OILFIELD AUTOMATION — TEN YEARS' EXPERIENCE

J. D. EGAN, A. L. COLE, H. A. McCABE, and F. G. OAKES
Amoco Production Company

INTRODUCTION

The year of 1976 represents a milestone for Amoco Production Company as they complete a decade of experience in computer-controlled oilfield automation. Table 1 presents a summary of percentages of wells and production being received by automation projects which Amoco had installed as of the first of this year and what they currently estimate their position in automation to be within the next five years.

As can be seen, as of January 1, 1976, Amoco had 35% of its company-operated oil wells and 6% of its company-operated gas wells automated and under computer control. These wells produce 49% of Amoco's company-operated gross oil production and 19% of its operated gross gas production, respectively. In addition, 25% of the injection wells in Amoco-operated secondary recovery projects were automated at the beginning of this year. These automation projects are located throughout Company operations including Canada, the Rocky Mountains, Oklahoma, Louisiana, (onshore and offshore) and Texas.

TABLE 1—AMOCO PRODUCTION COMPANY AUTOMATION STATUS 1976

	PRESENT	WITHIN FIVE YEARS
PERCENT AMOCO OPERATED OIL WELLS AUTOMATED	35	58
PERCENT AMOCO'S COMPANY OPERATED GROSS OIL PRODUCTION	49	78
PERCENT AMOCO OPERATED GAS WELLS AUTOMATED	6	21
PERCENT AMOCO'S COMPANY OPERATED GROSS GAS PRODUCTION	19	44
NO. INJECTION WELLS AUTOMATED IN AMOCO OPERATED SECONDARY RECOVERY PROJECTS	25	79

Within the next five years, Amoco expects to have 58% of its company-operated oil wells and 21% of its company-operated gas wells automated. These wells currently produce 78% of Amoco's company-operated gross oil production and 44% of its operated gross gas production. It is further anticipated that 79% of the injection wells in Amoco-operated secondary recovery projects will be automated.

HISTORY

Amoco's early automation projects were basically monitoring and automatic well test systems which generated large quantities of data. Little emphasis was placed on interpretation or control by the computer. This method of operation created a great deal of paper output; so large a quantity, in fact, that in many cases the interested personnel could not read and interpret the data effectively. Consequently, Amoco has now adopted an operating philosophy which develops computer output that is primarily exception reports. This method points out only those problems which require corrective action that are beyond the computer's capability to correct. In addition to exception reports, reports such as individual well tests, injection well reports and production reports are generated routinely or on demand to present more detailed data for analytical work performed by engineers and operating personnel.

In summary, the present system performs the following four basic functions:

1. Status and alarm detection and reporting
2. Production monitoring and reporting
3. Automatic well testing and reporting
4. Injection well monitoring, control and reporting.

Amoco has found that some of the most important factors in designing an automation system is to incorporate the ability to: expand the system, adapt it to changing operating conditions, add new enhancement application functions, and absorb new developments in technology. Amoco has adopted the policy of installing the basic system in a field which will perform normal operating functions first. After the basic system is operating efficiently, new application functions are considered and incorporated when they can be justified. This method greatly simplifies debugging the basic functions, thus allowing the system to be operational in the minimum amount of time.

Unfortunately, time will not permit discussion of all the individual projects which Amoco has installed. We will discuss in some detail the installation of Amoco's West Texas automation system. This system incorporates several operating offices and fields. It is Amoco's largest single system. We will discuss the overall system in general and will include specific information on one field which has been automated.

COMPUTER HARDWARE AND SOFTWARE

A large percentage of Amoco's producing operations in West Texas are similar in that they are under secondary recovery operations. Based on the experience gained from earlier installations, it was evident that significant savings in both time and money could be obtained by standardizing computer hardware and software. Accordingly, Amoco has developed the standard operating system and application software for the West Texas automation system. It was designed so that it could be adapted for ready implementation as additional projects were approved for automation.

The original study of various available computer configurations indicated that a two-computer-level approach had the greatest economic advantage and offered the needed flexibility for expansion to encompass automation operations throughout West Texas. Further studies of cabling costs utilizing conventional RTU's indicated that these costs could be reduced by the development of a mini-RTU. With the reduced overall cabling and RTU costs, a new problem developed - - how to scan this greatly increased number of RTU's in a satisfactory time frame.

This problem was solved by modifying the concept from a two-level computer system to a three-level system. The additional computer level, located in the field, was to have the primary responsibility for scanning and collecting data from the mini-RTU's on a timely basis and executing controls (causing the RTU's to start/stop motors, close/open valves, etc.) as directed by the next higher level computer. Although the mini-RTU concept required an additional computer, the investment required for this type system was much less than a two-level system without mini-RTU's.

The system configuration concept had, at this point, essentially reached its final form (refer to Fig. 1).

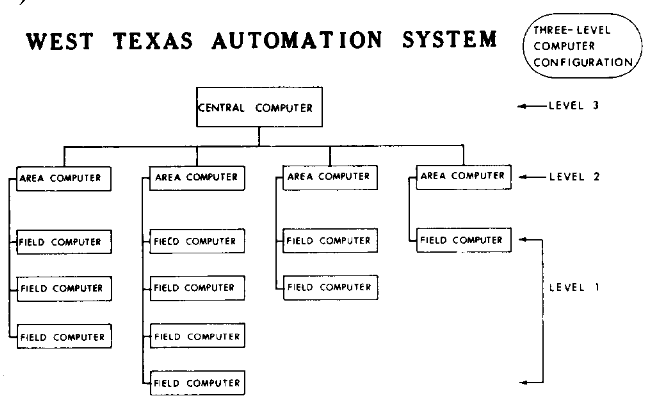

FIG. 1—WEST TEXAS AUTOMATION SYSTEM

The three-level computer system for West Texas automation consists of:

1. Mini-RTU's located in the field and connected by buried cable to the various end-devices
2. Field computers in the field to scan the mini-RTU's
3. A computer in Amoco's Area office to collect data from the Field computers and connected to each of that Area's field computers by telephone lines
4. A third-level computer connected to each of the Area office computers to provide for the consolidation and storage of data and to provide capabilities for performing overhead functions relative to programming maintenance, development, etc.

A discussion of the functions performed at each level and of the interactions of computers at each of these levels provides a better understanding of the system.

Field Level

As stated earlier, the field computers connected to the RTU's via an interface, are responsible for collecting data from the field and holding it for transmission to its Area office computer. In addition, controls to be executed are directed to the proper RTU via this computer. In order to provide operations personnel with current data, the capability to print alarm messages and reports in the field is included. A unique set of software was developed for this computer level to perform these functions. The field computers are relatively small mini-computers with two keyboard printers for printing alarms and reports. They are occasionally used by programmers and hardware technicians for testing and maintenance purposes.

Area Level

An Area-level computer is located in each of Amoco's West Texas offices that have automated fields. These computers are basically the same as those at the field level but have additional peripheral devices attached - - magnetic discs as auxiliary storage and a high-speed, paper-tape device for input/output of programs and data.

This computer level is the focal point of automation operations in an Area. The standard primary application programs directing each of the automation functions for all fields reside at this level. Data scanned and held by each of the field-level computers is requested by the Area-level computer on a periodic basis and sorted for use by the various programs.

Status point indicators are scanned to determine if any have made the transition to an alarm condition. Status-type alarms are of three classes: alerts, alarms and callout alarms. The designation of the class is an option available to field operating personnel and is dependent on their estimation of the relative importance of the alarm.

Motor status and the malfunction status of each pump-off controller are monitored. This provides for an accumulation of data relative to pumping time and notifies operating personnel in the event of a malfunction. The option of starting and stopping the wells by computer control is also provided.

A well test program performs the tasks routinely performed by pumpers in nonautomated installations. Volumes of oil and water are validity-checked against preset upper and lower limits. This screening assures, with a high degree of reliability, that only representative test values are placed into the historical files. It also provides for a method of detecting and pointing out either drastically changing producing characteristics of a particular well or problem conditions at a test site.

Another set of programs provides the capability of monitoring and/or controlling water injected into each of the automated injection wells based on preset rate/pressure limits. The monitoring programs accumulate injected volumes and report abnormal volumes or pressures. Working with this data, and from pressure readings at the the injection stations and wells, the control programs provide closed-loop control of injection rates and pressures.

Third Level

Data from each of the Area-level computers is transmitted to this central computer for storage. This data is used in various reports which are transmitted back to the Areas for use by office and field personnel. This central computer also compiles historical files that are useful in the determination of production trends.

One of the major uses of this central computer, indirectly related to actual automation operations, is that it provides the capabilities necessary for program development and maintenance.

Software Standardization

Drawing from various departments within Amoco, a team was established to design, program, and implement the software necessary for operation of the West Texas automation system. Software specifications were developed detailing the field functions to be performed. The completed specifications were reviewed by engineering and operations personnel; and after all revisions and corrections had been made, the final specifications were approved by management as the basic standardized software for all West Texas projects.

The development of the standardized specifications is of primary importance, not only as the basis for program development, but also as a means of involving user personnel (operations, engineering, etc.) at an early stage in the project. This permits taking full advantage of their experience and unique knowledge and eases the transition into the new operational methods and techniques.

Software implementation began upon approval of the specifications, with efforts directed toward detailed system design. The first step in this detailed design was a determination and definition of exactly what programs were needed and at which computer level they would reside. This concentrated very heavily on assuring that the final software system would be modular in nature and have sufficient flexibility to enable additions and/or deletions of wells, leases, fields, etc., without necessitating changes in the actual programs. In addition to these design considerations, existing and future producing characteristics, piping designs, etc., had to be anticipated. It was at this point that ready access to the knowledge and experience of personnel intimately familiar with the field operations was required.

Throughout the programming phase, each program was checked to assure proper interface to the hardware (telecommunication lines, peripheral devices, etc.) and other programs. When all primary programming had been completed, system checkout began with a detailed simulation of actual field conditions to add as much realism as practical.

Detailed testing in this manner, within a controlled environment, allowed for checkout of all phases of the sytem and for introduction of known error conditions with immediate observation of the system responses. This checkout phase was considered complete only when it was evident that the system, as a whole, could perform the functions for which it had been designed.

Efforts then shifted to system checkout under actual field conditions. This phase was one of the more tedious, since it required field personnel to visually verify the response obtained at each end-device following a computer demand. Though time-consuming, this is the only method of assuring that wiring, programming, and data file errors are eliminated.

OPERATIONS AND BENEFITS

Preautomation

In a typical West Texas field, trunk lines bringing fluid to the consolidated battery originate at satellite collection tanks where gas has been separated from the liquids. Oil may enter the trunk lines from production headers with all produced fluids being driven to the battery by wellhead pressure. At the satellite or production header, a test manifold allows switching one well at a time to a test vessel. Figure 2 represents a schematic of a typical satellite and test station.

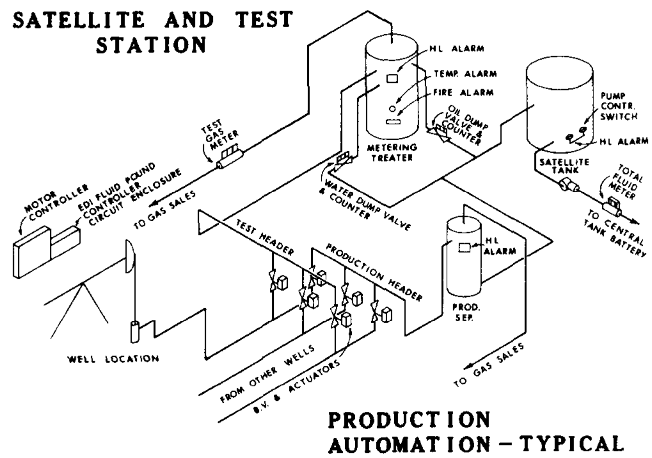

FIGURE 2

Water injection stations and injection systems are generally of two types: (1) large central pump stations with large trunk lines distributing the water, with metering and control at each well, and (2) smaller stations with radial injection lines and control and metering at central points.

As field conditions change through installation and expansion of secondary and tertiary recovery operations, much more data will be required in the future to operate a field efficiently. An increase in manpower would be required to accomplish this. The only alternative to increasing manpower is automation.

After Automation

Amoco has taken a bold approach to automation. It was decided early that more than a simple system for production metering, critical point alarm, and well testing would be required.

The features considered important to automation were determined by an early pilot project and have been confirmed by full-scale, large automated systems. Automated operations in the field have been standardized to a certain extent to allow use of the standard computer software. Cable is run to all producing wells and to the control and metering point for injection wells. Pump-off controllers are self-contained and some benefits can be obtained from them without full-scale automation. We find that monitoring of wells under pump-off control with automation is quite important and beneficial because of earlier detection of malfunctions. It is commonly known that when a producing well in a waterflood project is down, the opportunity is presented for crossflow between zones and back-flooding of oil into watered-out zones. Both of these conditions can cause a permeability hysteresis which will cause a decrease in the producing capacity of the well and ultimately shorten its producing life by reaching its economic limit sooner. Also, when a well is down, oil can bypass the well and be trapped beyond it or even be driven across a lease line and lost. Amoco, as well as others, believes that these conditions support the conclusion that the early detection feature of automation will provide an increase in ultimate recovery. The magnitude of this increase varies from field to field and is dependent on the type waterflood pattern and the characteristics of the reservoir rock.

Automation of injection wells varies from simple injection well *rate monitoring* to *monitoring both rates and pressures and controlling* with a throttling valve. Automated pressure *control* is quite important, but the additional investment in some installations may not be economically justified. This will depend on the design and condition of the system being automated. At one extreme will be a radial injection line pattern with several wells being metered and controlled at a central point. Self-contained, direct operated, pressure regulators for each well are installed. Very little plugging takes place, so that a flow rate can be matched to the desired pressure. Alarm limits can be set for high and low flow rates. This is a simple system with low labor requirements and is easily automated for pressure control. At the other extreme, metering and control points are located at the individual wells. Plugging causes problems with the manually-set throttling valves or pressure regulators using this design. The plugging causes the rate and pressure match for a well to continually vary. This is a condition that may justify full automation and pressure control, but at a greater cost. With computer monitoring and control, the potential exists for injection well testing to be done automatically.

Following is a summary of one of Amoco's typical automated oil fields under secondary recovery operation.

Monitoring of Pumping Wells

The motor controller on each producing well is monitored to obtain the pumping time each day. If a well is equipped with a self-contained pump-off controller, the malfunction status is also monitored. The malfunction status is useful as an alarm for rod parts. The malfunction alarm condition also shuts the pumping unit down. Although it is desirable to have excess pumping capacity when faced with increasing production due to waterflood response, some wells may start to pump continuously due to response or as a result of failing pumps. This is a condition that is detected by the computer and results in an alarm being reported. An alarm is also given if a continuous producer is found not to be pumping.

The run time for each well is kept by the third-level computer. When the run time varies from the average in excess of a certain percentage for a 24-hour period, this is reported as an alarm on the morning report. The average run time is maintained on a current basis for each calendar month. For days that a well is under an alarm condition, or if a computer is down, the average run time is not changed. A run time report for all wells is available on demand at any time.

Injection Well Monitoring of Rate or Full Automation with Monitoring of Rate and Pressure and Control

Where injection rates are relatively stable, it has been found satisfactory to share a time-rate card in the RTU between a number of turbine meter signals. The turbine meter pulses are counted in an accumulator.

If full injection automation is economically justified, pressures are obtained for each injection well by a strain-gauge-type transducer. The pressure transducer for each well is connected, in the RTU, to an analog-to-digital converter.

Control of the injection well flow rate or pressure is effected by sending a variable number of pulses to open or close an electrically actuated ball valve. The number of the control pulses sent, when the controlled parameter is found to be out of range, is calculated by use of valve-sizing data and the valve coefficients.

The system keeps a running average rate and pressure for each well during normal operation for the calendar month. The monthly cumulative and historical cumulative figures are also maintained. The system prints an alarm when a well's rate or pressure is outside of certain control limits. Since it is known that continuous fracturing of the formation by injecting water at excessive pressures will result in unbalanced flood fronts and a loss in recoverable reserves, controls and alarms are usually based on pressure. In all cases, alarms are given or control is maintained to insure that the injection pressure never exceeds that pressure equivalent to 50 psi below formation parting pressure. For each injection system, a pressure switch is kept set slightly below the station operating pressure. If the station pressure drops below the limit, the system senses this condition and inhibits control or printing of alarms for low rate or pressure until the condition is corrected. It is at pressures above this switch setting that rates and pressures are considered for keeping the averages mentioned above.

Production Well Testing

Metering treaters perform most satisfactorily in measuring liquid production. The treaters dump one barrel of oil or water at a time when the measuring chamber becomes filled. The number of dumps during a test are counted by accumulators in the RTU. In fields where gas is measured, almost any kind of gas-measuring instrument can be equipped to output a pulse per unit volume. Positive displacement meters are simple to operate and maintain. A constant, known pressure must be maintained to allow proper measurement with this type meter. Electrically actuated ball valves are used and are quite economical for test manifold construction. A test valve and production valve must be installed for each well.

Some well test manifolds are located remotely from the test station. For this type installation, two lines are run from the manifold, one for production and one for the test well. This requires that the test line be purged between tests of different wells. The purge time depends on the producing rate of the well and the line capacity. Before testing, the well is allowed to purge liquid equivalent to the capacity of the test facility.

Each well is assigned a test frequency which determines the number of tests it will receive, compared with other wells at its test site. For example, a well with a test frequency of 2 receives twice as many tests as one with a test frequency of 1. This feature is useful on wells experiencing flood response where more frequent testing is needed to evaluate performance. The test duration time of each well is preset. Generally, low producers require more test time than large producers to obtain a valid test. Validity test limits are stored in the form of percentage variation as compared with the average of the last three tests. A sliding scale is used, with a larger percentage variation allowed for smaller producers. If a well test does not meet the validity check, the well is retested. On the retest it must again pass a validity check, either for the previous test or the average of the last three tests. If a test is valid, the results are stored. If a test is invalid, the results are printed out to serve as an alarm.

One of the advantages of automation is that shorter and more frequent well tests can be run. A 24-hour test is no longer mandatory due to being restricted to the frequency of a pumper's visits.

A demand test can be run on any well by making a manual entry at the second-level computer. Alarm conditions sensed at the test site cause a test to be aborted, and no well is put on test until the alarm clears.

Daily Production Accounting Reports

Each morning the fluid handled during the last 24 hours by each satellite or production trunk line is printed on a report. Also, cumulative volumes for the month-to-date, averages for month-to-date during normal operation, and fluid handled during each of the last four days are printed for comparison. Since each satellite or trunk line production represents the output from certain wells, the summation of the last well tests for each is given for comparison. Other metered volumes shown on the daily production reports are LACT volumes, water transferred through various meters, and master injection water meters.

Status and Alarm Programs

An extensive system of alarms is used in each automated field. Treaters are alarmed for high level, high and low temperatures, and fire outside the fire tube. All tanks and separators are monitored for high level and some for low level. Other alarms are : bad oil, pump shut down, vapor recovery unit down, and various others. Some alarms are programmed alarms, such as "welldown" alarm, wrong well switched to test, and injection well pressure out of limits. Scan frequency for alarms is a variable set by operating personnel at each area location.

Alarms are divided into three different levels of importance as follows:

1. Alert - Least serious alarm, only printed on a periodic alarm summary
2. Alarm - Printed as it occurs and as it clears. It is printed on the periodic summary until cleared.
3. Callout Alarm - Handled as in 2 above and, in addition, is printed on the remote printer at a gasoline plant with 24-hour attendance at night and on weekends when the Area office is closed.

Callout alarms result in appropriate personnel being called out if personnel are not on duty in the field at the time.

Software provides that a given number of consecutive alarm conditions are required before a valid alarm is considered to exist. This allows intermittent and temporary conditions to be ignored.

It is generally considered that highly repetitive operations are most attractive for automation. The equipment subject to infrequent operation is usually hard-wired and sometimes only monitored by the automation system. This applies to functions such as filter backwashing and automatically searching for a malfunctioning treater in case of bad oil in a parallel treater operation. Any type of alarm is handled quite easily, with the provision that a given number of consecutive alarm conditions are required before the condition is reported.

To reduce the amount of data that must be reviewed, exception reporting is used to the greatest extent possible. For example, printing all well tests as they are concluded results in a tremendous time requirement if they are reviewed completely. Therefore, the practice of printing only invalid tests is followed. Each invalid test is treated as a potential alarm since either the well or the test station may require some attention. Of course, some routine data is required for engineering studies and for analyzing a certain problem. Such data is available on demand.

To illustrate the utility of a complete automation system, visualize the foreman of a field as he arrives at work in the morning. Awaiting him on the printer is the Daily Production Report which allows him to check the LACT volumes, detect production shortages and also check the produced water volume. If he has an oil shortage, a coinciding produced water shortage could have meaning. He then reviews the satellite metered volumes, comparing them with the averages and with the volumes for each of the four previous days. A shortage will be readily apparent. If a satellite shows a shortage, he may already know the cause. For example, he knows the wells that were down on the previous day. If he does not know the reason for the shortage, he looks at the last alarm summary and invalid tests that were concluded during the night. If the reason still escapes him, he looks at the run time exception report for low pump run times. By the time the pumpers arrive, he will have appropriate investigations ready to assign to them.

Similarly, he can analyze the water injection situation quickly. He looks at the master meter injection volumes, injection wells in alarm condition, or for a station or pump shut-down.

Benefits - Field Case History

It has been determined that fewer pumpers per well are required with automation; however, this benefit is somewhat offset by the addition of automation technicians. It is quite essential that pumpers be utilized efficiently in order to realize a maximum reduction in manpower. To accomplish this, the pumpers are equipped with two-way radios and someone reviews the alarm printout frequently during the day to notify them of alarms. With this tremendous tool for rapidly finding trouble points and the radio dispatching of personnel to take corrective actions, the use of pumper time has been optimized.

The benefits of automation have exceeded expectations. Contributing to this is the fact that prior to automation, there were some voids of information concerning the actual length of time producing wells were off production as well as how much of the time injection wells were taking less than the optimum amount of water. Satellite daily production curves were utilized in evaluating the effects of automation on this project. An example of before and after automation conditions appears in Fig. 3. The potential production and average production of several satellites were determined from the curve characteristics for a one-month period before automation and for a one-month period after automation. The difference between the potential and average represents a production loss. The loss for the satellite depicted was 115 BFPD prior to automation and 20 BFPD after automation. The loss at this satellite was reduced by 8.3% of the total production after automation. Certainly, it is much easier to keep the production loss at a minimum when a frantic and extended search for the cause of low production is unnecessary.

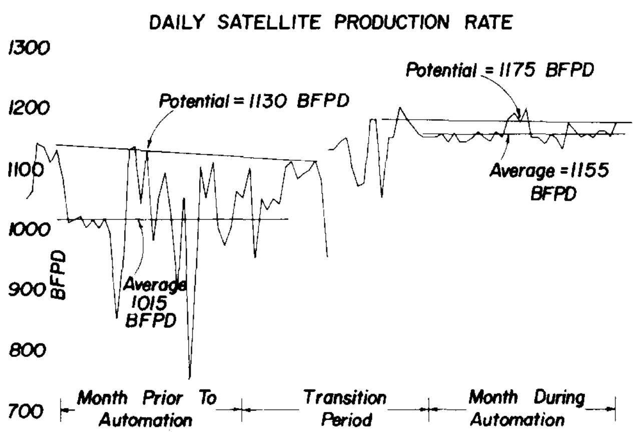

FIGURE 3

In summarizing the benefits of automation for this project, Amoco has realized an increase in current production of from 2-3% by earlier detection of wells being down or off in producing rate. The benefits of pump-off control in optimizing production are not included; however, the benefits of monitoring the malfunction alarm feature of pump-off control are included. It was further found that the amount of water injected increased approximately 2-3% and a corresponding increase in fluid production was realized. This will vary from field to field depending on the degree of fillup. The labor saving benefits are attractive, but were obscured somethat by inflation and the demands of more complex operations. The operating costs were reduced 3.5% after automation, while the remaining properties operated by the same office experienced an increase of 39% over the same period.

Naturally, when the management of a company invests capital in a project, it expects to recover more money than it spent. Amoco has always justified its automation projects on the merits of the basic system and the benefits which can be reasonably predicted. It has been Amoco's experience that unanticipated benefits are experienced in virtually all projects which enhance the economics of the project and quite often the unanticipated benefits equal or exceed the original estimate of benefits.

Table 2 presents the estimated and actual economics for the case history which we have just discussed.

TABLE 2—ECONOMICS OF AUTOMATION
A WEST TEXAS FIELD

	EXPECTED	ACTUAL
PRODUCTION INCREASE	1.3%	4.3%
PAYOUT (AFIT)	3.4 YRS.	1.4 YRS.
P. I. (AFIT)	-	100 %+
RETURN ON INVESTMENT (AFIT)	-	27.6
RODCO (10%)	1.2	-
INCREASED PRESENT WORTH (10%)	$525M	$11,673M

Although all of Amoco's automation projects do not show such a dramatic increase in "after" economics, this case is not considered to be unusual because of similar experiences in other projects. Probably the most impressive factor in this project was one which was not anticipated. This was the actual slight decrease in labor and total well expense in 1974 under automated conditions during an extremely volatile inflationary period as compared to 1973 when this field was not automated.

CONCLUSIONS

Amoco and other companies have proved that automation is technically sound and feasible. It can provide benefits and generate additional income if the system is used effectively and accepted by operating personnel. It is absolutely necessary that the management of a company create an atmosphere which will generate acceptance, support and enthusiasm for the project. It is only under these conditions that one can be assured of optimum use and benefits from a computer-controlled supervisory system.

From the several projects which Amoco has installed during the past ten years, it has been found that the major benefits include the following: (1) increased oil production, (2) increased water injection, (3) decreased labor costs, (4) decreased well expense, (5) earlier detection of wells being down, (6) miscellaneous benefits as a result of more efficient operations, and (7) increased reserves as a result of early reaction to wells being off production.

In conclusion, as a result of ten years' experience, Amoco's management has accepted oilfield automation as a successful operating tool and plans an aggressive program to automate additional fields in the future. Amoco expects that within the next five years, 78% of its gross company-operated oil production and 44% of its gross company-operated gas production will be monitored and controlled by computer-controlled automation systems.

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