

# Production Automation in the 21st Century: Opportunities for Production Optimization and Remote Unattended Operations

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## Introduction

Production automation systems have been around for decades. In the 1960s, systems were used primarily to monitor production variables (e.g., pressure, temperature, and flow rate) with limited remote control functions (e.g., automatic well testing, pump start/stop, and remote facility shutdown), and the term supervisory control and data acquisition (SCADA) was developed to describe the system. Progress was slow because of many problems with instrumentation, communications, computer hardware and software, limited coverage of production operations, and lack of understanding and acceptance of this new technology.

However, changes have been dramatic, especially during the past 10 to 15 years.<sup>1,2</sup> Today, oilfield automation focuses on enhanced production management and optimization, which reaches from the reservoirs, into the wells, through the gathering, testing, treating, and handling facilities, to the final point(s) of sale. Today, instrumentation, communications, and computer hardware and software are, for the most part, accurate, reliable, and reasonably priced. Moreover, understanding, acceptance, and use of this technology to enhance the business of oil and gas production are growing.

Yet the state of the art of production automation systems is best described as mixed. In many cases, provision of the automation and information technologies (e.g., measurement and control devices, communications equipment, computer hardware and software, and databases) is ahead of the ability to effectively implement, understand, and apply this technology. One of the largest challenges to acceptance and support is insufficient training and staff development. People who have the necessary knowledge, skills, and motivation must be developed and retained. Both producers and suppliers must improve delivery of support and training systems if this technology is to reach its full potential.

The business case for applying this technology effectively is so compelling that the industry, both suppliers and operating companies, must rise to the challenge. In

these times of stretched staff and limited budget resources, automation and information management can leverage limited resources to improve the profitability of oil and gas production operations—profitability in the largest sense. It can help optimize production levels, capital investments, operating costs, and repair and maintenance. In addition, it can help minimize health, safety, and environmental incidents and provide opportunities for staff development.

The purpose of this paper is to challenge management and staff in operating companies, service and supply companies, and others to understand and appreciate the significant benefits that can be realized with effective implementation and use of production automation. The business objectives that can be achieved through automation are summarized, the specific operational and economical benefits that can be realized with various automation applications are discussed, and some of the interesting developments that are becoming possible with new technologies are highlighted.

## Automation Objectives

The primary objectives of most modern production automation systems fall into one or more of the following categories.

**Safety and Environmental Protection.** Unsafe or faulty operations are detected, systems or wells are shut down if needed to protect people or the environment, and information is provided to those who must make repairs, restarts, and other such actions. Well and facility operations are coordinated to permit safe shutdowns and restarts.

**Cost Reduction.** The number of people, along with the associated equipment and vehicles required for routine checking, data gathering, and manual control tasks are minimized. Job content and satisfaction are improved by converting low-skill manual-labor tasks to career opportunities requiring technical skills and knowledge. Repair and maintenance costs are minimized by keeping equipment operating within the safe operating envelope. Making optimum use of equipment minimizes unnecessary capital expenditures. Automating data capture and transmission from the field to all people and information systems that need information, both inside and outside the organization, reduces support costs.

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**Surveillance.** Immediately detecting when a well is either off production for an unexplained reason or is underproducing relative to its potential can minimize production deferment. Operating in the optimum envelope can maximize equipment performance and life.

**Production Optimization.** Investment and production must remain balanced to improve economics. In gas lift systems, continuous injection-vs.-production balance is required even during severe facility upsets. In pumping systems, pump capacity must be balanced with well productivity to avoid underproduction or overstress of the system.

**Reservoir Recovery.** Monitoring and controlling injection and production systems maximizes recovery. Appropriately balanced injection and production volumes can maintain reservoir pressure and sweep efficiency. Collecting injection rate and pressure data determines and tracks injectivity. Downhole measurement and control of production from different branches in multilateral completions improves reservoir drainage.

**Staff Efficiency.** Efficiency requires sending summarized (exception) information and insights to all parts of the organization. Virtual meetings with field and office staff are facilitated through videoconferences and online real-time work. Effective learning aids must be delivered to people when and where needed.

**Remote Operations.** Remote operations can be changed to unmanned systems by automating manual tasks. Maintenance crews can be advised of conditions to expect and how to prepare before they visit a remote site.

## Applications

Several applications make strong economic sense for production automation. Although it may appear expedient to apply separate specifically tailored systems, from separate suppliers, for each application (e.g., one for beam pumping, one for gas lift, and one for well testing), there are many advantages in the use of an integrated system with a common hardware and software platform, a common user interface, and a single database. Such fully comprehensive, fully integrated systems are available. Typical economic benefits are given below for each application. Where multiple applications are addressed in the same production operation, the total benefits are additive.

**Beam (Sucker Rod) Pumping.** More wells are produced by beam pumping than by any other means, natural or artificial. Automation systems are used to protect the pumping equipment against failure from overpumping or overload, optimize production by continuously balancing the pump's outflow capacity with the well's inflow, and provide operating staff with information to diagnose and solve problems.

The most common beam-pump automation is pumpoff control. The pumping system is designed to pump slightly more fluid than the well can produce. The automation system is designed to detect the instant when the well is pumped dry (the fluid level is pumped down to the pump intake), and stop the pump for a predefined time to allow the fluid level to rebuild. Then the cycle is repeated. This

method minimizes fluid pound and requires the pump to operate only when there is fluid to pump.

An alternative is termed "almost" pumpoff control in which the system detects the pumpoff state just before the fluid level is drawn down to the level of the pump intake. This method avoids the fluid-pound effect. A more advanced approach is to use a variable speed drive, whereby the pumping capacity of the system can be kept precisely in balance with the inflow rate of the well.

Good beam-pump automation systems continuously check for various fault conditions and can stop the pump before serious damage, such as a rod break, occurs. In addition, these systems can alert the production operator to the occurrence and, often, help determine the cause of the problem.

Beam-pump automation systems can increase oil production 5 to 7% with effective pump control and by minimizing unscheduled downtime and associated deferment. Energy consumption can be lowered by 15 to 20% by pumping only when necessary to produce fluid. Repair and maintenance costs can be lowered by 25 to 35% through reduced wear and tear on rods, pumps, tubing, and other equipment. Manual well operations and surveillance time and expense can be reduced also.

**Electrical Submersible and Other Pumps.** Electrical submersible pumps (ESPs) are used to increase production rates and, often, ultimate recovery can be greater than that obtained with other forms of artificial lift. ESPs can produce higher rates than most other pumping systems and achieve lower bottomhole pressures than gas lift systems. Because ESP systems represent significant capital investment, it is sound economic policy to monitor and control the systems as effectively as possible.

The primary automation objectives with ESPs include the following.

- Facilitating the startup or restart process, especially when wells must be beamed up slowly when producing high rates of sand or gas.
- Keeping each pump/well system operating within its target operating envelope and as close as possible to its optimum operating point.
- Properly handling different causes of shutdown and the appropriate restart process after each type of shutdown. In some cases, pumps must be restarted manually after correcting the cause of the shutdown. In other cases (e.g., after a power failure or a noncritical trip), pumps can be restarted automatically under carefully controlled conditions.
- Continuously collecting information for problem detection, troubleshooting, and cause/effect analysis.

Field applications of ESP automation show that oil production increases by 3 to 7% by use of enhanced startup procedures, improved pump control, and fewer unplanned deferments. The pumping system run life can be extended by 6 to 12 months by keeping the system operating inside its safe operating envelope. Manual well operations and surveillance time and expense can be reduced.

In some situations, such as heavy oil, sand production, and associated gas production, progressing-cavity or hydraulic pumps may be effective alternatives to ESPs. Production automation can be applied in these cases with similar objectives and benefits.

**Gas Lift.** In many cases gas lift is the preferred artificial lift method. It is especially well suited for wells that produce a significant amount of free gas, produce sand with the oil, are highly deviated, have a strong waterdrive (bottomhole pressure depletion is not an issue), or are drilled from confined locations such as offshore platforms.

Gas lift differs from other forms of artificial lift in that both the individual wells and the gas lift system must be considered in an effective automation and surveillance system. Anything that happens in the gas lift system affects all the wells served by the system. Also, anything that happens to one well in the system can affect other wells.

The chief automation objective for gas lift is to control the gas lift system and all wells in the system to maintain stable pressure, even with severe system upsets, such as a compressor trip or restart or a production station trip or restart. All gas lift designs are, at least to some degree, sensitive to the pressure of the injected gas. If a stable system pressure can be maintained, gas lift designs can be based on this pressure, thereby enabling optimum performance by designing to achieve maximum lift depth, given the available pressure.

For continuous gas lift operation, the three primary objectives, in order of importance, are to inject gas as deep as possible (consistent with the system pressure and well configuration and conditions), inject gas at a stable rate and pressure, and inject at the rate that will optimize the economic balance between investment (injection gas) and return (production).

For intermittent gas lift, the primary objectives are to inject each intermittent cycle at the optimum frequency and at the optimum amount (volume of gas) to achieve optimum production both on a per-cycle and a per-day basis.

The role of gas lift automation is to achieve the system objectives through continuous control of the injection rates into each well to maintain a balance between gas availability from the system and gas demand to the wells. The inflow/outflow performance and the gas lift valve design in each well must be taken into account so that each well, whether it is continuous or intermittent, can achieve its objectives. In addition to control, the system must continuously monitor both the gas lift system and its wells to detect any deviations from the desired performance, then must be corrected as rapidly as possible.

Gas lift systems can increase oil production 5 to 10% by keeping injection in each well deep and stable and by reducing production deferment with immediate detection of and help in diagnosis of problems. Automated systems can reduce injection-gas requirements by 5 to 10% by not overinjecting wells, reducing manual well operation and surveillance time and expense, and optimizing capital investment by deferring investment in additional gas compression and associated equipment.

**Reservoir Injection.** Secondary- and tertiary-recovery systems are common in the U.S. and are becoming more so internationally. Just as with production systems, it is important to optimize these systems through effective monitoring and control. Primary objectives include the following.

- Keep the injection system and all wells operating at peak efficiency by continuous monitoring and control. This objective includes keeping the system in balance by

keeping the total demand (injection into the wells) equal to the total supply on a continuous basis. It often includes maximizing injection into wells while limiting the injection pressure to avoid fracturing the reservoir rock. It also can include making automatic measurements to determine well injectivity. These determinations can be made with step-rate, step-pressure, or pressure-falloff tests, all of which can be conducted automatically.

- Maintain continuous, accurate measurement of the volume of fluid injected into each well and into each part of the reservoir. In thermal-recovery projects, it also is important to measure steam quality to determine the amount of heat injected.

- Often, a third objective is to balance injection/production patterns by balancing the production and injection of the wells in the pattern. This balance is often complicated because some wells are part of more than one pattern at the same time.

**Well Monitoring.** Methods are evolving to determine the production rate of each well on a continuous basis. For very important wells, effective but expensive multiphase metering systems exist. For routine wells that produce no free gas, the coriolis meter works well to measure oil and water production continuously. For shallow beam-pumped wells, the production rate can be calculated from the surface pump card (graph of load vs. position) and the pumping frequency.<sup>3</sup> For wells that produce all three phases (oil, water, and gas), there is a technique based on measuring the differential pressure across a restriction that works well to provide a continuous estimate of flow rate.<sup>4</sup>

Continuous well monitoring can raise an alarm if the production rate changes significantly, up or down, from the expected value. The total production of each well can be determined (or at least estimated) on a daily basis for comparison with the total measured production from the production facility. Production during a well test can be measured or estimated and can be very useful in evaluating and validating the well test. The production response to a change in the artificial lift system (e.g., a change in the pumping operation or in the gas lift operation) can be analyzed immediately to adjust the system for optimum production.

**Fig. 1** shows the use of the differential-pressure technique to monitor the production rate of a gas lift well. The method shows the well dying when the well is closed in or the lift gas is turned off. The effect of the spurious test separator readings is also evident. These events were caused by inadvertent gas flow through the liquid meter of the separator.

**Smart Wells.** Many companies are installing, or at least considering, smart (intelligent) wells. Typically, these wells have downhole instrumentation to measure pressure, temperature, flow rate, vibration, and other data. They may have sophisticated instruments to measure reservoir properties or track the movement of water/oil or gas/oil contacts in the reservoir. In addition, downhole control capabilities can enable adjusting the production rates between different laterals in a multilateral completion.

Smart wells must be connected to and supported by a system for collecting downhole information, providing

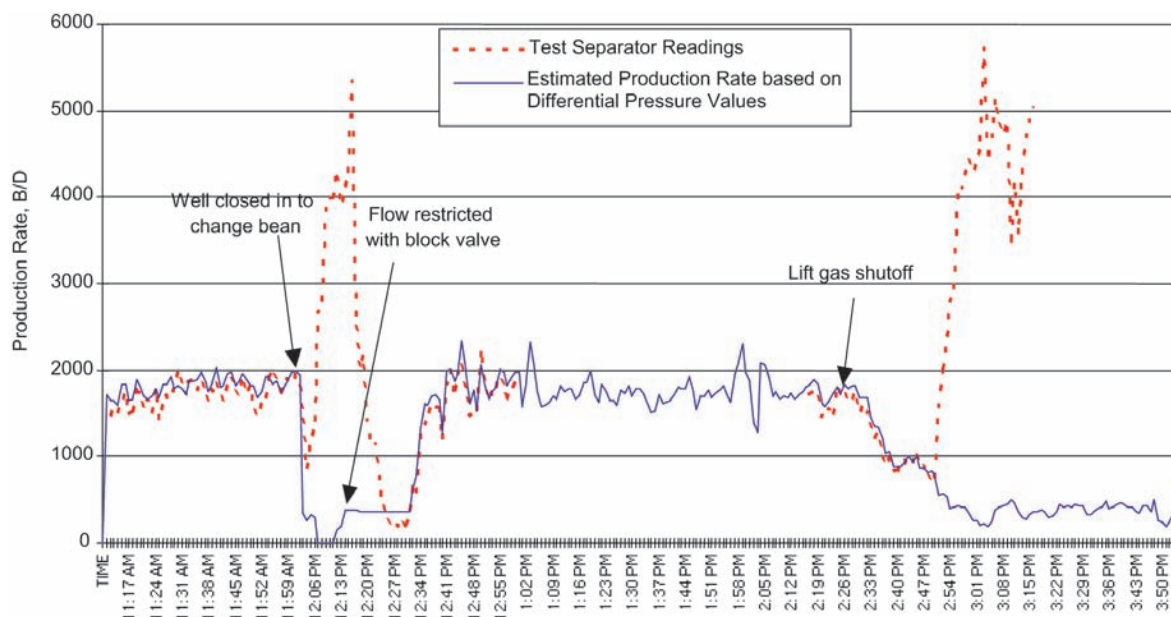


Fig. 1—Gross production rate calculated from differential pressure and measured by a test separator.

data to a wide range of staff and information systems, and, where appropriate, allowing staff to execute downhole controls. Ideally, this system should be the same one that provides the production automation functions.

Although smart-well technology is an important emerging technology, its day has not fully arrived. “Smart-well technology is still the exception rather than the rule when it comes to completing most wells in the world today. The application and miniaturization of technology in our everyday lives promotes creative application of technology in the wells we design and work on every day. Smart-well systems are focused on the subsea, offshore, and complex-reservoir completion market. Still, across all markets, most technology professionals are hampered by lack of data and control when diagnosing problems and maximizing the recovery of their hydrocarbon resources. Providing remote or automated control (downhole if necessary) of the elements that will increase production at a lower cost is what smart-well technology is all about.”<sup>5</sup>

**Well Testing.** Often, well testing is required to determine production rates of individual wells when several wells are commingled into one production system. During a well test, production is routed into a separate test system where oil, water, and gas rates can be measured. Even when a well monitoring system is used, well testing may be required to confirm or calibrate the well monitoring system.

Automating the process enables testing wells at any time, day or night, without manual intervention. Often, an automatic well test system can conduct four or more tests/day on each test separator, whereas a manual system usually is limited to one or two tests/day. Coordinating well testing with well operations ensures that the well is in a testable state or skips it for another well if it is not testable. Automating the well test schedule enables testing wells in priority order on the basis of their value and current conditions, not in the order in which they happen to be connected to the test manifold. Monitoring well test

progress enables stopping the test as soon as sufficient data are obtained to provide accurate results.

Automatic well testing supports other forms of well testing, which may be more cost effective. For example, use of a multiphase meter in lieu of a well test separator may be less expensive than a test separator system and may be more accurate. Also, supporting parallel well testing, in which multiple well test lines from remote manifolds come to a common test separator, can be coordinated so that one or more lines can be purged while a well in another line is on test. Automatic well testing also supports semiautomatic systems, in which wells must be manually switched into and out of the test facility, but all other well test data-management processes are fully automated.

**Facilities.** Production automation systems have been used for many years to monitor production facilities (e.g., rates, levels, pressures, and temperatures). Another long-term capability is facility control, especially the shutdown of remote facilities in case of severe storms or other problems. A recent innovation is condition monitoring that detects out-of-envelope operation to enable correcting the condition.

Another objective of facility automation is improved equipment maintenance. Many facilities are maintained with a fix-it-when-it-breaks strategy, which may result in significant unplanned downtime and production deferment. Another strategy is campaign maintenance. This strategy doesn't eliminate all breaks, and it may result in performing some maintenance more often than needed. A third approach is predictive maintenance, which strives to predict the need for maintenance or replacement before a failure occurs or before efficiency is reduced to a low level. The prediction is based on statistical analysis in conjunction with a comparison of actual vs. ideal equipment performance on the basis of an operational model of the equipment being analyzed. The model must contain both performance and economic aspects because the decision to perform predictive maintenance or replacement must



always be on the basis of a balance between the cost of repair and the cost of a likely failure.

### Production-System Optimization

When all the capabilities discussed above are combined and integrated, the opportunity for full production-system optimization exists.<sup>6,7</sup> This optimization includes the wells, the facilities, and all other components in the entire system at the same time.

Every system has a bottleneck or some point that limits its capacity. This bottleneck may be in the facilities, flowlines, artificial lift systems, or in the well completions. Some restrictions are easily correctable if they can be clearly identified. For example, field production restricted (bottlenecked) by a too-small separator is a case for separator replacement.

A goal of production system optimization is to detect system bottlenecks and provide information needed to identify, evaluate, and justify corrective action to eliminate the bottleneck. The goal should be to eliminate all man-made bottlenecks and to produce the maximum capacity permitted by the reservoir and project economics.

Another goal is to keep the entire production system operating at an optimum level by keeping all components of the system in balance. This goal may include not producing each well at its individual optimum but optimizing the overall system production. For example, it may be necessary to limit the production of some wells (e.g., high-water-cut wells) to allow capacity for more profitable wells.

Another goal is to maintain continuously updated information on the performance of the entire system and all system components, then to make it available to people and to information systems enabling continuous improvements.

Normally, if the primary components (wells, lines, and facilities) in a production system are automated, production-system optimization does not require installation of additional equipment. It requires taking a system-view perspective, which may identify additional required measurements. There must be sufficient measurements to define fully the input and output from each part of the system. However, the primary requirement is that automation (and information) of the various system components be integrated. Use of special software (or a database) may be required to provide an integrated view and an understanding of the entire production system.

Nodal analysis software attempts to model an entire system (e.g., a well inflow and outflow system, or a system of wells and their associated gathering system) to detect limitations and bottlenecks. Online real-time systemwide nodal analysis that is always looking for and highlighting system limits or bottlenecks is required for effective production system optimization. This task is not easy, but it is possible.<sup>6,7</sup>

### Future Directions

The technologies that support modern production automation and information systems are continuing to advance at an ever-increasing pace.

**Data Management.** In the past, every bit and byte of information was evaluated. Was storing it justified? How long would it be needed? Today, modern data-acquisition systems, database technology, and data historians enable storing millions of pieces of information, in a highly compact form, on a second-by-second basis if needed, for years if

necessary. For example, operations in the North Sea require very extensive data storage. If a problem occurs, second-by-second data may be needed to analyze the precise sequence of the cause and effect of the incident.

The primary question today isn't "Can we afford to store information?" It is "Can we effectively use the collected and stored information?" For all this data to be useful, data systems must store data in a way that it is easily retrieved and in a way that can be easily understood and used. Often, the information must be presented to key decision makers, in graphical or pictorial form, on an exception basis. Often, the raw data itself is not needed, only the summary information or insights derived from the data. Automation systems can overwhelm people with too much data. To be effective, this information must be very carefully managed.

**Web.** Two important tools in information management are the intranet and Internet. Information can be accessed any time from virtually anywhere in the world. Experts within the company or in some other company or organization can work with live or current information to help identify and solve problems.

Someday, production-system experts will be able to support production operations around the world from their office or home. An expert will be able to check well or system performance, compare it with ideal performance on the basis of calibrated models, diagnose any problems or deficiencies, evaluate alternatives, access currently available resources, and recommend the most cost-effective solutions. The expert will be able to produce a work prognosis and monitor the necessary repair or reconditioning work by use of the same data-access system. Finally, the expert will be able to evaluate the results of the job and use this information to improve the process continually for the future.

**Training.** To be most effective in optimizing production operations, people must have the knowledge and skills to understand the production system they are trying to optimize. They also must have the tools available to perform this task.

To be most effective, training must be provided to whom it is needed, when it is needed, and where it is needed. Some of this training can be provided in the classroom, but this is not sufficient. Perhaps the most effective training is that which is provided on the job, with the trainee working one-on-one with an experienced person. But this method usually is very costly.

New forms of training are being developed that show promise. Programs are needed to train the trainer or mentor so that trained staff can be available to work one-on-one with staff in each location. Online training, in which training aids are available online, can take place within the context of the system being used for routine production automation activities. Online simulators can provide real-world conditions and can be used for various types of training or what-if studies. Physical models can have built-in simulators and training programs. Online conversational courses can be offered on intranet or Internet sites.

Production automation and surveillance tools exist that significantly improve the efficiency, cost effectiveness, and profitability of oil and gas production operations. The key to achieving these gains is having people who can use these tools correctly.

**Failure Tracking.** Stuff fails. No matter how good equipment is or how well it is installed and operated, it will fail at some point. There is a growing trend in the industry to collect information on each failure and on the history of the production operation that led up to the failure, and to analyze this information. It can be used to learn a great deal about the causes of failure and about the right and wrong places and conditions in which to apply specific equipment. Ultimately, failure tracking will minimize failures by improving the selection, installation, and operation of systems.

**Leverage.** Production operations are experiencing staff reductions. People are asked to operate more wells and facilities across wider geographical areas. The only way to do this profitably is to leverage each person's reach as much as possible with automation and information processing tools. Each person must be able to spend his/her time solving problems rather than performing manual work, looking for problems, or even worse, making incorrect decisions because of insufficient understanding.

### Conclusion

Modern oil and gas production automation and information systems can be highly effective in improving profitability. Effective production automation systems exist to optimize all aspects of production systems, from the reservoir to the wells (producers and injectors), through the collection, testing, treating, and handling facilities, and to the final point(s) of sale. Production information can be collected, stored, and provided to anyone anywhere in the world on a timely basis, enabling them to contribute to optimization of the production operation. More work is required on the part of both suppliers and operators to make the most effective use of this technology through development of their personnel to be able to fully accept, understand, and use the technology to optimize day-to-day operations. **JPT**

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