, provide advice on the proper course of action, explain how the agent arrived at its conclusions, and take action on behalf of the operator, if desired.

**Optimizing Gas Lift Wells**

**Value of Optimization**

For many years, production engineers have recognized the value of gas lift optimization as a means to generate incremental production and reduce operating expenses\(^5\). Although gas lift wells represent a relatively small portion of the well population, they generate a significant portion of the industry’s oil and gas production. Further, industry experience has shown that gas lift wells seldom operate under optimal conditions\(^6\). As a result, significant production gains can be achieved through the optimization of gas lift systems.

**Objectives**

In general, gas lift optimization efforts have the common objective of producing the greatest amount of oil with the least amount of gas injection. For this to occur, a variety of related tasks must be accomplished. These include: (1) injecting as deeply as possible, (2) lifting the well from a single point of injection, (3) injecting under stable, steady-state conditions, (4) injecting the optimal amount of gas for the given production based on individual well performance, (5) minimizing back pressure and (6) allocating injection gas amongst a population of wells in the most resource efficient manner possible.

**Optimization Project Classes**

In order to achieve these objectives, operators will often initiate some form of optimization project. Such projects can be described using three main classes or tiers.

**Tier 1**

The first, most common, tier of gas lift optimization project is well-by-well optimization. Well-by-well efforts include such tasks as trouble-shooting of wells, individual well modeling using systems analysis, replacing gas lift valves, back pressure reduction, and other tasks that are focused on improving the production performance of individual wells.

**Tier 2**

The second tier of optimization project can be defined as full-field optimization. Full-field optimization projects focus on managing the interactions of a population of wells with each other, their production network, the gas distribution network, and, in certain cases, with the reservoir over time. The aim of such projects is to maximize the net present value of the asset while honoring system constraints. Such projects generally require sophisticated software models and specialists to run them, and are dependant on prior steps carried out in tier one\(^7,8\).

**Tier 3**

The third tier of optimization project can be defined as real-time enabled full-field optimization. Tier three is actually an extension of tier two, where realtime data is used to continuously update network and well models, enabling operators to sustain the production enhancements achieved in tier two over an extended period of time.

Research indicates that, of the three tiers, tier one is by far the most commonly employed. This is because well-by-well optimization is often the least expensive of the three and will generally produce the greatest performance gains. In terms of the Pareto principle, well-by-well optimization is the “20% of effort that yields 80% of the results”. This is depicted in Figure 1, below.
While a number of gas lift automation projects have been carried out to address tier three \cite{9,10}, this project is somewhat unique in that it focuses on leveraging technology to allow engineers to more easily carry out tasks related to tier one.

Well Performance Issues
A variety of issues can impact the performance of gas lift wells. These issues are frequently classified as either “inlet” issues, “outlet” issues or “downhole” issues \cite{11}.

**Inlet Issues**
Inlet issues include those conditions which inhibit or obstruct the injection of gas into the well. Such conditions include (1) frozen or plugged injection control valves, (2) inadequate supply pressure to kick-off or unload the well and (3) unstable or irregular gas supply pressure.

**Outlet Issues**
Outlet issues include those conditions, downstream of the wellhead, which impair a well’s ability to flow. Such items include excessive back pressure due to (1) production chokes, (2) undersized flowlines or manifolds and (3) high separator pressures.

**Downhole Issues**
Downhole issues include events occurring below the wellhead which impair a well’s production performance. Such conditions include: (1) multi-point injection, (2) valve cycling, (3) tubing-to-casing communication, (4) instability due to injection in sub-critical flow across an orifice, (5) plugged operating valves, (6) inadequate differential pressure at depth, (7) re-opening of upper valves, (8) flow cutting of gas lift valves, (9) temperature locking of injection pressure operated valves, (10) circulating gas above the active fluid level in the tubing; as well as a variety of other known issues.

Tools and Techniques
A variety of tools and techniques have been developed and used over time to aid in gas lift trouble-shooting and diagnostics. These include such things as (1) flowing pressure and temperature gradient surveys, (2) annular fluid levels, (3) CO$_2$ tracer surveys \cite{12}, (4) systems analysis \cite{13}, (5) calculation of valve state \cite{14}, (6) evaluation of gas passage, (7) dynamic simulation \cite{15,16}, (8) surveillance of key performance parameters, and numerous other such techniques.

Historical Approach
Historically, well-by-well trouble-shooting and optimization has often been performed on an ad-hoc or as needed basis. In most cases, an internal or external expert would be called upon to assist in evaluating a well once it had been identified as having a problem. This expert might then use some or all of the tools described above to assess the well’s condition, identify the root cause of performance problems and recommend corrective actions. This expert may even oversee the implementation of these corrective measures and evaluate the performance of the well after performing these services. In certain cases, a more proactive approach might be used, where an expert is placed in-house with the task of systematically identifying under-performing wells and addressing well performance issues in a prioritized, sequential manner.
Challenges with Historical Approach
The approach described above presents a variety of challenges to operators. One of the most fundamental challenges is that this approach tends to be both reactive and episodic in nature, resulting in missed opportunities for production enhancement. In addition, much of this work requires individuals with specialist artificial lift domain expertise which is becomingly increasingly scarce as the demographics of the industry change over time. Even in those cases where a resident expert is present in an asset, their ability to detect and address the numerous opportunities in a field is limited by the labor-intensive nature of the work and the sheer volume of competing priorities. Finally, it is common for problems in gas lifted wells to go undetected for months or even years due to the fact that gas lift is such a forgiving artificial lift method. Even those gas lifted wells which have a serious performance problem and are producing sub-optimally will often continue to produce fluids. By comparison, with other forms of lift, failures tend to be catastrophic in nature and are identified and addressed much more quickly.

Addressing the Need
Role of Intelligent Agents
In order to address these challenges, an intelligent agent system has been developed to provide realtime diagnostics of continuous gas lift wells. The role of the intelligent agent system is to enable every surveillance engineer – regardless of experience or skill level – to make decisions that will lead to optimization of his wells with the knowledge of a world-class gas-lift analyst.

Intelligent Agents do this by providing engineers with the status of all gas-lifted wells under their control. Agents monitor the wells’ situation by collecting and cleansing data, assessing the meaning of these data, recommending actions for correcting problems and responding to threats, and explaining their assessment results and recommendations. Agents can detect the initial symptoms of a problem and prompt for corrective action before the well’s performance seriously degrades. The performance of these key functions enables surveillance engineers to optimize a much larger number of wells on a continuous basis.

Once armed with these tools, engineers no longer have to assess the state of each well manually. The agents integrate continuous data such as pressure readings with well test data and predictions from commercially available systems analysis tools, and use diagnostic principles stored in a knowledge base to determine each well’s condition and recommend corrective actions. The agent reviews all gas lifted wells in the field and prioritizes recommended actions in accordance with pre-established criteria that includes increased production potential and possible cost efficiencies.

System Components
Knowledge Base
The central component of the system is its knowledge base. The knowledge base is the portion of the system that captures the mental model of the engineer. In this project, it was important to have a system that was tolerant of missing or inaccurate data and could produce reliable answers in less than ideal conditions. It was also desirable for the system to be able to learn from experience and generate increasingly reliable answers over time. In order to accommodate these needs, the knowledge base was assembled in a manner that (1) was non-hierarchical, (2) combined both deterministic and probabilistic methods and (3) was over-defined.

Unlike typical trouble-shooting methods, this knowledge base did not rely upon a top-down hierarchical workflow. Instead, knowledge was organized as a series of individual cases (diagnoses), each with a unique set of attributes. This is illustrated in Figure 2, below. In all, over sixty unique cases were defined for wells operating via continuous gas lift with either IPO or PPO gas lift valves.
By organizing the knowledge base in this manner, the system could accommodate a number of possible diagnoses for the same condition, each with its own level of probability. Although the individual attributes were each deterministically derived, the arrangement of these into a set of discrete cases enabled the system to provide a probability (or likelihood) for each diagnosis. This arrangement also enabled the system to identify which individual attributes contributed most strongly to a given diagnosis.

Another key aspect of the knowledge base is that it was over-defined. For a given condition, there could be multiple attributes that would identify its occurrence. As a result, even when certain information was unavailable or inaccurate, the system still had the ability to correctly identify a given condition. Having more than one such attribute present would simply increase the certainty of a given diagnosis.

**Agent Attributes**

Because of the realtime nature of this project, the scope of work could only include those techniques which could be performed automatically. Therefore, manual, episodic operations such as flowing gradient survey acquisition and interpretation were not considered. Instead, a series of attributes were collected that were either a function of analog inputs, the results of systems analysis, calculation of valve state, calculation of gas passage or a calculation based on a combination of these items. In all, over thirty attributes could be collected for each analysis run.

**Technology**

The agent’s underlying technology is an adaptation of methods that are used in applications such as document classification and search on the internet. Software programs known as entity extractors can electronically read documents and pick out the persons, places, events, organizations and other “things” mentioned in the document. Other programs can determine which entities typically occur together in a document of a particular type. Given a query string such as “US Airways Hudson river”, search programs can find documents and materials related to the 2009 crash landing of a US Airways flight in the Hudson river. Document searching is an application of pattern matching.

Relating the notion of pattern matching to gas lift analysis, we know that in cases of valve cycling, the attributes “Casing Heading: Yes” and “Tubing Heading: Yes” typically occur together. In wells behaving normally, the attributes “Casing Heading: No” and “Tubing Heading: No” typically occur. Gas lift experts understand the complex patterns of data that characterize various gas lift fault states.

The gas lift intelligent agent follows essentially the same process as a knowledgeable engineer. The engineer typically examines well test data, reviews trend data such as casing and tubing pressures, and refers to analytical models using systems analysis tools. In many cases, at least some of the data will be either missing or suspect. Making sense out of this “dirty” and sometimes conflicting data is the art practiced by an expert gas lift engineer.

The agent treats the art of gas lift diagnosis as a pattern matching problem which involves overlaying the data that describes a well’s current state with information in the knowledge base that describes problem states for gas lift systems. The set of attributes being compared is fairly large – on the order of 25+ attributes. Like an internet search program, the agent returns an ordered list of the best matches it finds. A site like Google might return thousands of matches, but the gas lift agent is configured to return only three top candidate cases.
The agent has features that make it uniquely suitable for gas lift. First, the pattern matcher can be tuned to handle special circumstances. An attribute can be weighted (its importance can be decreased or increased) if the attribute’s value is suspect or if the attribute should be given special consideration during pattern matching. Second, the pattern matcher can explain its results by providing information about the attributes which most strongly influenced its selection of a case. This feature provides a way for users to “see what the agent is thinking.” Finally, over time, and as needed, the agent’s knowledge base can be extended with additional cases which reflect conditions actually encountered in the field. Thus, the agent’s performance can be refined over time.

Data Requirements
As depicted in Figure 3 below, a variety of data elements are required in order to fully define the flowing state of a gas lift well. These data include real time, well test and static data elements. Real time data includes analog inputs such as flowline pressure, supply pressure, casing head pressure, flowline temperature, flowline pressure and gas injection rate. Well test data includes information such as production rates (oil, water and gas), gas injection rates, tubing and casing pressures and fluid gravities. Static data includes physical attributes such as perforation depths, well deviation, completion geometry, inflow performance data and gas lift valve specifications. Each of these data items are collected and used to populate the intelligent agent system and the well models it uses in conjunction with systems analysis operations.

![Figure 3: Gas Lift System Data Elements](image)

System Architecture
Because oil production companies use a wide variety of databases and analytical models, the agent has been designed to be used in a variety of IT environments. Figure 4 represents the system’s architecture.
The system is implemented with a thin-client / server architecture. System components communicate with each other using a web services protocol.

**Security Layer**
The Security layer (see top of diagram) controls user access to the system using Windows login ID’s so that users do not have to login separately to the system. The Security system is being enhanced to provide basic role-based access control that distinguishes between “Super Users” with administrative privileges and ordinary users.

**Data Migration Layer**
The Data Migration layer (see bottom of diagram) is responsible for fetching data from a production company’s data stores, including well configuration data, well test information, and trend data. The agent is currently integrated with Weatherford’s Life of Well Information Software (LOWIS). However, Data Migration is designed to enable integration with whatever data sources are used by a producer, including real-time sources. The Data Mover pulls data from their sources and pushes data to the Middle Tier where it is stored in the Gas Lift System Database which is a cache for storing data used during analysis and the results from analysis.

**Middle Tier**
The Middle Tier includes the business logic for analyzing a well. The Application Server module combines well test data and any available trend data. It invokes an Analytical Well model to gather information about the well’s configuration (e.g., types of valves, their depths, and so on). The agent currently uses WellFlo as its analytical well model. However, consistent with the principle that it should run in many IT environments, the agent will be integrated with additional analytical models such as Prosper, WinGLUE and others. Using data derived from the analytical model, the server next performs calculations to determine whether valves are open, closed, or back-checked, and it determines gas passage for each open valve. It combines this information with all the other data gathered into a single record. This record is an Input Context which is a vector of attributes that describes the current state of the well. The pattern matcher compares the well’s state with cases in the knowledge base and returns the top three similar cases to the application server. The Post Processor performs additional calculations primarily related to economic benefits which might be realized by optimizing the well.
**Client**
The Client is the agent’s primary user interface and is discussed in the next section.

**Client Graphical User Interface**
The Graphical User Interface (GUI) is a thin client that communicates to the Middle Tier using web services. It is not a web application, though a browser-based interface could certainly be implemented. The user interface is just an interface, meaning that its function is to simply display data rather than to perform any analysis functions. The GUI’s purpose is to present information to production engineers in a manner consistent with the mental model for gas lift analysis. The mental model describes how users typically think about gas lift analysis, including the kinds of data that are useful when assessing a well. A simple example of the mental model is that some users measure depth in feet and others in meters. Accordingly, the GUI includes a unit editor so that users can tailor unit values to their preferences. The GUI is illustrated in Figure 5 and Figure 6. Figure 5 is the system dashboard.

![Figure 5: System Dashboard](image)

The display provides a number of features for filtering and sorting data. The dashboard is essentially a tool for doing management by exception. Users can select a well from the dashboard and drill down to a detailed display.
Figure 6 is the Details display; it displays comprehensive information about the well’s current diagnosis and supporting information for this diagnosis as gathered from the latest well test, from trend data, from the analysis model and from the knowledge base.

- The Analysis History section (left hand side of the display) lists all the analysis results performed for the well. Users can select any of the items in the history list for review.
- The Well Header pane provides basic well configuration data.
- The Analysis Results section (Figure 7) lists three possible diagnoses for the well: a Primary, Secondary and Tertiary Condition. The Likelihood value provided for each diagnosis is a rough measure of similarity between the well’s input context and a diagnosis case, normalized to 1 across the three cases. The likelihood is NOT a probability.
- The **Analysis Trend Data** region (Figure 8) provides graphs of well trend data such as casing and tubing pressures, gas injection rate, and supply pressure.

![Analysis Trend Data](image1.png)

**Figure 8: Analysis Trend Data**

- The **Diagnosis Inputs** section (Figure 9) is the input context for this analysis run. All of the attributes used by the pattern matcher are included in this panel.

![Diagnosis Inputs](image2.png)

**Figure 9: Diagnosis Inputs**

- The **Valve Mechanics** section (Figure 10) provides comprehensive information about the valves installed in the well, including their mechanical status (open / closed / backchecked), calculated gas passage, and so on.

![Valve Mechanics](image3.png)

**Figure 10: Valve Mechanics Panel**

- The **Well Test** panel (Figure 11) provides data from the well’s last well test and additional attributes calculated using the analytical well model.

![Well Test Panel](image4.png)

**Figure 11: Well Test Panel**

- The **Analysis Model Graphs** region (Figure 12) provides graphs generated by the analytical well model such as pressure drop curves.
The Impact Model Output section (Figure 13) provides estimates of revenue and production rates that may be possible if the well’s performance issues are corrected.

Testing
The system prototype was thoroughly tested in a laboratory environment prior to the field trial. The objectives of the lab testing were to evaluate three major criteria. First, does the system's data migration layer correctly import data into the system, including both analog and well test data? Second, does the system's workflow layer follow the correct steps with respect to gathering data and invoking the correct analytical calculations? Finally, does the system’s knowledge base component generate correct results?

The following discrete tests were performed:

Data retrieval testing
The purpose of this test was to ensure that the system pulls the correct real time and well test data and populates this information in its database and well models.

Testing of analysis modes
The system was required to support 3 mode of analysis – (1) periodic (analysis is triggered each time a new well test file is shipped into the system), (2) continuous (analysis is performed once a day based on average values of the analog signals over the previous 24 hours using the most recent test rates, and (3) manual (analysis process is initiated by a user at any time).

Testing of the agent's output results and recommendations on corrective actions
The software was fed a set of well test data representing different well performance conditions (normal operation by injecting at deepest point, multipoint injection, circulation of gas above the top valve, over injecting lift gas, etc…) and allowed to perform the analysis and provide diagnostic results and recommendations. At the same time, experienced gas lift experts independently analyzed the same set of data using stand alone system analysis software, and recorded their observations about the performance of analyzed wells. In most cases, the experts were also able to collect and evaluate current flowing pressure and temperature gradient survey data to aid in this evaluation. The results and recommendations
of corrective actions generated by the software were then compared to the ones provided by the experts. The software was considered to pass the test when its conclusions coincided with the conclusions of the independent manual analysis.

Data validation testing (handling missing data)
This test concerned the ability of the system to handle missing or invalid data. If a well test file is missing the following parameters, the system will substitute values from corresponding analog data that is concurrent with the time of the well test. These attributes include flowing wellhead pressure, supply pressure, gas injection rate and flow line temperature.

The ability of the system to perform boundary checking (determining if data is out of range) was also tested. In addition, the ability of the software to detect no-flow conditions based on the slope of change of flow line temperature and pressure was tested.

Analysis workflow testing
A specific analysis workflow is incorporated in the Agent. The workflow consists of a number of consecutive computations and comparison of computation results against the knowledge base. This test concerned the system’s ability to successfully execute this workflow.

Training of the Knowledge Base and Agent Memory (Prediction)
Two unit tests and one system-level test were performed on the agent memory.

First, the memory was tested with input contexts fully defined for each of the cases in the knowledge base. This test ensures that the memory is trained correctly and that the knowledge base performs as expected when queried using a fully defined context. This is a unit-level test.

Second, the memory was tested using input contexts which were partially defined for each of the cases in the knowledge base. This case is consistent with the conditions expected to be found in the field. The missing input contexts included all attributes that require a measured fluid level as well as all attributes that require a separator pressure or back pressure. This is a unit level test.

Finally, the memory was tested using “real-world” data. This test is a system-level evaluation.

The software successfully passed laboratory testing. It gave reliable diagnostic results and recommended corrective actions which, in most of the cases, were in line with the results obtained by experienced gas lift engineers by analyzing the same set of data independently using stand-alone software. Those few cases where the ternary diagnostic results were not in agreement with those of the specialists where investigated; and, the software knowledge base was expanded or refined to accommodate those cases.

Field Trial
Following the laboratory testing, a field trial was conducted in a large, mature water flood located in the Western United States. This onshore field has several thousand wells operating on a variety of forms of lift, including natural flow, reciprocating rod lift, electric submersible pumping, progressing cavity pumping and continuous gas lift. At the time of the field trial, 84 of these wells were actively producing via gas lift. Each of these wells is fully instrumented and controlled using an RTU, which in turn, communicates via radio to a host system. Typical instrumentation includes the following:

- Gas lift supply pressure, psig
- Casing head pressure, psig
- Flowing wellhead pressure, psig
- Flowline temperature, degrees Fahrenheit
- Gas injection rate, MSCFD

As with the laboratory testing, each of these analog inputs, along with relevant well test parameters were imported into the intelligent agent system for use in its analysis.

The goals of the field trial were similar to those of the laboratory testing. First, the system had to successfully import well test and analog input data from the real time host system. It then had to follow the correct steps with regard to importing data and invoking its analytical processes. Finally, it had to generate results that were consistent with those which were independently obtained from the gas lift experts.

Deployment
In preparation for this field trial, the system was deployed to a field trial server isolated from the local operational server but available on the corporate WAN. The field trial machine was a mid-level server running Windows XP. LOWIS, WellFlo, SQL Server, and the agent were installed on the machine. To ensure data integrity on the operational system, local IT staff developed a manual procedure for copying data from the live LOWIS instance to the LOWIS instance on the field trial server. The client (i.e., the user interface) was installed on several user desktop computers both at the field and the corporate offices in Houston. Thus, the agent functioned as if it were operationally deployed, except that it used a copy of the local data.

Results
Consistent with the performance seen in the laboratory test environment, the system produced impressive results once deployed in the field. In general, the system provided diagnoses and recommendations which were consistent with the manual diagnoses of the experts, often with a startling degree of accuracy. The following case studies illustrate three such examples of system performance.

Case Studies

Well 1
This well had been producing stably for the previous 15 months with an average production rate of 1323 blpd, a 98% water cut, 895 MSCFD of produced gas and 881 MSCFD of injected gas. As can be seen in Figure 14 below, the flowing wellhead pressures, casing head pressures, gas injection rates and temperatures were stable over the previous several months with only minor fluctuations in flowline temperatures due to day/night patterns.

![Figure 14: Well 1 Historical Data Trends](image)

After analyzing the conditions for this well, the agent made the following primary diagnosis:

Scenario: Steady single point injection at deepest valve in well.
Condition: No apparent problems at this time.
Likelihood: 42.68%
Action Recommended: Gas lift design is appropriate for conditions.

This diagnosis was influenced by a variety of attributes, but the key contributors to this particular diagnosis were that (1) only one active gas lift valve (the deepest) was determined to be open, (2) the gas injection rate was not fluctuating and (3) the deepest active gas lift valve was not closed. This diagnosis along with the secondary and tertiary diagnoses can be seen in Figure 15, below. As Figure 15 illustrates, other (less likely) diagnoses included “Steady single point of injection NOT at deepest point in well” and “surging single point of injection through deepest valve in well, low casing pressure.”
Independent of this diagnosis, two gas lift engineers evaluated the same information as well as a recent flowing pressure and temperature gradient survey for the well (see Figure 16 below).

After modeling the well and evaluating the flowing gradient survey, both engineers independently concluded that the well was indeed operating through single point injection at the deepest station in the well and that performance was close to optimal. This was consistent with the diagnosis provided by the agent.

Well 2
This well had been producing at an average production rate of 272 bldp, a 95% water cut, produced gas rate of 18 MSCFD and a gas injection rate of 542 MSCFD. The well was unstable and experienced both tubing and casing pressure heading with an extremely low casing head pressure (approximately 200 psi). After analyzing the conditions for this well, the agent made the following primary diagnosis:

Scenario: Gas is injected / valve mechanics indicate that valves should be closed.
Condition: Possible communication at or above 4355.12 feet.
Likelihood: 50.98%
Action Recommended: It may be possible to confirm communication as follows: (1) first, shut in tubing, (2) continue to inject gas into annulus, (3) once the pressures equalize, bleed down the annulus as quickly as possible, then (4) observe tubing pressure. If tubing pressure drops...
with casing pressure, this confirms communication exists. It is also useful to shoot the fluid level in the casing before and after bleeding down the casing. If fluid level rises, this also indicates communication. Alternatively, run a flowing gradient survey to identify point(s) of injection.

The primary contributors to this diagnosis were that (1) the casing pressure at depth was less than the opening pressure for all valves, (2) the gas injection rate into the well was greater than the throughput of all active valves and (3) based on valve mechanics alone, no valves were determined to be open.

Following this analysis, trouble-shooting operations were conducted in the field using slickline based methods. Operations personnel confirmed that a hole was present in the tubing at a depth of 4360 feet – just 5 feet below the communication point predicted by the agent.

A decision was then made to replace the tubing string. The well was subsequently re-completed to restore tubing integrity. Following the re-completion, the well returned to operation with a stabilized production rate of 330 blpd – a 21% increase in production.

![Figure 17: Well 2 Historical Data Trends](image)

**Well 3**
This well had been producing at an average production rate of 1197 blpd, a 95% water cut and a produced gas rate of 128 MSCFD with a gas injection rate of 631 MSCFD. As can be seen in Figure 18, the well was unstable and experienced severe tubing and casing heading, along with fluctuations in gas injection.
After analyzing the conditions for this well, the agent made the following primary diagnosis:

**Scenario:** Multi-point injection through valves 1, 2.

**Condition:** Valves failing to close properly. This could be due to flow cutting, bellows failure or mechanical obstruction.

**Likelihood:** 37.86%

**Action Recommended:** Consider running flowing gradient survey to confirm multi-point injection. Replace valves as appropriate.

The primary attributes contributing to this diagnosis were that (1) the gas injection rate was greater than the combined capacity of all active valves, (2) the casing pressure at depth was less than the opening pressure of all valves and (3) the gas injection rate was greater than the capacity of the deepest open valve.

After independently evaluating this data along with a recent flowing gradient survey obtained for the well, each of the gas lift experts determined that the well was indeed injecting through the top two gas lift valves. This well is currently being evaluated for possible corrective action.

**Benefits Realized**

Based on its initial deployment and use in the field, it is evident that the system provides a number of clear benefits to the operator. Among these benefits are the following.

1. Well performance issues and optimization opportunities can be identified much faster than is possible through conventional means.
2. Operations personnel are able to analyze more wells in less time.
3. The system provides a means to prioritize work opportunities and direct operations and well servicing resources toward those efforts which provide the greatest value.

In addition to the benefits described above, the system plays a key role in the production management workflow.

**Role in Production Management Workflow**

A variety of production management activities are performed in any oil and gas producing asset in order to optimize well performance and maximize uptime. These activities can be described by a common workflow such as the one depicted by Figure 19, below. The first step in this process is to "get data". This includes all of the manual or automatic collection, sorting and aggregating of data needed to perform basic surveillance and analysis of the wells. The second step is to use this data to identify opportunities for improvement. Next, these opportunities are analyzed to validate the opportunity, identify corrective actions, identify the cost and benefit of such work and rank the opportunities as candidates for well work. Next, the work is executed in the field. Once the work is completed, scorecarding is then performed to evaluate the effectiveness of this work and provide lessons learned which can be used to aid future decisions. Upon completion of these steps, the process is repeated.

The intelligent agent system plays a key role in this process by automating most, if not all, of the first three steps. By collecting and aggregating all of the pertinent data, identifying opportunities for improvement and providing detailed
analysis of these opportunities, the system frees personnel to focus a majority of their energy on the actual execution of work and evaluation of results. In this way, the system shifts the focus of the production management process from purely reactive activities to proactive high-value activities.

Areas for Improvement and Future Development
Intelligent gas lift agents are designed to learn more, and therefore, improve over time. This ongoing process is vital for the continued value and utilization of the agents. As the system is exposed to a greater number of real-world cases and conditions, the knowledge base will need to be expanded and the agents trained to better match reality.

Training of Agents
The agent has been trained to date using the knowledge base without including many “real-world” observations. However, further training is possible and desirable. It is expected that the fully trained agent will have on the order of a few hundred cases in addition to the base cases in the knowledge base. An important point is that the agent is not configured to learn on its own. Rather, the agent is configured for directed learning meaning that the agent learns what we teach it. The question then is what is the protocol for training the agent using real-world data?

An old adage related to computers is “Garbage In / Garbage Out”, meaning that the results produced by a system are only as good as the data fed to the system. The same adage applies to an intelligent agent. In other words, poorly trained agents perform poorly. Agent training has to be done in a carefully controlled manner.

The agent’s knowledge base is well conceived and implemented. However, the real world can be unexpectedly complicated, and the agent may not always perform as users expect. While field users should be able to provide feedback related to the agent’s performance, they should not be able to train the agent themselves. After all, different users – and indeed different experts – have different opinions. Accordingly, the following protocol has been adopted for agent training:

1. A “Feedback” button has been incorporated on the agent’s Well Details display. Users who disagree (or agree) with the agent’s diagnosis can state their position and electronically forward a packet of well data back to a customer support desk.
2. A gas lift expert at the support center assesses the merits of feedback and determines whether the case should be added to the knowledge base. This assessment process may involve some back-and-forth communication between experts at the support center and users in the field.
3. The engineering support staff adds cases to the knowledge base as directed by the gas lift expert.
4. Periodically, a new release of the agent is distributed that incorporates new cases.

Stated succinctly, the knowledge base is treated as a corporate asset and procedures have been adopted that ensure the knowledge base’s integrity is preserved.

Future Development
Future developments in intelligent agent technology in the production domain will include support of new work processes and development and deployment of agents for other activities in artificial lift, flow assurance, and secondary recovery. Agents will also be built in a manner enabling collaboration with other agents. This will help manage the trade-off between maximizing gains in one area while hindering the optimization of other areas.

Conclusions
The field trial was successful in demonstrating the benefits that can be derived from using agents to enable production engineers to manage and optimize many more gas lifted wells than has been possible in the past. A variety of insights were gained from this project. These include:

1. Agents are able to process the massive amounts of data that needed to be monitored from all of the gas lifted wells.
2. The agents used the knowledge base effectively to reach conclusions about well conditions, explain the diagnoses given, and recommended the right remedial actions.

3. The knowledge base used by the agents system was sufficiently comprehensive so that the system functioned efficiently from the beginning. This requires comprehensive domain expertise but makes performance less dependent upon training from representative data sets which are hard to acquire. Continuous training is then carried out in the future.

4. The agent was required to increase the productivity of both the experienced and inexperienced operators. The agents overcame the lack of experience of individual surveillance personnel. It enabled non-engineers to use the results from sophisticated tools that would otherwise not be available to them. The criteria for success from this type of operator was met: the agent had to be “fast, easy to use, and accurate”. This will be critical in the future because of the much-publicised “big crew change” occurring in the industry. Such a tool will allow experienced operators to analyze many more wells than they could in the past in a given period of time.

5. The knowledge incorporated by the agent was sufficient from the start so that the agent correctly diagnosed the conditions in the vast majority of cases. The agents received further training in cases which were discovered during the field trial. These were unusual cases and required modification of the knowledge base. These modifications were easily achieved.

6. The agents were able to help optimize the performance of many wells which weren’t even looked at in the past because there were not enough experienced people assigned to perform the work. This resulted in increased production and income.

7. The gas lift agents overcame a fundamental problem that has plagued the industry in the use of certain types of artificial intelligence systems: you do not know why “the black box” has reached specific conclusions. The fact that agents emulate normal decision making through the display of the scenario, condition, likelihoods, attributes considered and the weight given to each attribute, models used, well test data, and actions to be taken means that the agent can be trusted by the operator.

8. The agents were able to identify systems analysis models which were not reflective of current conditions and needed to be investigated and tuned. This is an extremely helpful feature for surveillance engineers as it ensures accuracy of the information used to make decisions. Often, models are not maintained because it is impractical to do so. Agents identify which models are no longer accurate as conditions change, enabling engineers to quickly update those models in need of attention. This provides additional value in cases where the models are being used in conjunction with a full-field network model.

9. The incorporation of production costs provided the basis for the selection of which wells should receive remediation by virtue of the greatest ROI or other applied criteria. This was important in the demonstration of the specific value that can be created on a well-by-well basis.

10. The use of gas lift agents appears to overcome some of the difficulties encountered in processing and cleansing large data sets, fusing attributes from multiple sources, and enabling operators to understand what is going on by capturing his mental model. This provides the possibility of using Agents in other production applications.

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Nomenclature

Blpd – Barrels of Liquid Produced per Day
IPO – Injection Pressure Operated
IT – Information Technology
MSCFD – Thousands of Standard Cubic Feet Produced per Day
PPO – Production Pressure Operated
RTU – Remote Terminal Unit
WAN – Wide Area Network

References


